MINISTRY OF HIGHER EDUCATION
AND SCIENTIFIC RESEARCH
UNIVERSITY OF BAGHDAD
COLLEGE OF SCIENCE
Department of Geology

WATER RESOURCES MANAGEMENT IN RANIA AREA
Sulaimaniyah NE- IRAQ

A
DISSERTATION
SUBMITTED TO THE COLLEGE OF SCIENCE
UNIVERSITY OF BAGHDAD IN PARTIAL FULFILLMENT
OF THE REQUIREMENTS FOR THE DEGREE OF
DOCTOR OF PHILOSOPHY OF SCIENCE
IN
GEOLOGY (HYDROGEOLOGY)

BY

DIARY Ali MOHAMMAD AMEEN Al-MANMI
M.Sc. 2002

Supervised by

Prof. Qusai Y.Al-Qubaisi, Ph.D.   Expert. Sadiq B. Jawad, Ph.D.

MARCH - 2008

بسم الله الرحمن الرحيم

أَلَمْ تَرَ أنَّ اللهَ أنْزَلَ مِنَ
السَّمَاءِ مَاءً فَسَلَكَهُ يَنَابِيعَ
في الأرْضِ ثُمَّ يُخْرِجُ بِهِ
زَرْعَاً مُخْتَلِفاً ألْوَانُهُ ثُمَّ
يَهِيجُ فَتَراهُ مُصفَرّاً ثُمَّ
يَجْعَلُهُ حُطاماً إنَّ في ذلِكَ
لَذِكْرى لأُلي الألْبَابِ
{21}

صدق الله العظيم

من سورة الزمر

Supervisors Certification

We certify that this dissertation was prepared under or supervision at the University of Baghdad as a partial fulfillment of the requirements for the degree of Doctor of Philosophy in Geology (**Hydrogeology**).

	Advisor		Co-Advisor
Signature:		Signature:	
Name	Dr.QusaiY. Al-Qubaisi	Name:	Dr.Sadiq B. Jawad
Title:	Professor	Title:	Expert
Address:	College of science University of Baghdad	Address:	Baghdad Water Resources Management Directorate
Date:	6 / 3 / 2008	Date:	6 / 3 / 2008

◆

In view of the available recommendations, I forward this dissertation for debate by the Examining committee.

Signature:
Name Dr.Saad S. Al-Sheikhly

Title: Professor
Address: Head of Geology Department/ College of Science /University of Baghdad.

Date: 6 / 3 / 2008

We, the members of examining committee certify that after reading this dissertation entitled (**Water Resources Management of Rania Area Sulaimaniyah NE-Iraq**) and examining the student in its contents, we think it is adequate for the award of the degree of Doctor of Philosophy in Geology (***Hydrogeology***) with (**Excellent**) grade.

Signature:
Name Dr. Habib R. Habib
Title: Professor
Address: Geology Department
College of Science
University of Baghdad.
Date: 20 / 7 / 2008

Signature:
Name Dr. Naheda A. Muhammad
Title: Assistant Professor
Address: Geology Department
College of Science
University of Baghdad
Date: 20 / 7 / 2008

Signature:
Name Dr. Muhannad J.Al-Kazwini
Title: Assistant Professor
Address: Collage of Civil
Engineering University of
Technology.
Date: 20 / 7 / 2008

Signature:
Name Dr. Ayser M. Al-Shamae
Title: Assistant Professor
Address: Geology Department
College of Science
University of Baghdad
Date: 20 / 7 / 2008

Signature:
Name Dr. Hatem K. Saleh
Title: Chief Researcher
Address: State Company of
Geological Survey and
Mining
Date: 20 / 7 / 2008

Signature:
Name Dr.Qusai Y.Al- Qubaisi
Title: Professor
Address: Geology Department
College of Science
University of Baghdad
20 / 7 / 2008

Signature:
Name Dr. Sadiq B. Al-Jawad
Title: Expert
Address: Baghdad Water Resources
Management Directorate
Date: 20 / 7 / 2008

Approved by the council of the College of Science

Signature:
Name Dr.Khalid S.Al-Mukhtar
Title: Professor
Address: Geology Department Collage of
Science University of Baghdad.
Date:

Dedication

To my father's spirit spotless …

To the tree that shaded my path and provided with shelter, my mother...

To my brother and sisters who supported me all the way through my pursue to higher education...

To my children Lawand and Lara, with my love and appreciation for them…

To my wife Dalia , for her efforts, suffering, moral support and endless encouragement...

To all my friends who cared for me and cared for him…

Diary

Acknowledgment

I would like to express my sincere thanks and greatly indebted to my supervisors Prof. Qusai Y.Al-Qubaisi (University of Baghdad) and Dr. Sadiq B.Jawad (Baghdad Water resources management directorate), for their supervision, formulating the subject of the dissertation, fruitful discussion encouragement and support throughout all stages of this work.

I am also grateful to the University of Baghdad, University of Sulaimaniyah, the deans and heads of geology departments of both universities for their support during my courses of study. Special thanks are extended to Dr.Kamal Haji , Dr.Salahdadeen Saeed, and Dr. Dana Maulood for their valuable assistance, scientific advice and importance notices in the field work. Special thanks to Dr.Mohamad Ali and Dr. Khalid for their support and encouragement.

I pay tribute to Huner Hiwa ,Saud Amer ,Hiwa Salh , Dler Ahmad, Zardasht Ahmad, Omed Mustafa ,Erfan Omer ,Kardo Sardar, and Twana Jalal for their assistance during laboratory and field works. Much gratitude to the geologist Baba Rassol, Director General of Drilling Company and the geologists Farhad and Shawenm, for their assistance during data collection. Special thanks are due to the directorate of Dokan and Bakrajo meteorological stations especially Salam and Karzan for providing climate information of the area. Thanks are also extended to Ali M.Jawad for his help in construction of groundwater model. Special thanks are due to the Survey directorate and Mapcom Company, for providing the maps of the area. My sincere thanks to Reston isotope Lab., for analyzing isotopes. I would like to express my special thanks to Mr.Mohammad the director of water and municipal directorate of Rania for providing valuable information on water demand in Rania area .Special thanks are due to Dr.Kamal K. and Dr.Aram A.. in the College of agriculture for providing some references.

My great thanks go to my brother Mohammad for his assistance during field work. My deep gratitude goes to all Rania citizens for their continuous help during the period of my study. I would like to express my gratitude and appreciation to my sisters and my friends Diah and Shereen. I would like to express my deepest gratitude to my wife, without whose companionship, support and much kindness ensured that this work became both easier and more enjoyable. Finally many thanks to the ones who gave me their help and I forgot to mention them.

With my love and respect **Diary**

ABSTRACT

The studied area is located in northeastern Iraq between latitudes 35° 31` 26`` - 35° 35` 37`` north and 45° 22` 10`` - 45° 28` 48`` east covering an area of 981 km^2. This area contains many geological formations. The oldest is Sarki Formation of Early Jurassic age and the youngest is Tanjero Formation of Cretaceous age .

There are several aquifers in the studied area like Jurassic, Bekhme, and Quaternary. The groundwater movement is from northwest to southeast .

Regarding the climate in the area is characterized by rainy cold winter and hot-dry summer. The average annual rainfall for the period (1980-2005) is 743 mm/year, average relative humidity is 56.5 %, average temperature is 33.3 °C, average wind speed is 2.36 m/sec, and annual pan evaporation is 2408.3 mm/year. According to Mehta’s simple water balance model the total runoff is 143 mm which is 19.2 % of the total rainfall and the groundwater recharge is 117.2 mm which is 15.75 % of the total rainfall.

By applying (CROPWAT 4.0) program the annual reference evapotranspiration on the bases of Penman equation was 1709.5 mm, annual actual crop evapotranspiration was 1230.8 mm, and effective precipitation was (620.6 mm). The crop water requirements for Wheat, Barley, Sunflower, Chickpea, Maize, Tobacco, and Sweet Melon were calculated by same program; also the net irrigation requirements were calculated.

Well tests performed in (11) wells that penetrate the Quaternary aquifer indicated hydraulic conductivity with median value of 2.09 m/day, transmissivity with median value of 169.6 m^2/day, and specific yield with median value of 0.079.

From the time series analysis of main springs discharges, it concluded that the springs are belong to different systems and controlled by different mechanism which are karst and karstic fissured.

From the environmental isotopes analysis(^{2}H and ^{18}O); all water samples fall between the global meteoric line (GMWL) and Eastern meteoric water line (which is the meteoric line of Mediterranean precipitation) (EMWL) and there are three mechanisms of recharge.

The hydrochemical study of tube wells, and spring for two seasons, dry and wet, showed that the water is colorless, odorless characterized by low value of total dissolved salts, predominant ions are calcium and bicarbonate and the chemical type of water is calcium bicarbonate.

The water in the studied area is suitable for drinking purposes except for some samples; also suitable for agricultural, construction and some types of industries. From the equilibrium speciation based on and (WATEQE4F) computer program it can be seen that most of the samples are under saturated with respect to calcite, aragonite, dolomite, gypsum, anhydrite, and magnisite.

From the groundwater model which constructed for Quaternary aquifer it concluded that the Dokan lake has significant effects on groundwater level in the area close to the lake, also the maximum head decline is about 0.94 m after one year transient simulation with pumping and 0.96 m after five years transient simulation with pumping.

CONTENTS

Subjects **Page**

Chapter One -Introduction

Subjects **Page**

Chapter Two-Meteorological Data Analysis

Subjects **Page**

Chapter Three-Hydrogeological Conditions

Subjects **Page**

Chapter Four-Environmental Isotopes

Chapter Five-Hydrochemistry

Subjects Page

Chapter Six-Groundwater Flow Modeling

Subjects **Page**

Chapter Seven-Summery, Conclusions, and Recommendations

Appendix

LIST OF FIGURES

FIGURE	**page**

LIST OF Plates

LIST OF TABLES

TABLE

Page

List of Symbols and Abbreviations

Abbreviations	Descriptions	Units
UNJHC	United Nations Joint Humanitarian Information Center	---
VES	Vertical Electrical Sounding	---
TU	Turbidity	NTU
EC	Electrical Conductivity	µS/cm
VSMOW	Vienna Standard Mean Ocean Water	---
GMWL	Global Meteoric Water Line	---
LMWL	Local Meteoric Water Line	---
SLAP	Standard Light Antarctic Precipitation	---
VPDB	Vienna Peedee Belemnite	---
USGS	United States Geological Survey	---
HDPE	High-density Polyethylene	---
O.M	Organic Matter	%
ETo	Reference Evapotranspiration	mm period $^{-1}$
Rn	Net Radiation at the Crop Surface	MJ $m^{-2}day^{-1}$
G	Soil Heat Flux Density	MJ $m^{-2}day^{-1}$
T	Mean Daily Air Temperature at 2 m Height	^{o}C
U_2	Wind Speed at 2 m Height	ms^{-1}
es	Saturation Vapor Pressure	kPa
ea	Actual Vapor Pressure	kPa
es-ea	Saturation Vapor Pressure Deficit	kPa
Δ	Slope Vapor Pressure Curve	kPa ^{o}C
γ	Psychrometric Constant	kPa ^{o}C
ETc	Crop Evapotranspiration under Standard Conditions	mm period $^{-1}$
CWR	Crop Water Requirement	mm period $^{-1}$
PE	Potential Evapotranspiration	mm period $^{-1}$
Nm	Correction Factor Depending on the Latitude	---
J	Annual Temperature Constant	^{o}C
j	Monthly Temperature Parameter (Heat index)	^{o}C

P_{eff}	Effective Rainfall	mm period $^{-1}$
AI	Aridity Index	---
Kc	Crop Coefficient	---
TAM	Total Available Moisture	mm
RAM	Readily Available Moisture	mm
TAW	Total Available Water	mm
FWS	Field Water Supply	l/s/ha
IWR	Irrigation Water Requirements	mm
Etc	Actual Crop Evapotranspiration	mm period $^{-1}$
NIWR	Net Irrigation Water Requirements	mm period $^{-1}$
AWC	Available Water Capacity	mm
APWL	Accumulated Potential Water Loss	mm
f	Reservoir Coefficient	---
SW	Soil Water	mm
S	Retention	---
SCS	Soil Conservation Service	---
CN	Curve Number	---
WTF	Water-table Fluctuation	m
Sy	Specific Yield	m^{-1}
α	Recession Coefficient	---
rk	Autocorrelation	---
COV	Covariance	---
VAR	Variance	---
LC	Limits of Confidence	---
S (f)	Spectral Density Function	---
$S_{xy}(f)$	Cross-Spectral Density Function	---
$\left\|S_{xy}(f)\right\|$	Cross-Amplitude Function	---
COxy	Coherence	---
$g_{xy}(f)$	Gain Functions	---
T	Transmissivity	m^2/day

$\overline{S_w}$	Corrected Drawdown	m
b	Saturated Thickness	m
ρ	Mass Density	M/L^3
α	Aquifer (or Aquitard) Compressibility	T^{2}L/M
β	Compressibility Of Water	T^{2}L/M
S	Storativity	m^{-1}
K	Hydraulic Conductivity	m/day
TD	Total Depth	m
SWL	Static Water Level	m
E. N	Electroneutrality	%
SD	Standared Diviation	---
TDS	Total Dissolved Solids	mg/l
a_i	Activity of Certain Ion	mol/kg
m_i	Molar Concentration	mol/kg
γ_i	Activity Coefficient	---
I	Ionic Strength	mol/kg
SI_x	Saturation Index of Mineral X	---
IAP (T)	Ion Activity Products At Specified Temperature (^{O}C)	---
P_{CO2}	Partial Pressures of CO_2	Bar
WHO	World Health organization	---
SARadj	Adjusted Sodium Adsorption Ratio	---
δ	Delta Parts per Thousand	---
d	Excess Deuterium Excess Index	‰
Ro	Initial Isotope Ratio	---
R	Ratio After the Process Occurs	---
f	Equilibrium Fractionation Factor	---

CHAPTER ONE
INTRODUCTION

Introduction

1.1 Location and Area

The studied area is located in the northeastern of Iraq to the northwestern part of Sulaimaniyah Governorate between latitude (36° 09^{-} $42^{=}$, 36° 32^{-} $00^{=}$) and longitude (44° 30^{-} $00^{=}$, 44° 59^{-} $41^{=}$), with an approximate area of (981) km^2. The municipal center of Rania is located approximately 10 km north of Dokan Lake. It is approximately 131 km, from the Sulaimaniyah city. The topography of the district is mountainous in the north, with elevations exceeding 2400 m.a.s.l., while in the southern plains near Dokan Lake the elevations reduce to about 500 m.a.s.l., Fig. (1.1).The district is hydrologically situated in the Dokan sub-basin which is a sub-basin of the lower Zab basin (Jawad, 2008), with two main streams Diman (Shaoor) and Qashan flowing from north to south, ultimately discharging into Dokan Lake. The Rania area is selected for the hydrogeological study due to its high groundwater resources potential for irrigation of medium and large scale projects .Being part of the Betwen Merga plain which has the most fertile soil,the area is therefore a prospective land for further agricultural development .The Rania plain is trending northwest-southeast as an elongate and wide valley, located between Rania, and Pelewan anticlines.The sources of potable water in the Rania district are wells, springs and streams. It is reported that potable water in Rania district is available about 90 % of the population (UNJHC, 2002).In addition to the municipal center, the Rania District has three other subdistricts: Betwata, Hajiawa, and Chwarqurna. In addition, the district has about 114 villages located in the mountains. Winters in the district are snowy and rainy, while spring and fall are pleasant as are the summers. Tobacco, wheat, barley, Sunflower, etc farming are popular in the district.

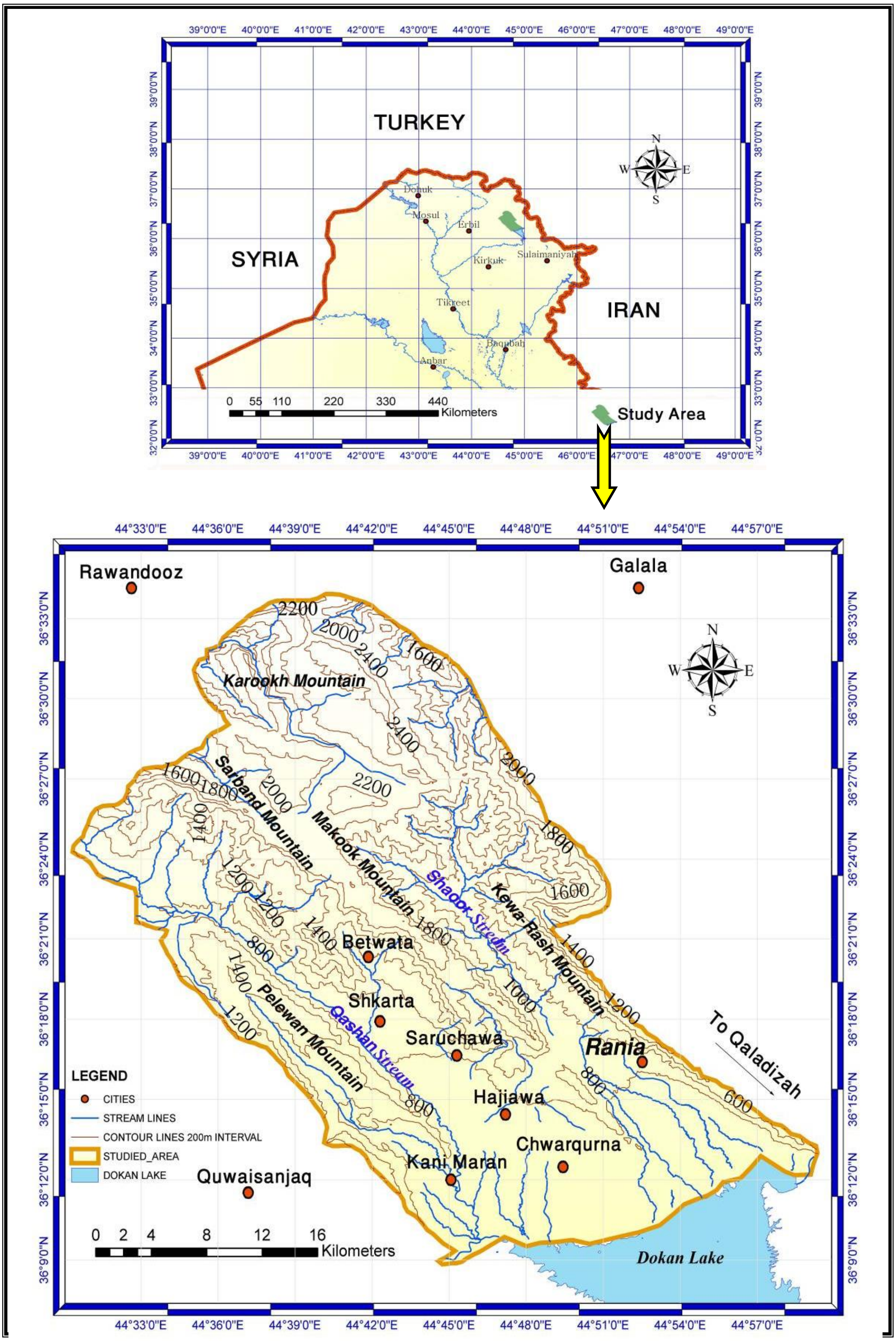


Fig. (1.1) Location Map of the Studied Area
(Survey Directorate, 2003)

1.2 Population

The estimate of population in 2005 was about 192,000. A breakdown of this population by subdistrict, as estimated by the Statistics Directorate of Sulaimaniyah is shown in table (1.1).

Table (1.1) Population of the Rania District in 2005
(Statistics Directorate of Sulaimaniyah)

Subdistrict	Urban	Rural	Total
Municipal center(Rania)	65,000	0	65,000
Betwata	13,247	7,405	20,652
Hajiawa	35,000	4,441	39,441
Chwarqurna	40,000	27,061	67,061
Total	**153,247**	**38,907**	**192,154**

1.3 Water Source

1.3.1 Rania city

The source of water for Rania City consists of the Qula spring and 26 deep wells. The Qula spring is located within 1 km of Rania City. The minimum flow from the spring occurs in the fall, the flow was measured to be 735 m^3/h on 06 September 2001(Parson, 2006). The same study reported that a low flow occurred during the summer of 2000 due to the drought had occurred between 1999 and 2000. The minimum-recorded flow then was approximately 500 m^3/h.Water is collected from the Qula spring in a circular collection tank, and is pumped to Rania by means of pumping through pump station PS1. The Qula Spring is used to supply Rania for about 15 h/d. The remainder of the time the spring flow is used for irrigation purposes. Accordingly, the yield of this source is estimated at approximately 7,500 m^3/d (500 m^3/h for 15 h/d). It is reported that the water quality of the Qula spring is good. The wells for the Rania supply are located within the city area. They have an average depth of 110 m and an average diameter of 200 mm. The productivity of the individual well is in the range of 40 m^3/h. It is reported that the deep wells are operated during summer for about 14 h/d. During the winter, they are operated about 8 h/d, based on operation for 8 h/d; the estimated production from the wells is 3,100 m^3/d. The potential production of the wells, based on a 24 h/d operation (and assuming the new wells 25 and 26 are connected to the system) is estimated at approximately 10,500 m^3/d (Parson, 2006). There is no reported seasonal variability in the quality of the water from these wells.

1.3.2 Chwarqurna, Hajiawa, and Betwata

The characteristics of the water system are shown in the table (1.2)

Table (1.2) Characteristics of the Water Systems in the Urban Areas (Parson, 2006)

	Rania	Betwata	Hajiawa	Chwarqurna
Population (estimated)	65,000	13,247	35,000	40,000
Area (km^2)	10	8	5.5	6
Density (persons/km^2)	6,500	1,656	6,364	6,667
Water source	Qula Spring& deep wells(26) 10,600 m^3/d	spring – 7,000 m^3/d	Wells (22) -3,000 m^3/d	Wells (23) - 2,500 m^3/d
Projected demand 2005 (m^3/d)	28,080	4,769	13,860	15,840
Projected demand - 2025 (m^3/d)	50,716	8,613	25,033	28,609
Water supply cap - 2005	10,628	7,000	3,000	2,500

1.4 Major Problems

The main water supply problems in the district are listed in table (1.3)

Table (1.3) Main Water Supply Problems in the Studied Area (Parson, 2006)

Problems
Old and inadequate distribution network coverage
Shortage of maintenance equipment
Shortage of electricity
Lack of storage

1.5 Projected Needs

A) District Center

1. Demand Projection

Rania town represents the municipal center of the district. It has an urban population about 65,000. Over the planning period through 2025, its population is projected to increase to approximately 117,400, based on the water demand criteria, the year 2005 water demand of approximately 28,000 m^3/d is projected to increase around 50,700 m^3/d, by the year 2025(Parson, 2006).

2. Existing Supply Capacity

As presented above, the actual water production from the existing Rania water sources is approximately 10,628 m^3/d. The design capacity of the supply system, on the other hand, is influenced by several limiting factors, including availability of power supply, limited capacity of the supply facilities, etc. Based on a 24-hour operation of the existing system, at its design capacity, the Rania municipal center could attain a production approximately 18,036 m^3/d. This computation is summarized in table (1.4), (Parson, 2006).

Table (1.4) Existing and Design Production Capacities of the Rania Water Supply System (Parson, 2006)

Source	Existing Production	Design Production *
Springs	7,500	7,500
Wells	3,128	10,536
Total	**10,628**	**18,036**

* Based on a 24-hour operation.

3. Projected Needs for the District Center

A comparison between the potable water demands and the supply capacities for the years 2005, 2015 and 2025 are presented in table (1.5) for the district center. The table identifies the surplus and deficit in supply over the planning horizon.

Table (1.5) Projected Water Demand and Supply Capacity-Rania City (Parson, 2006)

Parameter	Quantity (m^3/day)
Existing operational water production capacity	10,628
Design capacity of the existing system	18,036
Projected water demand 2005	28,080
Projected water demand 2015	37,737
Projected water demand 2025	50,716
Projected production capacity deficit 2005	17,452
Additional water production needed in 2015	27,109
Additional water production needed in 2025	40,088

As shown in the above table, the design capacity of the existing system does not meet the present water demand of Rania City either now or on into the future.

B) Other Urban Areas

Projection of water needs have also been carried out for Rania's subdistricts of Betwata, Hajiawa and Chwarqurna. The total 2005 urban population of the three-subdistrict center is approximately 88,247. Based on the water demand criteria, the combined water demand for these subdistrict centers is projected to increase from its present level of approximately (34,469 m^3/d) to around (62,254 m^3/d), by the year 2025 (Parson, 2006).

The design capacities of the water supply systems in the subdistrict centers are not always available. When such a figure has not been identified, the current estimated production has been taken to be the available design capacity of the existing system, taking into consideration the various factors that limit production.

A comparison between the potable water demands and the current production capacities for the years 2005, 2015, and 2025 are presented in the following table for the sub district centers (Parson, 2006). Table (1.6) identifies the surplus and deficit in supply over the planning horizon.

Table (1.6) Projected Water Demand and Supply Capacity Subdistrict Centers (Parson, 2006)

Betwata	**2005**	**2015**	**2025**
Existing water supply capacity	7,000 m^3/d	---	---
Projected water demand	4,769 m^3/d	6,409 m^3/d	8,613 m^3/d
Additional capacity	None	None	1,613 m^3/d
Hajiawa	**2005**	**2015**	**2025**
Existing water supply capacity	3,000 m^3/d	---	---
Projected water demand	13,860 m^3/d	18,627 m^3/d	25,033 m^3/d
Additional capacity	10,860 m^3/d	15,627 m^3/d	22,033 m^3/d
Chwarqurna	**2005**	**2015**	**2025**
Existing water supply capacity	2,500 m^3/d	---	---
Projected water demand	15,840 m^3/d	21,288 m^3/d	28,609 m^3/d
Additional capacity	13,340 m^3/d	18,788 m^3/d	26,109 m^3/d
Total of the Subdistricts	**2005**	**2015**	**2025**
Existing water supply capacity	12,500 m^3/d	---	---
Projected water demand	34,469 m^3/d	46,324 m^3/d	62,255 m^3/d
Additional capacity required	24,200 m^3/d	34,415 m^3/d	49,755 m^3/d

As shown in the above table Hajiawa and Chwarqurna suffer from a severe shortage, while there is currently surplus in Betwata subdistrict. Although the latter is projected to face water shortage by the year 2025 if no new supply sources are developed.

1.6 Aim of the Study

The main aims of the present study are to explore and assess available water resouces for use in the studied area, which will be done using the following approaches:

1. A geological, hydrological, and hydrogeological, investigation of the area.
2. An assessment of the available water resources.
3. Calculate water balance components based on hydrometeorological approach and crop water requirements approach.
4. Environmental isotopes (^{2}H, ^{18}O) anlaysis to investigate:
    A. The origion of groundwater.
    B. Groundwater connection to modern day infitration from rainfall.
    C. Determining the recharge areas to groundwater source.
    D.To trace the interconnection between groundwater and surface water.
5. A study of the system and storage of aquifers that feed major utilized springs in the area using time series analysis.
6. Examining water quality and suitability for different uses.
7. Constrution of numerical groundwater flow model for Quaternary aquifer at Rania area.
8. Application of different management approaches such as: water conservation methods and proper planning of drilling of deep and shallow wells to ensure environmentally safe groundwater extraction.

1.7 Previous work

Although the first geological investigation in Iraq aiming at the assessment of oil resources started only in the early 1920s, the development of groundwater is a very ancient art in the region. Tapping surface water from streams and groundwater from wells dug for irrigation purposes and construction of long channels was practiced for the first time in Mesopotamia thousands of years B.C.During 1950s, investigations of groundwater resources intensified. In 1953, Government of Iraq contracted Ralph M. Parsons Company to investigate and report on the groundwater resources in the area. The study focusing covered Sulaimaniyahyah liwa was finalized in 1957 (vo1.12) (Paron, 1957). The company's investigations included collection, evaluation, and correlation of geological and hydrological information pertaining to ground water in the area; available at that tune (drilled and hand-dug wells, karezes and springs were inventoried).Due to the unstable political situation, no hydrogeological investigation has been conducted in the area since 1990. Moreover, only part of the detailed topographical or geological maps, aerial photos, studies and reports were saved and are available at the local Universities, in some other local governmental institutions or in private libraries. Limited availability or in some cases, a total lack of technical equipment (hrydrogeological, hydrological and geophysical) resulted in use of inadequate methodology in selection of drilling sites, well development and field measurements in general. Until last few years, no accurate and adequate hydrogeological maps, essential for planning any groundwater exploration and exploitation were available for Northern Iraq or some targeted areas. Also, crucial data regarding well exploitation capacity, major springs discharge and groundwater level fluctuations have not been collected in a systematic manner.Recently, Food and Agricultural Organization Groundwater Programme (since year 2000) started to fill these gaps and provide a base for a new groundwater management in the region.The results of this work was published by (Stevanovic, and Markovic, 2004) in two volumes the first describes the climate, geology, hydrology, and geomorphology of North-Iraq, while the second has focused on the general hydrogeology and aquifers system of northern Iraq. Other previous works as mentioned below were focused on many subjects:

-Bolton, 1956, studied the geology and economic prospect of Rania area.

-Bolton, 1958d, studied the geology of the Rania area.

-Buringh, 1960, studied soil properties in the Rania and Qaladza area.

-Bautrus, 1988, studied the hydrology of the lesser Zab; the main conclutions of his study is that the physical and chemical quality of water range from good to very good and suitable for human and irrigation use.

-Al-Shami, 1993, studied some water resources in Rania for some irrigation projects.

-Al-Surdashi, 1999, Studied Stratigraphy of Jurrasic rock, one of his sections was for the Rania area.

-Salae, 2001 studied the Stratigraphy and sedimentology of the Upper Jurassic succession, in NE Iraq, two of his studid sections were through the Rania area.

-Qadir, 2001, studied the erodibility and some physical properties of Rania Soil.

-Haji, et al., 2001, studied the agro-ecological zoning of Chuar Qurna, Bngrd, Sangasar, and Qualadza.

-Haji, et al., 2002 studied the agro-ecological zoning of Sulimani region, Rania included in this work.

-Fatah, 2004, studied some physical properties of soils in the Rania area.

-Stevanovic and Markovic**,** 2004 studied some hydrologic and hydrogeoloic elements in Kurdistan region like springs and streams discharge measurement, groundwater monitoring, classification of aquifers type.

-Parson, 2006, Studied Mini Master Plan for the Public Water Supplies for the Governorate of Sulaimaniyah.

-Qaradaghi, 2007-studied sedimentology of Sarmord Formation in Sulaimaniyah provenance, one of his studied sections was in Rania area.

- Mohyaldin, 2007 studied the stratigraphy and sedimentology of organic-rich limestones of the Chia Gara Formation in Rania area.

In conclusion, the Rania area lacks a comprehensive and systematic study of its hydrogeological conditions with little information is available of its groundwater resources.

1.8 Methodology

1.8.1 Pre-field Work

The pre-field work included the following:

1-In order to prepare the fieldwork, available basic data from different sources were collected, topographic and geological maps with relevant scale were selected, and satellite images suitable for background map were made available.

2- Relevant data from site on land use, soil type, groundwater, drilled wells documentations of wells, vegetation type, size of cultivated area, geophysical and relevant meteorological data (i.e. precipitation, evaporation, temperature, wind speed, relative humidity, river discharge) were gatherd from the respective offices. Lithological columns of drilled wells are obtained from Sulaimaniyah well drilling company, spring discharges were obtained from a previous report issued by (FAO) during (2000-2003). Many geoelectrical survey (VES) profiles on selected sites were taken from (Aziz, 2002).

1.8.2 Field Work

A field trip has been organized to collect primary data from the studied area; data of the following nature were noted or collected in particular:

1. Information about the geologic succession and the structure of the area.
2. Water table monitored in the (2) pizometers, also aquifer test done in the field for obtaining aquifer properties, plate (1.1.A, B) and Fig. (1.2).
3. Depth to groundwater was measured by electrical sounder plate (1.1.A).
4. Location of wells and springs were determined by a (GPS) device.
5. Stream velocity was measured by a current meter, model (Barel 18619), plate (1.1.C) and Fig. (1.2).
6. Two seasons were selected to determine the hydrochemistry of groundwater and for assessing seasonal variations. The first was during 6/10/2006 to 15/10/2006 which represents the minimum recharge period

and the second was during 1/4/2007 to 12/4/2007 which represents the maximum recharge period,for the two seasons water samples from (41) deep wells, (7) springs,and one stream were taken Fig. (1.2) and tables (1.7 and 1.8).All water samples were collected in acid-washed 250 and 500 ml polyethylene bottles, following the standard guidelines (Hem 1991, APHA, 1998 , and Schoenleber, 2005).

All water samples were filtered through 0.45 µm Millipore filters for cation and anion analyses upon return from the field (Schoenleber, 2005, Mustafa, 2007). Samples for cation analyses of Na^+ and K^+ were acidified with 0.5 ml concentrated (16 M) HNO_3 per 100 ml sample within days of collection to prevent precipitation on the bottle wall. Unacidified samples were analyzed for Ca^{2+}, Mg^{2+}, SO_4^{2-}, Cl^-, NO_3^- and PO_4^{3-}. Gas (H_2S) was stabilized in the field by pouring a portion of the sample to (100 ml) volumetric flask then adding (4 ml) % 20 zinc acetate($Zn\ CH_3COO)_2$ and (1ml) (1N) NaOH then the volume is completed with water sample (Al-Janabi, et al., 1992).

Furthermore (21) samples were collected for isotopic analysis during 24-25/1/2007. Water samples were collected in (60 ml) polyethylene bottle with polyseal cap, which was provided by the United State Gological Survey (USGS) Reston Isotope Lab., Plate (1.1.D). In situ determination of (T^oC, EC, and pH) were done during sample collection for isotopic analysis to aid interpretation, plate (1.1.E).The distribution of the sampled points in the area of study was selected according to the field information . Field samples were analyzed immediately (APHA, 1998) for temperature (T^oC), pH, turbidity (TU) and electrical conductivity (EC) using portable multiparameter analyzer model (TPS/90FL-T Field Lab. Analyzer), plate (1.1.F).

Plate (1.1) A) Water Level Measurement

B) Drawdown Measurement from Monitor Well

C) Stream Velocity Measurement at (Shaoor) Gauging Station by Current Meter Model (Barel 18619)

D) Polyethylene Bottles with Polyseal Cap (USGS Reston Isotope Lab.)

E) Water Samples Collection for Isotopic Analysis and in Situ Measurement of (EC, $T^{o}C$)

F) Portable Multiparameter Analyzer Model (TPS/90FL-T Field Lab Analyzer)

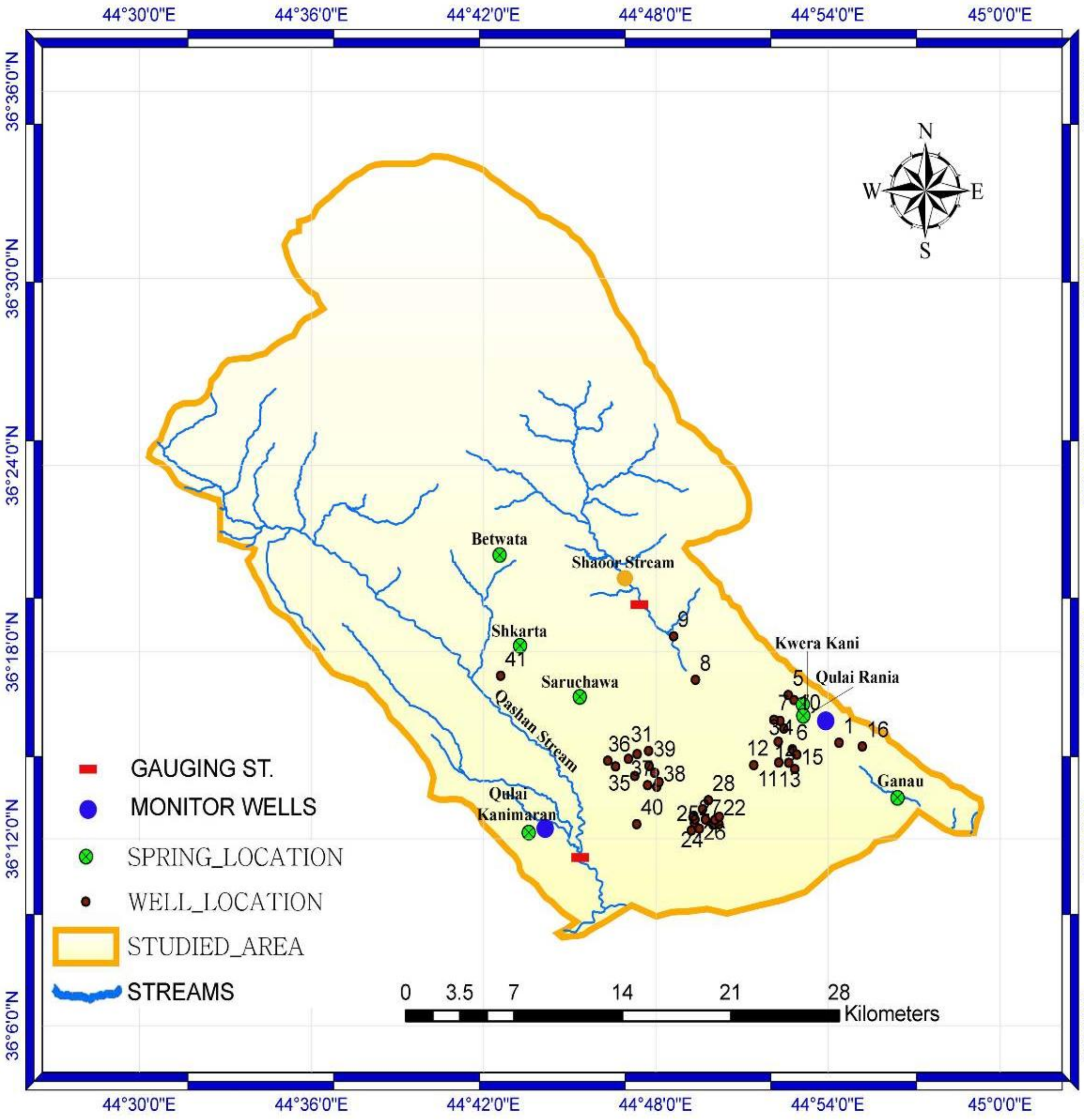


Fig. (1.2) Rania Map Depicted on it Sampling Locations, Streams Gauging Stations and Monitoring Wells Locations

Table (1.7) Name and Geographic Location of Selected Springs for Hydrochemical Analysis

No.	Name	District	Long.	Lat.	m.a.s.l
1	Betwata	Betwata	44 ° 42' 33"	36 ° 20' 33"	1047
2	Qulai Kanimaran	Chwarqurna	44 ° 43' 34"	36 ° 12' 28"	541
3	Shkarta	Betwata	44 ° 43' 16"	36 ° 18' 23"	723
4	Qulai Rania	Rania	44 ° 53' 07"	36 ° 15' 23"	564
5	Saruchaua	Saruchawa	44 45' 21"	36 16' 33	766
6	Ganau	Rania	44 ° 56' 25"	36 ° 12' 51"	515
7	Kwera Kani	Rania	44 ° 53' 08"	36 ° 15' 15"	593
8	Shaoor Stream	Rania	44 ° 46' 56"	36 ° 20' 18"	585

Table (1.8) Name and Geographic Location of Selected Wells for Hydrochemical Analysis

No.	Name	District	Long.	Lat.	m.a.s.l
1	Saidawa	Rania	44^{o} 54' 23"	36^{o} 15' 05"	561
2	Azadi	Rania	44^{o} 52' 20"	36^{o} 15' 47"	599
3	Bolch factory	Rania	44^{o} 52' 28"	36^{o} 15' 32"	591
4	Nawroze	Rania	44^{o} 52' 16"	36^{o} 15' 07"	598
5	Hassan Agha	Rania	44^{o} 52' 37"	36^{o} 16' 37"	581
6	Peshawa	Rania	44^{o} 52 46"	36^{o} 14' 52"	580
7	Awarakan	Rania	44^{o} 52' 07"	36^{o} 15' 49"	602
8	Sarkapkan	Rania	44^{o} 49' 23"	36^{o} 17' 06"	674
9	Mekuka	Rania	44^{o} 48' 37"	36^{o} 18' 30"	714
10	Hospital	Rania	44^{o} 52' 49"	36^{o} 16' 27"	590
11	Nawroze2	Rania	44^{o} 52' 17"	36^{o} 14'27"	582
12	Gas factory	Rania	44^{o} 51' 25"	36^{o} 14' 22"	598
13	Rapareen 3	Rania	44^{o} 52' 38"	36^{o} 14' 26"	576
14	Rapareen 4	Rania	44^{o} 52' 51"	36^{o} 14' 14"	574
15	Rapareen1	Rania	44^{o} 52' 55"	36^{o} 14' 42"	586
16	Bosken	Rania	44^{o} 55 '12"	36^{o} 14' 58"	589
17	Haji Homaran	Chwarqurna	44^{o} 49' 38"	36^{o} 12' 57"	560
18	10	Chwarqurna	44^{o} 49' 44"	36^{o} 12' 37"	547
19	Camp 13	Chwarqurna	44^{o} 50' 00"	36^{o} 12' 27"	546
20	Camp 14	Chwarqurna	44^{o} 50 12"	36^{o} 12' 28"	542
21	17	Chwarqurna	44^{o} 50' 04"	36^{o} 12' 36"	554
22	16	Chwarqurna	44^{o} 50' 13"	36^{o} 12' 42"	544
23	Bn Zeri	Chwarqurna	44^{o} 49' 18"	36^{o} 12' 41"	550
24	2	Chwarqurna	44^{o} 49' 21"	36^{o} 12' 30"	545
25	Rapareen	Chwarqurna	44^{o} 49' 14"	36^{o} 12' 16"	553
26	Rezgary	Chwarqurna	44^{o} 49' 31"	36^{o} 12' 19"	559
27	Shilanaee	Chwarqurna	44^{o} 49' 22"	36^{o} 12' 37"	544
28	Electricity station	Chwarqurna	44^{o} 49' 50"	36^{o} 13' 14"	557
29	Mirabag	Haji Awa	44^{o} 47' 03"	36^{o} 14' 34"	593
30	Malawaee	Haji Awa	44^{o} 47' 21"	36^{o} 14' 43"	602
31	Razga	Haji Awa	44^{o} 47' 45"	36^{o} 14' 49"	618
32	Tekosher	Haji Awa	44^{o} 48' 02"	36^{o} 13' 40"	582
33	Industrial	Haji Awa	44 47' 16"	36^{o} 14'01"	581
34	Paroyeakan	Haji Awa	44^{o} 47' 58"	36^{o} 14' 07"	587
35	Kifradol	Haji Awa	44^{o} 46' 36"	36^{o} 14' 19"	578
36	Kifradol 14	Haji Awa	44^{o} 46' 20"	36^{o} 14' 30"	574
37	Tekosher 17	Haji Awa	44^{o} 47' 43"	36^{o} 13' 43"	568
38	Tekosher 18	Haji Awa	44^{o} 48' 07"	36^{o} 13' 49"	583
39	Sardam	Haji Awa	44^{o} 47' 46"	36^{o} 14' 20"	593
40	Grdjan	Haji Awa	44^{o} 47' 20"	36^{o} 12' 28"	545
41	Shkarta camp	Betwata	44^{o} 42' 36"	36^{o} 17' 14"	614

1.8.3 Lab Work

Water samples were analized in the laboratories of Health, and Environmental Protection Office and the Geology Department at University of Sulaimaniyah.The standard methods according to (APHA, 1998, Al-Janabi, 1992) were followed.

-Total dissolved solids (TDS) were computed by multiplying the EC by a factor (0.64).

-Calcium and magnesium ($Ca^{2+}$and Mg^{2+}) were analyzed titrimetrically, using standard (0.02 N EDTA) and E.B.T indicator.

-Sodium (Na^{+}) and potassium (K^{+}) were measured, using a flame photometer (Genway PFP7).

-Bicarbonate (HCO_3^{-}) and carbonate (CO_3^{2-}) were analyzed by titrating with (0.04N HCl), using Methylorange and Phenolnephthalene indicator.

-Chloride (Cl^{-}) was determined titrimetrically by standard (0.05N $AgNO_3$), using (K_2CrO_4) indicator.

-Sulphate (SO_4^{2-}), nitrate (NO_3^{-}), phosphate (PO_4^{3-}) were analyzed, using spectrophotometer type (HATCH).

-H_2S was determined titrimetrically using (0.01N) Iodine and (0.01N) Sodium Thiosulphate with (% 1) starch indicator.

-Hydrogen isotope ratio analysis have been performed in USGS Reston Isotope Laboratory using a hydrogen equilibration technique (Coplen et al., 1991, Revesz and Coplen, 2003a), rather than the zinc technique used prior to that date. (Kendall and Coplen, 1985).The hydrogen equilibration technique measures deuterium activity, whereas the zinc technique measures deuterium concentration.The zinc reagent was prepared from pure metal by adding Sodium as an impurity (Kortelainen and Karhu, 2004). For the majority samples, the differences in reported isotopic compositions between the two techniques are not significant. However, in brines, the difference may be significant (Sofer and Gat, 1972, 1975). Reported $\delta\ ^{2}H$ values of activity are more positive than δ ^{2}H values of concentration and this difference is proportional to molalities of the major dissolved solids. Some examples of the differences between activity ratios and concentration ratios for δ ^{2}H in (1) molal salt solutions are shown in table (1.9) (Horita et al., 1993). The data for individual salts may be multiplied by molality to obtain adjustments to delta values based on concentration. Isotopic ratios of produced CO_2 and H_2 were measured by a Finnigan MAT 251 gas source mass spectrometer.The analytical precission was ± 0.1 ‰.

Table (1.9) Differences between Activity Ratios and Concentration Ratios for δ^{2}H in (1) Molal Salt Solutions (after Horita et al., 1993)

Solution(1 molal)	**Delta ^{2}H (activity) - Delta ^{2}H (conc.) (30 degrees C)**
NaCl	+2.07 per mill
KCl	+2.42 per mill
$CaCl_2$	+5.31 per mill
$MgSO_4$	+1.12 per mill

-Water samples are measured for δ ^{18}O using the CO_2 equilibration technique of (Epstein and Mayeda, 1953), which has been automated (Revesz and Coplen, 2003 b). Therefore, both oxygen and hydrogen isotopic ratio measurements are reported as activities. Oxygen and hydrogen isotopic results are reported in per mill (per thousand ‰) relative to Vienna Standard Mean Ocean Water (VSMOW) and normalized (Coplen, 1994) on scales such that the oxygen and hydrogen isotopic values of SLAP (Standard Light Antarctic Precipitation) are -55.5 per mill and -42.8 per mill, respectively. Oxygen isotopic results of a sample Z can be expressed relative to VPDB (Vienna Peedee belemnite) using the equation:

δ ^{18}O of Z relative to VPDB =

(0.97001 times δ ^{18}O of Z relative to VSMOW) - 29.99

The 2-sigma uncertainties of oxygen and hydrogen isotopic results are (0.2) per mill and (2) per mill, respectively, unless otherwise indicated. This means that if the same sample was resubmitted for isotopic analysis, the newly measured value would lay within the uncertainty bounds 95 percent of the time.

1.9 Sample Preservation

Certain analytical methodologies for specific analytes require chemical additives in order to stabilize and maintain sample integrity. Generally, this is accomplished under two scenarios:

- Preservative may be added to the sampling bottles by the laboratory prior to shipment into the field or,
- Preservatives are added in the field immediately after the samples are collected.

According to (Clark &Fritz 1997, Schoenleber 2005, USGS Reston Isotope Lab.) the following guidelines, as tabulated in table (1.10) are recommended to achieve safe and accurate preservation of samples in the field. These guidelines may indicate any additional preservation required upon arrival of samples at the laboratory as cited in the specific methodologies.

Table (1.10) Required Preservation, Container, and Maximum Holding Times for Water Samples

Parameter	Preservation &Treatment	Container	Maximum Holding Time
Calcium	Conc. HNO_3 to pH < 2	Glass or polyethylene	6 months
Magnesium	HNO_3 to pH < 2	Glass or polyethylene	6 months
Sodium	HNO_3 to pH <2	Glass or polyethylene	6 months
Potassium	HNO_3 to pH <2	Glass or polyethylene	6 months
Alkalinity	Cool 4 ^{o}C	Glass or polyethylene	l4 days
Chloride	None	Glass or polyethylene	28 days
Sulfate	Cool 4^{o}C	Glass or polyethylene	28 days
Nitrate	Cool 4 ^{o}C	Glass or polyethylene	48 hours
Phosphate	Cool 4 ^{o}C	Glass or polyethylene	48 hours
pH	None	Glass or polyethylene	Analyze Immediately
Temperature	None	Glass or polyethylene	Analyze Immediately
Electrical Cunductivity	None	Glass or polyethylene	Analyze Immediately
Turbidity	Cool 4 ^{o}C	Glass or polyethylene	48 hours
Sulfide(H_2S)	Cool 4 ^{o}C, add zinc acetate& NaOH to pH > 9		7 days
^{18}O, ^{2}H	Do not field rinse bottle Do not add chemical treatment Fill bottle two-thirds full with either raw or filtered water so that if sample expands or freezes during shipping, bottle will not break. Store at ambient temperature until shipped to laboratory	Glass or high-density polyethylene (HDPE) bottle with Polyseal cap to prevents evaporation of water. Must be made of such a design and appropriate material that any loss by evaporation and diffusion to or exchange of water with the surroundings is prevented. The isotope effect of evaporation can be significant: a 10% loss of sample results in an isotope enrichment of about 10‰ in ^{2}H and 2‰ in ^{18}O	>1 year

1.10 Software

The following softwares were used for many purposes like:

1. Ms-word and Ms-Excell, Golden Grapher 7.0 (2007) were used for typing, data tabulation, solving equations, and constructing diagrams like (Chadha, Us salinity, time series chart and water balance equations).
2. Adobe Photoshop 10.0 (2007) used for image editing.
3. CROPWAT.4.0 for window (1998) used for cropwater requirements, evapotranspiration, and effective rainfall calculation.
4. SURFER.8.0 (2002) and ArcDesctop 9.1 (2005) are used for contouring, location map preparation, and ploting sampling locations.
5. STATISTICA.6.0 (2001) used for time series analysis.
6. Aq.QA. (2005) used for hydrochemical data processing, $\delta^{18}O$ and $\delta^{2}H$ diagram, and Durov plot.
7. ROCKWORKS, (2006) and WINFENCE.2 used for cross sections construction.
8. WATEQ4F (2003) used for equilibrium speciation calculatuion.
9. AQUIFER$_{win32}$3.0 (2004) and AQTESOLV.4 (2006) used for pumping test analysis.
10. Processing Modflow Pro. (PMWIN Pro Version 7.0.13(2003) used for groundwater flow modeling construction.

1.11 Tectonics and Structural Conditions

According to tecto-structural conditions and physiographical classification the area of study lies within the unstable plateform, high-folded zone, Sulaimaniyahya-Zakho subzone (Jassim and Goff, 2006) Fig.(1.3), and in the Qamchuqa-Rania subzone according to (Buday and Jassim, 1987).

According to (Buday and Jassim, 1987) the structure of this area orogenically strongly uplifted units a very complex, though relatively uniform, one. The complex character is caused by the two main folding phases affecting this zone, furthermore, by differences in the rate of uplift, and by the relatively strong influence of both the transversal structures and the Alpine stress emanating from the nearby lying geosynclinal zone. This area is characterized by a dense net of high, mostly box-shaped, asymmetric anticlines, with relatively flat crestal parts, steep southwestern limbs disturbed mostly by reverse faults and somewhat gentler northeastern flanks. Sometimes, the steep southwestern flank is slightly thrusted over the next anticline. The synclines are narrow and all structures trend NW-SE.

The crestal parts of the anticlines are built by Jurassic- lower Cretaceous formations; the flanks and synclines mostly built by late Cretaceous, more rarely Paleogene beds. The anticlines in the southwestern parts of the unit are somewhat less expressive, built mostly by late cretaceous- Paleogene sequences, the synclines are filled always by Paleogene sediments. The anticlines become higher, the synclines narrower towards the northeast.There, overturned anticlines occur too and reverse faults are more widespread. The main structures are Rania, Makook, Pelewan, Karookh, and Handreen anticline.

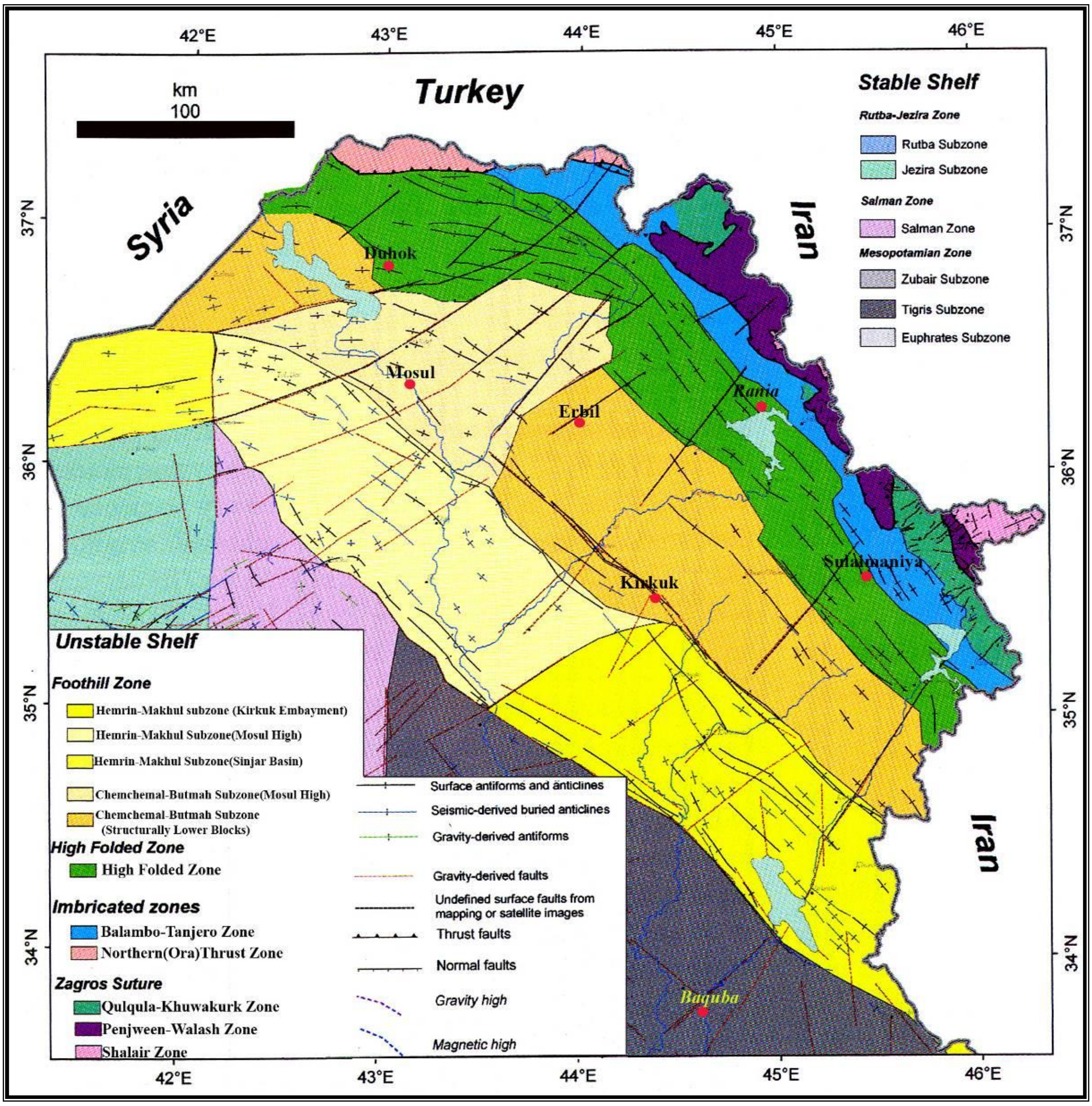


Fig. (1.3) Tectonic Location of the Studied Area According to (Jassim and Goff , 2006)

1.12 Geological Setting

The described geological setting of Rania district is mainly based on the publications of (Bolton, 1956, 1958d, Bellen et al., 1959, Buday 1980, 1987, and Jassim and Goff, 2006). Rania district composed of different geological rock units, which are shown in Figs. (1.4 and 1.5) and can be summarized as follows.

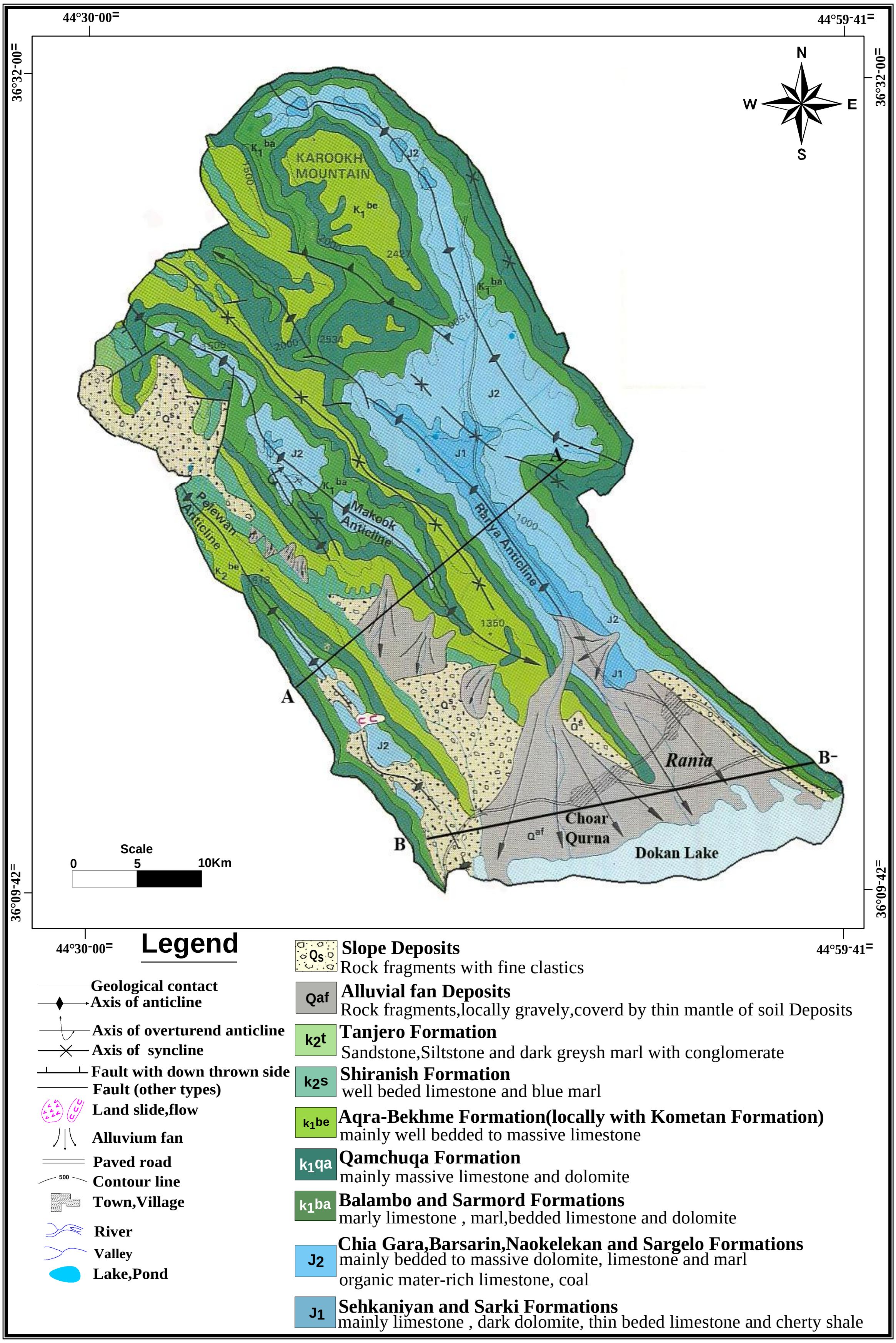


Fig. (1.4) Gelogical Map of the Studied Area (After Sissakian, 1997)

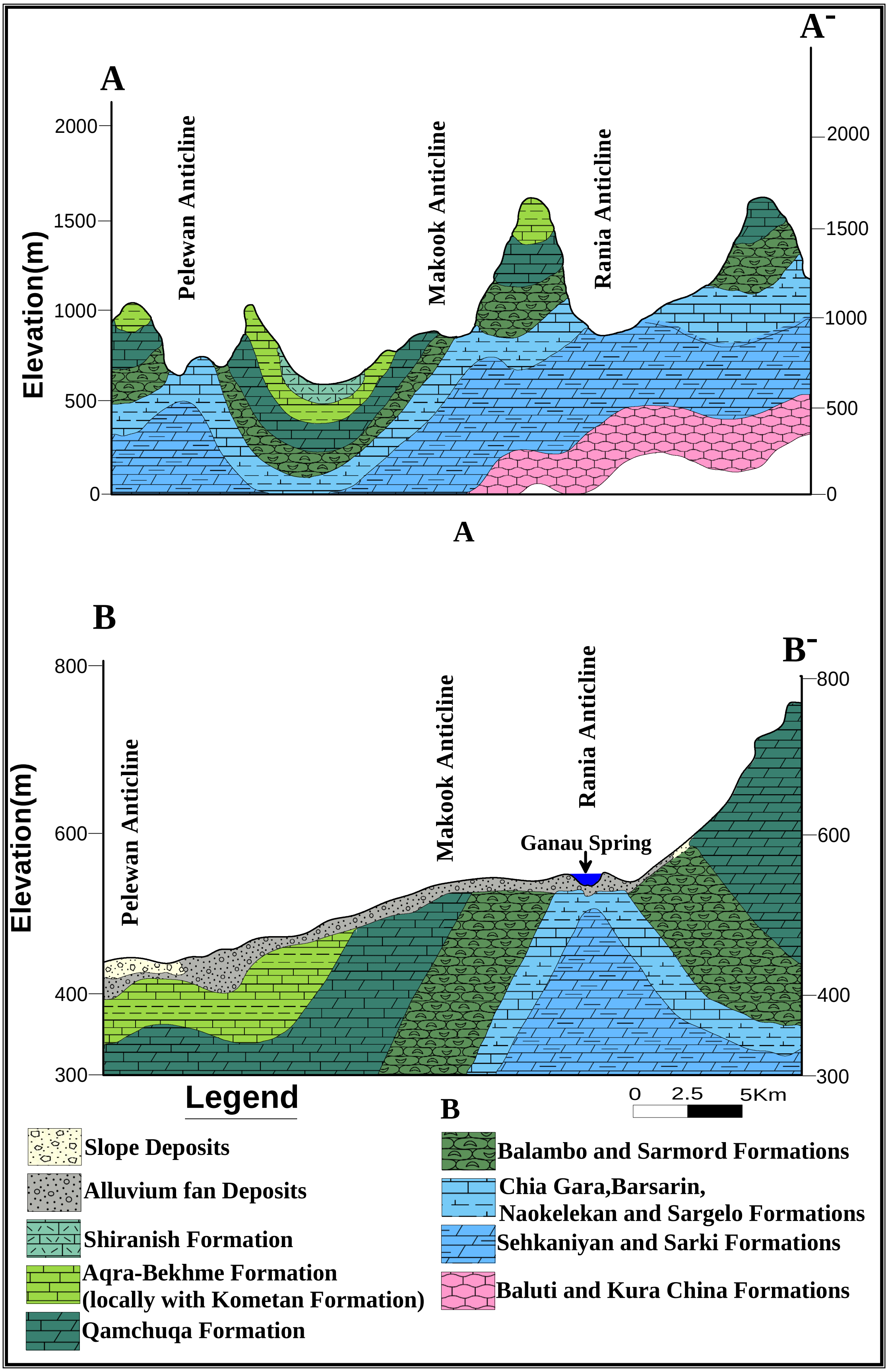


Fig. (1.5)A, B Schematic Geological Cross Sections along the Studied area (Modified from Sissakian, 1997)

1.12.1 Sarki Formation (Early Liassic)

The formation consists of a lower unit (120 m) thick comprising thin bedded, fine-grained, cherty and dolomitic limestone, alternating with cherty shale, occasional dark sugary dolomites, and bands of shell breccias, oolitic limestones, micro conglomerates and recrystallisation breccias (Jassim and Goff, 2006). A dark brown massive-bedded dolomite marks the base of the unit.

The upper unit (180 m thick) consists of most entirely of dolomites (Al-Surdashi, 1999). They are mostly soft and highly cavernous, alternating with soft, friable cherty dolomites and some shale and marls. In the Sirwan valley in NE Iraq the formation is 260 m thick (Bolton, 1958d) and comprises contorted dolomites with residual solution rubble and rare undissolved gypsum lemicles (Bellen et al, 1959). Near Rania at Hanjira village, which located to the north of Rania, the formation is predominantly dolomite.

1.12.2 Sehkaniyan Formation (Liassic)

Consists of (180 m) thick carbonate unit divided into three units, lower, middle, and upper units (Jassim and Goff, 2006). In the Northern Thrust Zone the formation consists of dark, fetid dolomites comprising saccharoidal dolomite, bedded very bituminous (locally cherty) dolomite, and fossiliferous dolomitic limestones with Posidonia, ammonites and fish remains, overlain by thick bedded grey dolomitic limestone (Al-Surdashi, 1999). It is likely that the section includes part of the Sargelu Formation. In the Rania area, where the formation is composed of dark dolomites only, the thickness reaches (300 m), (Bolton, 1958d).

1.12.3 Sargelu Formation (Bajocian-Bathonian)

The Sargelu Formation in its type section comprises (115 m) of thin-bedded, black, bituminous, dolomitic limestones, and black papery shales with streaks of thin black chert (Bolton, 1958d, Jassim and Goff, 2006). The upper and lower contacts of the formation are conformable and gradational.The upper boundary is often obscured by dolomitisation. The upper Sargelu Formation at the Hanjera village in the Rania city is characterized by the abundance of solution collaps breccia.The contact between it and Naokelekan Formation is marked by the disappearance of rich cherts and limestone beds of the Sargelu Formation, which underlies pink to white, medium bedded, and less indurated chalky limestone of the Naokelekan Formation (Salae, 2001).The Sargelu Formation was deposited in basinal euxinic marine environment.

1.12.4 Naokelekan Formation (Late Oxfordian-Early Kimmeridgian)

The (20 m) thick Formation comprises three units:a lower unit of laminated argillaceous bituminous limestone alternating with bituminous shale and fine grained limestone (Buday ,1980, Jassim and Goff, 2006). A middle unit consisting of thin-bedded fossiliferous dolomitic limestone referred to as the "Mottled Beds" and an upper unit (mostly obscured in the type section), of thin-bedded, highly bituminous dolomite and limestone with beds of black shale ("coal-horizons") in the lower part (Salae, 2001). The formation was deposited in an euxinic environment in a very slightly subsiding or starved basin.At the Hanjera village in the Rania city the formation thickness is (10 m) and subdivided into two lithofacies: Slump limestone lithofacies (3 m), and Mottled limestone lithofacies (7.0 m) thick highly ammonitiferous forming prominent cliff readily recognizable in the field. The lithofacies named (coal horizon) by Bellen et al. (1959); is absent at Hanjera village.

1.12.5 Barsarin Formation (Kimmeridgian-Early Tithonian)

The Barsarin Formation is (20 m) thick Overall, the Barsarin Formation at the outcrop seems to be dominated by two distinct colours a buffer creamy and a dark grey (Jassim and Goff, 2006). The first is generally associated with thick massive dolomite lithofacies, while the second is associated with the thin-bedded stratiform stromatolite, and the domal stromatolites .Another sedimentological attribute of the Barsarin Formation is its cyclicity (Salae, 2001).

The formation was deposited in a lagoonal often-evaporitic environment. The contacts of the formation appear conformable in the type area. The upper boundary is lithologically sharp though no break was identified in the type area. The boundary between the Naokelekan and the Barsarin Formations will be a distinct and conformable one, between the mottled lithofacies of the former, and base of the stratiform stromatolite of the latter. In Hanjera village, the formation can be divided into three lithofacies in ascending order (Salae, 2001): Stratiform stromatolite lithofacies (6 m) thick, blister-flat stromatolite lithofacies (1.12 m) thick, and thick bedded limestone lithofacies (1.37 m) thick; grey coloured, massive limestone, pink on weathering.

1.12.6 Chia Gara Formation (Late Tithonian)

The formation comprises up to (230 m) of thin-bedded limestone and calcareous shale, with a consistent bullion zone and Phacoid beds at the base. Argillaceous limestone and marl, interbeded with shale prevail in the upper part of the formation (Jassim and Goff, 2006). The contact with the underlying Barsarin Formation is conformable.To the SE of Sulaimaniyah the Chia Gara Formation passes gradationally into the Balambo Formation. However, a slight break may be present between these two Formations in the Rania (Mohyadin, 2007). The Chia Gara

Formation in Hanjera village consists of a succession of laminated organic matter-rich limestone beds, it is rich in ammonite impressions and thinly laminated sometimes papery, and brown to black fissile shale (Al-Surdashi, 1999 and Salae, 2001) .The lower part is characterized by a dominant brown to black shale with thin to medium thickness of limestone lenses. The limestone layers are rich in organic matter, which have formed structures in spherical and ellipsoidal shapes (Mohyadin, 2007).The lower contact is taken at the top of a stromatolitic limestone of Barsarin Formation, and it is a sharp contact .In contrast the upper contact which with Balambo Formation, is not sharp and needs accurate fieldwork to be determined.

1.12.7 Sarmord Formation (Valanginian-Aptian)

Sarmord Formation comprises (455 m) of homogeneous brown and bluish marls, with beds of argillaceous limestones. The formation was deposited in a deep inner shelf to outer shelf environment.It contains a higher proportion of limestones towards the SW where it passes laterally into the Qamchuqa Formation (Jassim and Goff, 2006).

In Rania **(**Hanjera village) the total thickness of Sarmord Formation in Rania section is about (403 m).The lithology of Sarmord Formation is only rhythmic alternation between marl and marly limestone.A bundle of Sarmord Formation is composed of marl bed and marly limestone beds, and the thickness of marl is larger than the thickness of marly limestone in each bundle (Qaradaghi, 2007).The upper contact is conformable, since the massive limestone of Qamchuqa Formation is above the marl bed of Sarmord Formation,while the lower contact is apparently gradational and conformable with the bedded light brownish gray Limestone of Balambo Formation (Qaradaghi, 2007).

1.12.8 Balambo Formation (Valanginian-Turonian)

Balambo Formation divided into two units. The upper Balambo Formation is homogeneous and consists of thin-bedded globigerinal limestone, passing down into radiolarian limestones (Bellen et al., 1959).

The lower Balambo Formation comprises (280 m) of uniform thin-bedded blue ammonite bearing limestones, with beds of olive green marl and dark blue shale (Jassim and Goff, 2006). The lower Balambo Formation passes into the Qamchuqa and Sarmord Formations to the W and SW. The formation is overlain by the upper Campanian Shiranish Formation or the Upper Turanian Kometan Formation (Bolton, 1958d).

In Rania area, the lower boundary of the formation is with Chia Gara Formation, which is characterized by a succession of limestone and marl. The boundary is taken at the beginning of pinkish limestone (weathering color) and the abundance of uncoiled ammonites (Mohyadin, 2007).

1.12.9 Qamchuqa Formation (Haulerivian-Albian)

The Qamchuqa Formation was described from the Qamchuqa Gorge in the High Folded Zone in NE Iraq (Bellen et al., 1959). It comprises thick-bedded organodetrital and detrital massive black to dark brown dolostone, dolomitic limestone and dolomitic mudstone. The thickness of the Lower Qamchuqa Formation in the High Folded Zone averages (250-300 m), exceptionally reaching (500 m) (Jassim and Goff, 2006).

The Qamchuqa Formation in Rania area especially in Kewa Rash Mountain is mainly composed of calcitic dolomite ,dolomite and limestone.The thick beds of limestone observed consisting of reefal limestone are abundant in the lower part of the formation (Ameen, 2008) . It is represented by containing the rudist, coral, algae, stromatolite, oncoid, orbitolina and mulascs, as well as the biotourbations, which are very common. The formation passes into basinal sediments of Balambo Formation (Jassim and Goff, 2006).The lower contact is conformable and gradational with the lower Balambo or Lower Sarmord Formations.The upper contact is an erosional unconformity with the Kometan Formations but with out angular discordance in the type section. The depositional environment of the Qamchuqa Formaton is suggested to be reefs in the lower part and to be shoal bank in the upper part (Ameen, 2008).

1.12.10 Kometan Formation (Turonian)

The Formation comprises 120 m of light grey, thin bedded, globigerinal-oligosteginal limestone, locally silicified (with chert concretions in some beds), with a glauconitic bed at the base (Jassim and Goff, 2006).

Sediments of the Kometan Formation were deposited in different environments ranging from shallow shelf, restricted (oligosteginal facies) to open marine (globigerinal facies).The lower contact of the formation is unconformity and the upper contact is disconformity (Jassim and Goff, 2006).

1.12.11 Bekhme Formation (Late Campanian)

The Bekhme Formation comprises bituminous secondary dolomite, replacing organic detrital limestones in its upper part (211m) thick, and reef detrital limestones, alternating with reef shoal limestones in the middle part (94 m) thick, with basal breccia conglomerate in the lower part (10 m) thick (Jassim and Goff, 2006).

The Bekhme Formation unconformably overlies the Qamchuqa Formation with a basal conglomerate. The upper contact of the Aqra Formation is marked by an erosional break at the Cretaceous-Tertiary boundary. The Bekhme Formation in Rania area characterized by thick and massive beds of limestone and dolomite that contains planktonic and benthonic Foraminifera.The lower contact is unconformable with Qamchuqa Formation and it wedges out relatively rapidly passing in to Shiranish Fomation (Jassim and Goff, 2006).

1.12.12 Shiranish Formation (Late Campanian-Maastrichtian)

The Shiranish Formation, in its type area, comprises thin bedded argillaceous limestones (locally dolomitic) overlain by blue pelagic marls (Bellen et al., 1959). The formation gradually passes into the Tanjero Formation to the NE.

In the type area, the Shiranish Formation is (225 m) thick. In other outcrop areas, it varies in thickness from 100 to 400 m.

In the type section, the Shiranish Formation conformably overlies the Bekhme Formation (Jassim and Goff, 2006). Elsewhere the Shiranish unconformably overlies older Cretaceous formations. The upper boundary is erosional or nonsequential where the Shiranish Formation is overlain by Palaeogene sediments.

1.12.13 Tanjero Formation (Late Campanian- Maastrichtian)

The type section of the formation comprises two divisions. The lower division comprises pelagic marl, and occasional beds of argillaceous limestone with siltstone beds in the upper part (Bellen et al., 1959, Jassim and Goff, 2006). The upper division comprises silty marl, sandstone, conglomerates, and sandy or silty organic detrital limestones; it interfingers with the Aqra Limestone. Karim (2004) showed that Tanjero Formation deposited in shelf, slope and basin environment (ranging between deep marine and continental). The formation usually conformably and gradationally overlies the Shiranish Formation. An unconformable lower contact was reported in the Rania area (Bolton, 1958d); however, the upper Cretaceous clastics here may belong to the basal unit of the Suwais Red Beds. The formation is usually unconformably overlain by Palaeogene formations except where it passes into the Shiranish Formation or is overlain by the Aqra Formation.

1.12.14 Quaternary Deposits

The age of these is Pleistocene, covering a wide area of the Rania plain. They compose alluvium fan, river terraces, and flood plain deposits, which usually consist of clay, loam, silt, sand and conglomerate, poorly sorted containing a weathered products of the mentiond formations. Slope sediments have formed along the flanks of the structures, usually in narrow belts; along high mountains, thick accumulations of limestone scree occur. The sediments filling the synclines consist mainly of a mixture of gravel and clay. They form pediment deposits, developed on the flanks of anticlines, passing laterally into river deposits towards the centre of the depressions. Some sreams breaking out from the anticlines produce alluvial fans like Chwarqurna and Rania alluvial fan. Accumulation terraces occur along the sreams. They consist of boulders, gravels, sands and clays that are often poorly cemented, the gravels are composed of abundant chert, carbonates, basic ultrabasic and metamorphic rock pebbles which drived from Nighboaring Mountains. Sheet run-off sediments cover flat areas between anticlines are comprise clay, silt and sand, sometimes covered with scattered gravels. Locally developed valley fill with deposits and flood plain sediments. These sediments now constitute good and exploitable aquifer in the area both for drinking and local irrigation. The thickness is highly variable in the area (ranged from 10 to 150 m) which increases toward the west and south of the area where it reachs its maximum thickness.

1.13 General Description of Existing Soil

The regions of the study are considered as inter-mountain valley with complex of hills and small valley bottoms, as well as Betwean and Sangasar plains, which are the most fertile plain in the region. Topography is almost flat to rolling. Valley plains consist of nongravelly and gravelly deposits and their geological Epochs belong to (Pilocene to Miocene) and (Pleistocene). Recent deposits; Whereas Intermountain valley consists of claystone, sandstone, conglomerate, marl, and limestone. The epoch of mountain valley, belong to Eocene to Miocen and Cretaceous.

Differences between the soils of the regions are due to parent materials, releif, runoff, soil depth, and maturity. Soils of the mountain are considered inhereted and shallow, formed from various kinds of limestone classified as Rendzina (shallow soil over limestone), Lithosoil (shallow soil over hard rock). Mountain soils are not suitable for agriculture because of their shallow depth (Retallack, 1997).

Soils in the intermountain are usually deep, well drained, and silty clay to clay, with surface crackes, self-mulching, weakly to well developed slickensides, and rich with lime content. Most soil are frible so they do not need deep tillage, plants grown in the flood plain do not need irrigation because of the high moisture content of the soil,whereas the areas farther from the Dokan lake are used for tobacco growing depending on lift irrigation. Plain Soils are very fertile since they are close to the Dokan Lake, classified as Fluvents (soil formed on silt and clay with conspicuous relict bedding). Most of the studied regions are considered vertisol (thick very clayey, slickensided soil, often with internal deformation of horizons) (Retallack, 1997) and Mollisols (grassland soil with a mollic epideon at least (18cm) thick, dark in color due to the presence of organic matter). Many authers studid the characteristics of the soil in the studied area like (Qadir, 2001, Haji et.al, 2002, and Fatah, 2004); the results of these studies are summarized in the table (1.11).

Table (1.11) Most Chemical and Physical Properties of the Soils (Qadir, 2001, Haji et.al, 2002, and Fatah, 2004)

Parameters	Ranya	Chwarqurna
pH	7.7	7.7
Ec	720	710
O.M%	2.27	1.4
$CaCO_3$%	11.9	57
Ca^{2+} meq/l	5	5
Mg^{2+} meq/l	3	3
Na^{+} meq/l	0.52	0.5
K^{+} meq/l	0.12	0.16
Clay%	50.9	16.56
Silt%	44.61	42
Sand%	4.49	41.44
B.Density g/cm^3	1.42	1.73
Permiability cm/hr	1.5	7.9
Colloids%	48.26	15.3
Textural name	Silty Clay Loam	Loam
Type of strcture	Ang.blocky	Blocky

CHAPTER TWO

METEOROLOGICAL DATA ANALYSIS

Meteorological Data Analysis

2.1Climate

The climate of the study area is mostly related to the Mediterranean semi-arid type, which has cold rainy and snowy climate during the winter, and dry hot continental climate type during the summer. Nearly 56 % of the annual rainfall is precipitating in winter (from December to February). Springtime (from March to May) is characterized by shower type of rain accompanied by thunder, hailstorms with precipitation of about 28 % of the annual precipitation. Summer (from June to September) is characterized by rapid rise in temperature, low humidity and absence of rainfall. Due to lack of meteorological station in Rania area, the long historical hydrometeorologic data (1984-2005) of the nearby Dokan station was used. The Dokan station is located 10 km south east of Rania at longitude (44^{o} 58^{-}) and latitude (35^{o} 55^{-}) with altitude (555 m) above sea level while the elevation of Rania is (573 m) above sea level .

2.2 Climate Elements

2.2.1 Precipitation

Precipitation is the most important parameter in the water balance and aquifer recharge. The area of study is a part of the region affected by Mediterranean climatological system, so its precipitation occurs during winter and spring seasons. The maximum monthly precipitation recorded was (422.6 mm) in January of 2003. The maximum average monthly precipitation is (148.9 mm) in December. The average annual precipitation was (743.8 mm) during the period of (1984-2005). Fig. (2.1) shows the average monthly precipitation for the period (1984-2005).

2.2.1.1 The Time Series Analysis of the Annual Precipitation

The time series is considered to be stationary if there is no change in the statistical parameters representing the series, such as the mean, standard deviation with respect to the time or the length of the samples, otherwise, it is non-stationary (Al-Nsour 2000). In this case, the phenomenon is time dependent. Similarly, the periodicity in a series means that it is non-stationary.

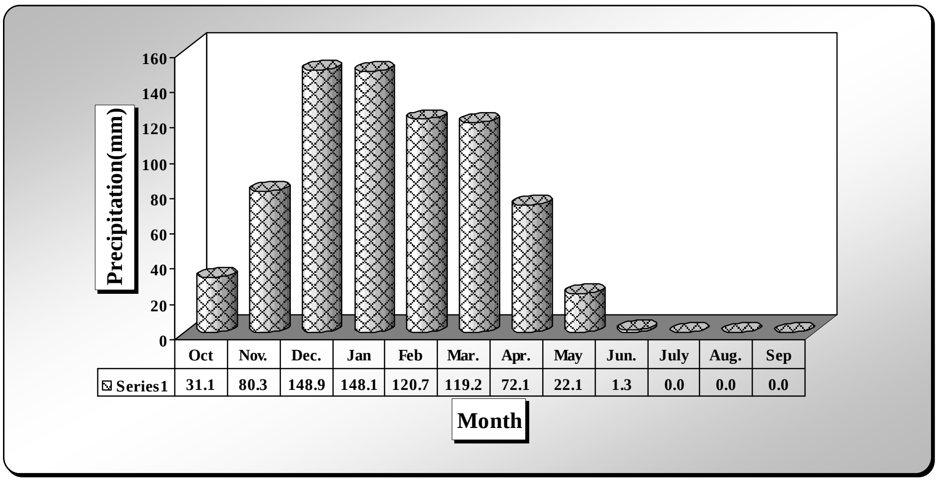


Fig. (2.1) Average Monthly Precipitation of Dokan Station for the Period of (1984-2005)

The annual precipitation values for Dokan station are plotted versus time with 5 years moving average Fig. (2.1). It is used to damp and smooth out the random component leaving the effects of longer wet and dry cycles in the records of the long-term annual precipitation. The wet period can be recognized by comparing the five-year moving line with the average annual precipitation of the Dokan station. This line fluctuated around the long-term mean. However, during drought period the five-year moving average line is located below the long-term average, while during the wet period it is located above the long-term average line. The trend line of the moving average shows gradual decrease in its values. The fitting curve using the linear regression models serve to determine the regional trend Fig. (2.2). The linear regression line of precipitation (y) versus the time (x) by the least square method, for the Dokan station can be represented by the following equation:

$$y = -2.882X + 778.75 \text{ ……….. (2.1)}$$

Where:

X: The serial number of the water year
y: The annual precipitation.

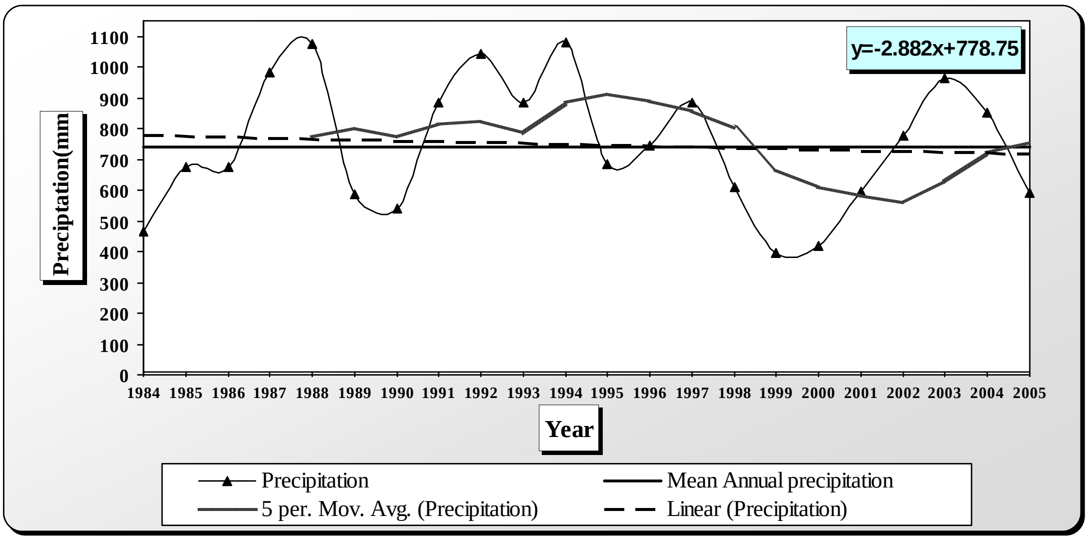


Fig. (2.2) Annual Long Term Precipitation Trend and Five Years Moving Average of Dokan Station for the Period of (1984-2005)

This equation may help to predict the general trend line of the precipitation at Dokan station at any desired water year unless the annual precipitation of long term does not show a significant change. The trend line of the precipitation of Dokan station suggests that there is a decline by (2.8 mm) of precipitation as a general, for each water year during the monitoring period (1984-2005).

The application of five years moving averages model for future prediction shows that over the next few years, the precipitation will be around the long-term average, but a rising limb will start. Construction of a new water supply project such as reservoirs in Rania area must be designed in the knowledge that such oscillations may affect the reliability of these projects.

2.2.2 Wind Speed

The process of vapour removal depends on a large extent on wind and air turbulence, which transfers large quantities of air over the evaporating surface. The (average) daily wind speed in meters per second (m s^{-1}) measured at 2 m above the ground level is required. It is important to verify the height at which wind speed is measured, as wind speeds measured at different heights above the soil surface differ (Allen et al., 2006). Average annual wind speed is (2.36 m/s). The average minimum and maximum value of this parameter in the study area is (1.605 m/s) and (3.405 m/s) in October and March respectively, Fig. (2.3) shows average annual wind speed for the period of (1984-2005).

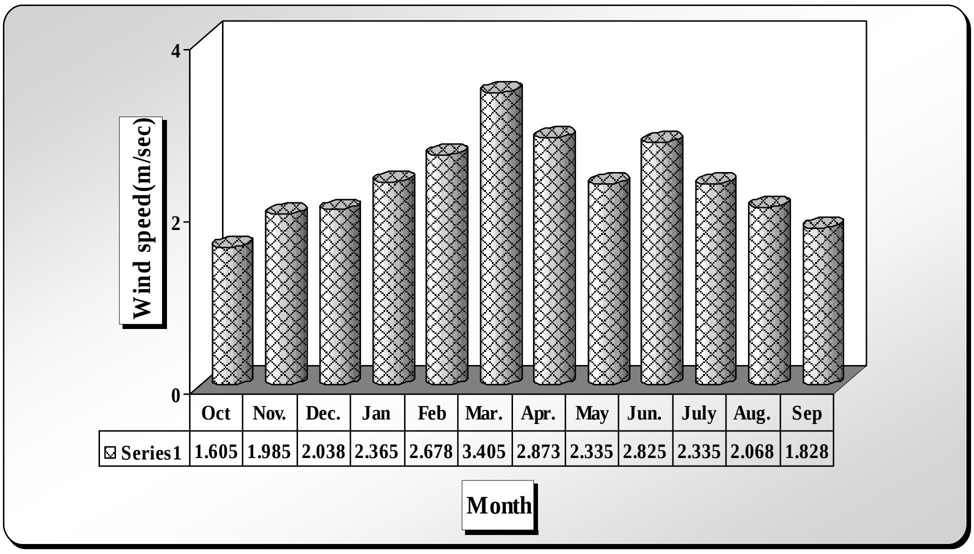
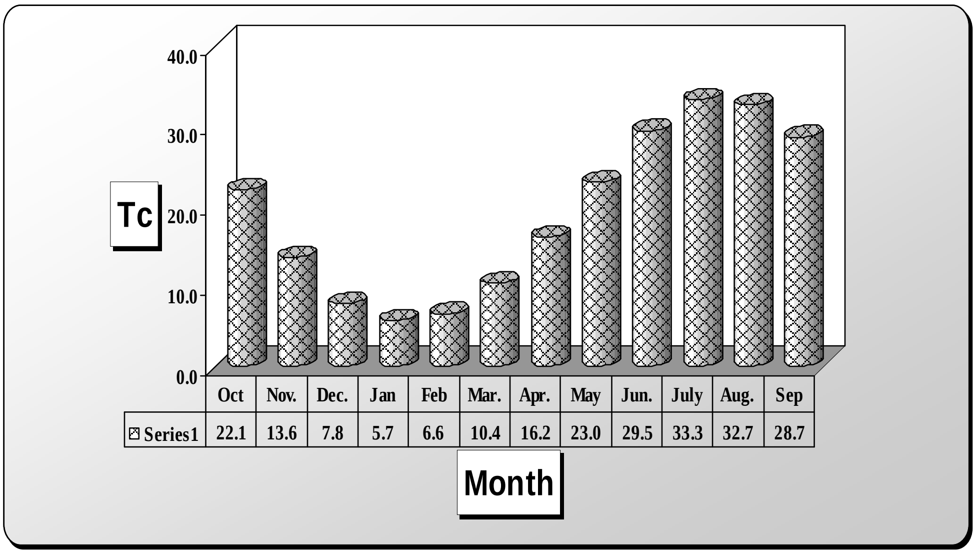


Fig. (2.3) Average Monthly Wind Speed of Dokan Station for the Period of (1984-2005)

2.2.3 Temperature

The average monthly temperature values for the period (1984-2005) was (19.1°C), and the maximum monthly average temperature was (33.3 °C) in July, while the minimum was (5.7 °C) in January, Fig. (2.4) shows the annual monthly average temperature for the period (1984-2005).

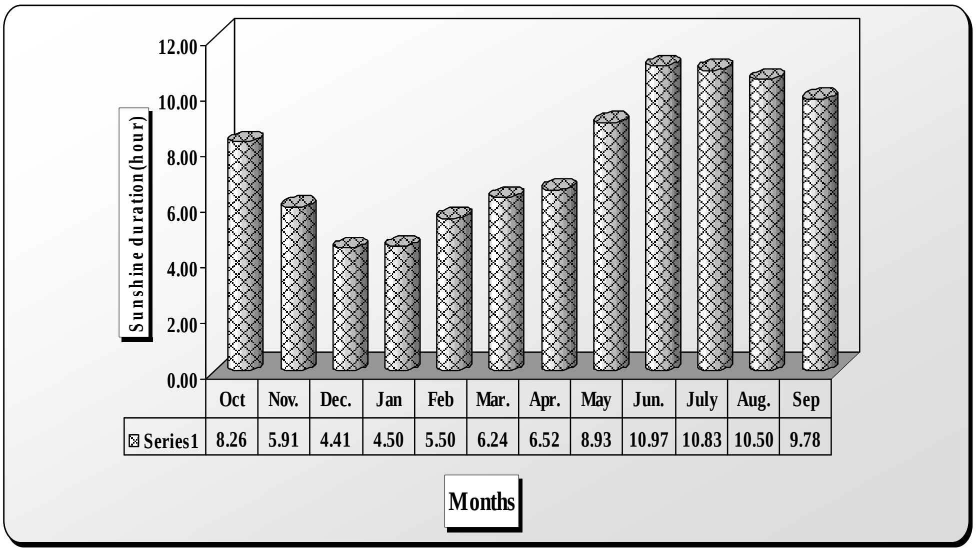


	Oct	Nov.	Dec.	Jan	Feb	Mar.	Apr.	May	Jun.	July	Aug.	Sep
▨ Series1	22.1	13.6	7.8	5.7	6.6	10.4	16.2	23.0	29.5	33.3	32.7	28.7

Fig. (2.4) Average Monthly Temperature of Dokan Station for the Period of (1984-2005)

2.2.4 Sunshine Duration

Sunshine duration and wind speed are the other parameters that are necessary for calculating reference evapotranspiration by Penman-Montith method (Allen et al., 2006). The average monthly maximum sunshine duration occurs in June with an absolute value of (10.97 hours/day), and the average monthly minimum duration occurs in December with an absolute value of 4.41 hours/day, Fig. (2.5) shows average annual sunshine for the period of (1984-2005).



	Oct	Nov.	Dec.	Jan	Feb	Mar.	Apr.	May	Jun.	July	Aug.	Sep
▨ Series1	8.26	5.91	4.41	4.50	5.50	6.24	6.52	8.93	10.97	10.83	10.50	9.78

Fig. (2.5) Average Monthly Sunshine Duration of Dokan Station for the Period of (1984-2005)

2.2.5 Relative Humidity

Relative humidity is one of the most important factors that directly affect evapotranspiration. Relative humidity is a measure of the water vapour content of the air at a given temperature. The variation in relative humidity is the result of the fact that the saturation vapour pressure is determined by the change of air temperature, the relative humidity is a cyclic variable. It is related to temperature and evaporation.

Based on Dokan station's data the average annual relative humidity is (56.5 %), the average minimum and maximum values of this parameter in the studied area are (33.5 %) and (74.6 %) in July and December respectively, Fig. (2.6). shows average annual relative humidity for the period of (1984-2005).

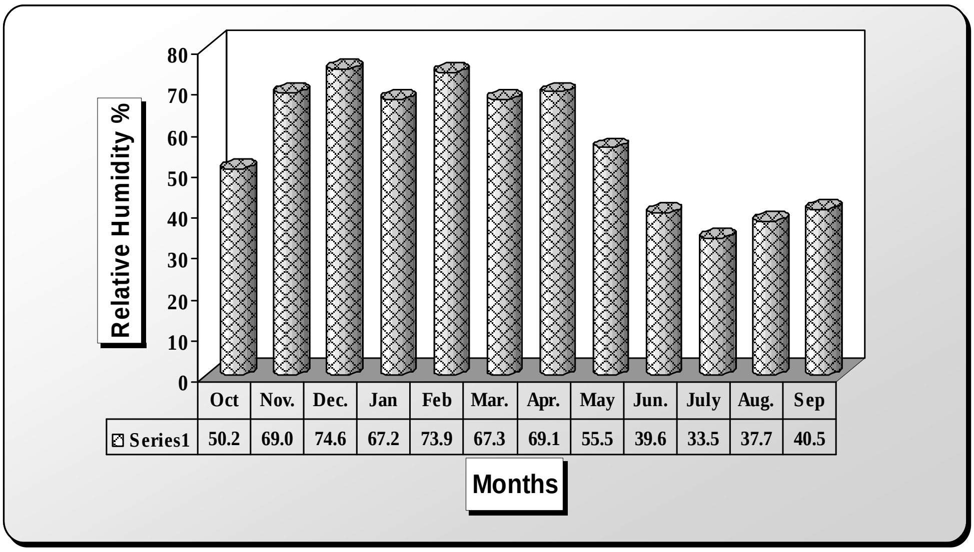


Fig. (2.6) Average Monthly Relative Humidity of Dokan Station for the Period of (1984-2005)

2.2.6 Evaporation From Class (A) Pan

Evaporation is a cyclic variable and affected by many other variables and physical factors (Fetter, 1994). The annual sum value of evaporation from class (A) pan was (2408 mm). The maximum annual average monthly evaporation was (430.2 mm) in July, while the minimum was (55 mm) in

January, Fig. (2.7). shows average annual evaporation from class (A) pan for the period of (1984-2005).

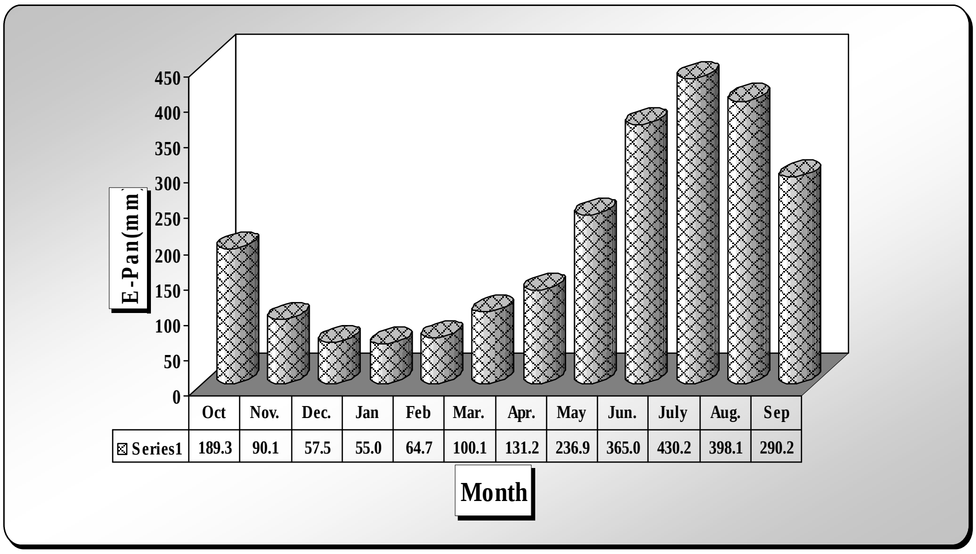


Fig. (2.7) Average Monthly Evaporation Class (A) Pan of Dokan Station for the Period of (1984-2005)

2.3 Land Use and Vegetation

The north and northwest mountainous area are poorly to moderately vegetated and the lowlands close to the foot of the escarpment are relatively well covered with mixed type vegetation. Remotely sensed images are vital in land use/land cover classification specially when dealing with large and inaccessible study areas. The land cover study of the catchment area is made based on satellite images (2007) and field observations, Fig. (2.8) illustrates satellite image showing land use in the studied area.

In the present survey cultivated land covered with various types of cereals like Wheat , Barley, Chickpeas, Maize , Sunflower, Tobacco, Sweet melon, grassland, shrubby grassland, lake area, and bare rock, plate (2.1) and they are considered the major land cover units in terms of the area they cover and their relative significance in the computation of evapotranspiration. For computational convenience land cover types of similar rooting depth and growth stage are combined to one and when there is considerable difference in rooting depth and if the area covered for specific type of vegetation .

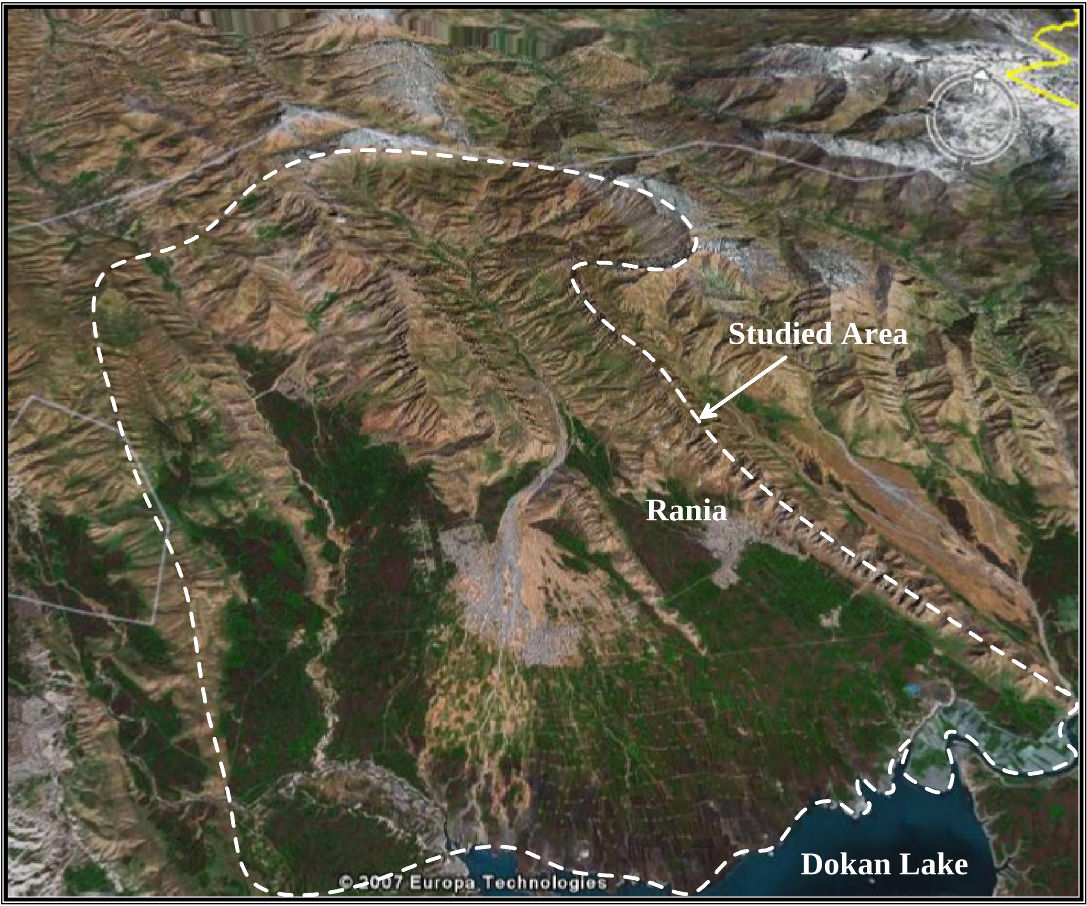


Fig. (2.8) Satellite Image Showing land use in the Studied Area (Adopted from Google Earth, 2007)

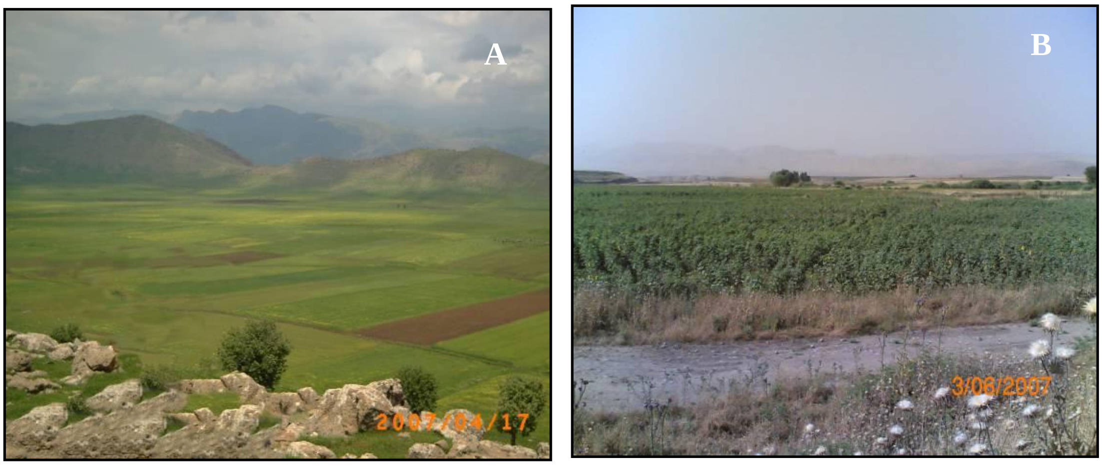


Plate (2.1) Part of the Studied Area

(A) During April Cultivated by Wheat, Barley, Grassland, Shrubby Grassland

(B) During June Cultivated by Sunflower

2.4 Evapotranspiration

Evaporation is the process whereby liquid water is converted to water vapour and removed from the evaporating surface to the atmosphere. Evapotranspiration is the combined term, which refers to the water flux from soil and vegetation surface by evaporation and form plant canopy by transpiration through openings called stomata **(**Fennessey and Vogel, 1996**)**. As evaporation proceeds, and if water is not limited, the surrounding air becomes gradually saturated and the process slows down and might stop if the wet air is not transferred to the atmosphere. The replacement of the saturated air with drier air depends greatly on wind speed (Allen et al., 2006). Major study has also been undertaken by American society of civil engineers and a consortium of European research institutes to evaluate the performance of different evapotranspiration estimation procedures under different climatoligical conditions. Both have indicated the FAO Penman- Monteith approach of reference crop evapotranspiration as relatively accurate and have consistent performance in both arid and humid climates.Reference evapotranspiration(ETo) is the rate of evapotranspiration from a hypothetical reference crop with an assumed crop height (12 cm), a fixed crop surface resistance (70 s m^{-1}) and albedo (0.23). Closely resembling the evapotranspiration from an extensive surface of green grass cover of uniform height, actively growing, completely shading the ground and with adequate water and is denoted as (ETo) (Allen et al., 2006). Thus, it is recommended as the sole standard method in the evapotranspiration estimation (Allen et al., 2006). The only factors affecting ETo are climatic parameters. Consequently, (ETo) is a climatic parameter and can be computed from weather data. Evapotranspiration of any crop could be estimated by multiplying the reference crop evapotranspiration with crop coefficient of the crop of interest. Estimated monthly average reference crop evapotranspiration using FAO Penman-Monteith approach has been used to estimate the crop potential evapotranspiration and actual evapotranspiration. The equation is expressed as (Allen et al., 2006):

$$ET_O = \frac{0.408\Delta(Rn - G) + \gamma \frac{900}{(T + 273)} U2(es - ea)}{\Delta + \gamma(1 + 0.34U2)} \quad \ldots\ldots\ldots\ldots (2.2)$$

ETo= reference evapotranspiration……………………...... [mm day $^{-1}$]
Rn= net radiation at the crop surface……………………... [MJ m^{-2}day^{-1}]
G= soil heat flux density………………………………….. [MJ m^{-2}day^{-1}]
T= mean daily air temperature at 2 m height………....... [^{o}C]
U2= wind speed at 2 m height……………………………. [ms^{-1}]
e s= saturation vapor pressure…………………………….. [kPa]
ea= actual vapor pressure…………………………………. [kPa]
es-ea= saturation vapor pressure deficit……………....... [kPa]
Δ = slope vapor pressure curve…………………………… [kPa ^{o}C^{-1}]
γ= psychrometric constant………………………………... [kPa ^{o}C^{-1}]

The calculated values of (ETo) are tabulated in table (2.1).

2.5 Crop Evapotranspiration Under Standard Conditions (ETc)

The crop evapotranspiration under standard conditions, denoted as ETc, is the evapotranspiration from disease-free, well-fertilized crops, grown in large fields, under optimum soil water conditions, and achieving full production under the given climatic conditions(Martin and Gilley,1993).

2.6 Crop Water Requirements

In addition, called (Crop evapotranspiration) is the amount of water used by vegetative growth of a given area by transpiration and that evaporated from adjacent soil or intercepted precipitation on the plant foliage in any specified time. (Martin and Gilley 1993, Kassam, and Smith, 2001, Allen et al.2006).

2.7 Effective Rainfall

Geohydrologists would define as effective that portion of rainfall, which contributes to groundwater storage. The extent of the rise in the water table or well levels would be the effective rainfall. This quantity comes under groundwater reservoir, river and deep percolation below root zone.

Agriculturists may consider as effective that portion of the total rainfall, which directly satisfies crop water needs and the surface run-off, which can be used for crop production on their farms by being pumped from ponds or wells. This fraction is equivalent to intercept by vegetation, reused at site, utilized for crop growth and stagnates on soil and evaporated (Dastane, 1978). The effective rainfall (Peff) can be calculated by CROPWAT model used by the U.S. Department of Agriculture and Soil Conservation Service (USDA) procedure as follow (Allen et al., 2006):

$$P_{eff} = T.\,R / 125 \times (125 - 0.2 \times T.\,R) \quad \ldots\ldots\ldots\ldots (2.3) \qquad (T.\,R < 250 \text{ mm})$$

$$P_{eff} = 125 + 0.1 \times T.R \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2.4) \qquad (T.\,R > 250 \text{ mm})$$

Where (T.R) is total rainfall.

The calculated values of (P_{eff}) are shown in tables (2.1).

Table (2.1) Mean Annual Values of Effective Rainfall and Reference Evapotranspiration for the Studied Area

	Oct	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Jun.	July	Aug.	Sep
P_{eff}	29.6	70	113.4	127.3	97.4	96.5	63.8	21.3	1.3	0	0	0
Eto	152.2	92.7	66.7	67.6	66.7	98	116	162	223	239	230	195.6

2.8 Climate Classification:

To determine the climate type and the aridity index of Rania area the classification suggested by (Al-Kubaisi, 2004) is used as follows table (2.2):

Mode 1: this option is to identify the possible climate zonation as (Humid, Moist) and (Arid, Sub-arid):

$$AI.1 = (1 \times P)/(11.525 \times t) \quad \ldots\ldots\ldots\ldots (2.5)$$

Mode 2: this option is to evaluate the sub-zones from the results of type.2 mode table (2.2):

$$AI.2 = 2\sqrt{P} / t \quad \ldots\ldots\ldots\ldots (2.6)$$

According to this classification the climate of Rania district classify as (humid-moist) for both mode (1 and 2).

Table (2.2) Type.l and Type.2 Mode Options Climate Classification (After Al-Kubaisi, 2004)

Type.1	Evaluation	Type.2	Evaluation
AI.1 > 1.0	Humid to Moist	AI.2 > = 4.0	Humid
		AI.2 < 4.0 AI.2 > = 2.5	Humid to Moist
		AI.2 < 2.5 AL2 > = 1.85	Moist Moist
		AI.2 < 1.85 AI.2 > = 1.5	Moist to Sub-arid
AI..1 < 1.0	Sub arid to Arid	AI.2 < 1. 5 AL2 > = 1.0	Sub-arid Sub-arid
		AI.2 < 1.0	Arid

2.9 Water Balance

A water balance is an accounting of all water volumes that enter and leave a 3-dimensioned space over a specified period. Changes in internal water storage must also be considered (Sokolov,et al., 1974). Both the spatial and temporal boundaries of a water balance must be clearly defined in order to compute and to discuss a water balance. A complete water balance is not limited to only irrigation water or rainwater or groundwater, etc., but includes all water that enters and leaves the spatial boundaries (Charles M. Burt, 1999, Mekonnen, 2005).

There are different methods for water balance calculation for any area; most of these methods depend upon the meteorological conditions and climatic elements of the studied area. Dokan meteorological station data were used to determine the climatological characteristics of the studied area and its effect on the water balance condition. Thus, these data were used to evaluate the water surplus and water deficit periods, which in term, indicates and affects the groundwater recharge.

The methodology adopted for water balance is as follows.

1. Selection of suitable maps for soil land cover, and land use identification.
2. Collection of primary data from the site on land use, groundwater, relevant hydrometeorological data (i.e. precipitation, evaporation, temperature, wind speed, relative humidity, and streams discharge).
3. Data organization, and data Pre-processing.

2.10 Methods Used to Compute Water Balance

2.10.1 Crop Water Balance

Precipitation provides part of the water crops need to satisfy their transpiration requirements. The soil, acting as a buffer, stores part of the precipitation water and return part of it to the crops (Gebreegziabher, 2004). In humid climates, this mechanism is sufficient to ensure satisfactory growth in rain fed agriculture. In arid and semi arid climates (such as study area) or during extended dry seasons, irrigation is necessary to compensate for the evaporation deficit due to insufficient or erratic precipitation (Allen et al., 2006). Net irrigation water requirements in irrigation are therefore defined as the volume of water needed to compensate for the deficit between potential evapotranspiration and effective precipitation over the growing period of the crop (Modi, 2000, Amin, 2003). It varies considerably with climatic conditions, seasons, crops and soil types. The detail procedure of crop water balance which applied by (***CROPWAT4 model***) is as follow:

1. CROPWAT4 Model

CROPWAT4 is a decision support system developed by the land and water development division of FAO for planning and management of irrigation. ***CROPWAT4*** is meant to be a practical tool to carry out standard calculations for reference evapotranspiration, crop water requirements and crop irrigation requirements, and more specifically the design and management of irrigation schemes (Behmanesh, 2003). It allows the development of recommendations for improved irrigation practices, the planning of irrigation schedules under varying water supply conditions, and the assessment of production under rain fed conditions or deficit irrigation (Clarke et al, 1998). Procedures for calculation of the crop water requirements and irrigation requirements are based on methodologies presented in FAO Irrigation and Drainage Papers No. 56 "Crop water requirements" by (Allen et al., 2006). The model uses the Penman-Montieth method for calculating the reference crop evapotranspiration. These estimates are used in crop water requirements and irrigation scheduling calculations.

1.1 Input Data

Calculations of the crop water requirements and irrigation requirements are carried out with inputs of climatic, crop and soil data. For the estimation crop water requirements (CWR), the model requires:

a) Reference Crop Evapotranspiration (ETo)

Values measured or calculated using the FAO Penman- Montieth equation based on decade/monthly-climatic data: minimum and maximum air temperature, relative humidity, sunshine duration and wind speed.

b) Rainfall Data (daily/decade/monthly data):

Monthly rainfall is divided into a number of rainstorms each month.

c) A Cropping Pattern

Consisting of the planting date, crop coefficient data files (including Kc values, stage days, root depth, depletion fraction) and the area planted (0-100 % of the total area); a set of typical crop coefficient data files are provided in the program. In addition, for irrigation scheduling the model requires information on:

1) Soil Type:

Total available soil moisture, maximum rooting depth and initial soil moisture depletion (% of total available moisture).

2) Scheduling Criteria:

Several options can be selected regarding the calculation of application timing and depth applications (e.g. 80 mm every 14 days, or irrigate to return the soil back to field capacity when all the easily available moisture has been used).

3. Calculation Methods

The model calculates the crop water requirements using the equation:

$$\boldsymbol{CWR} = \boldsymbol{ETo} \times \boldsymbol{Kc} \times \boldsymbol{area\ planted} \quad \ldots\ldots\ldots\ldots (2.7)$$

This means that the peak CWR in mm/day can be less than the peak ETo value when less than 100 % of the area is planted in the cropping pattern. The average values of crop coefficient for each time step are estimated by linear interpolation between the Kc values for each crop development stage Fig. (2.9). The Crop Kc values are calculated as (Kc x Crop Area), so if the crop covers only 50 % of the area, the .Crop Kc. values will be half of the Kc values in the crop coefficient data file(Allen et al., 2006).

For crop water requirements and scheduling purposes, the monthly total rainfall has to be distributed into equivalent daily values. ***CROPWAT4*** for windows does this in two steps, first the rainfall from month to month is smoothed into a continuous curve (the default curve is a polynomial curve, but one can select other smoothing methods available in the program e.g. linear interpolation between monthly values) (Martin and Gilley, 1993). Next the model assumes that the monthly rainfall in six separate rainstorms, one every 5 days (the number of the rainstorms can be changed). The model has available four Effective Rainfall calculation methods (the USDA SCS method is the default) (Allen et al., 2006). For the scheduling calculations can be selected from two options: Irrigation Scheduling and /or Daily Soil

Moisture Balance. The irrigation scheduling option shows the status of the soil moisture every time new water enters the soil, either by rainfall or a calculated irrigation application. Daily soil moisture balance option shows the status of the soil every day throughout the cropping pattern, how the soil moisture changes in the growing season. User defined irrigation events and other adjustments to the daily soil moisture balance can be made when the scheduling criteria are set to user-defined. *Total Available Moisture* (TAM) in the soil for the crop during the growing season is calculated as *Field Capacity* (which is the amount of water that a well-drained soil should hold against gravitational forces, or the amount of water remaining when downward drainage has markedly decreased) minus the *Wilting Point* (is the water content at which plants will permanently wilt) times the current rooting depth of the crop (Modi, 2000, Amin, 2003, Allen et al ., 2006). *Readily Available Moisture* (RAM) which is the fraction of *Total Available Moisture* (TAM) that a crop can extract from the root zone without suffering water stress is the (*Readily available soil water*) is calculated as (TAM x P) where P is the depletion fraction as defined in the crop coefficient (Kc) file. To avoid crop stress, the calculated soil moisture deficit should not fall bellow the readily available moisture.

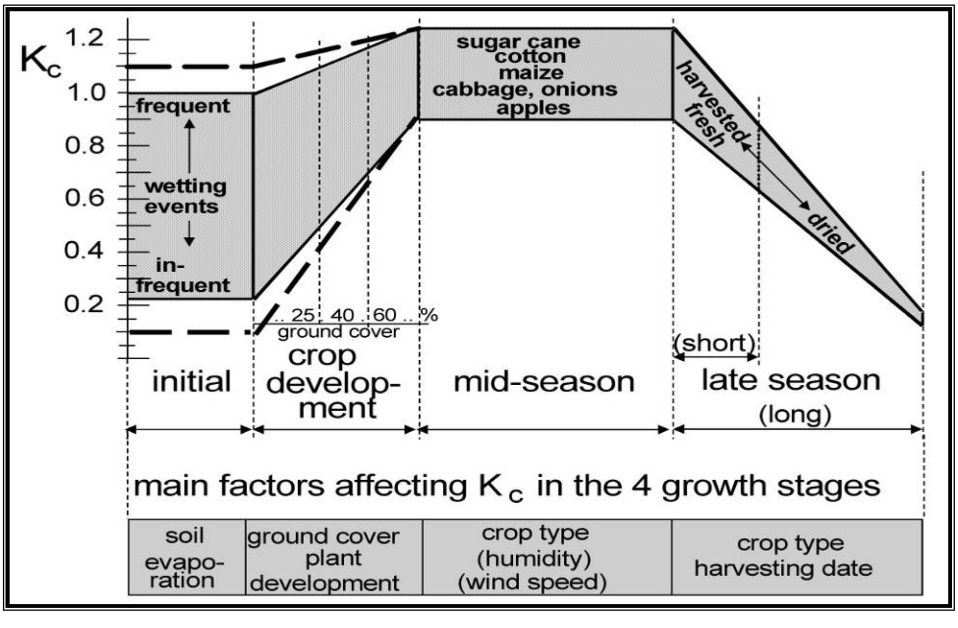


Fig. (2.9) Crop Growth Stages for Different Types of Crops (After Allen, et al., 2006)

4. Output

After entering all the data, ***CROPWAT4*** for windows automatically calculated the results as tables or plotted in graphs. The time step of the results can be any convenient time step: daily, weekly, decade or monthly. The output parameters for each crop in the cropping pattern are (Allen et al., 2006):

-Reference crop evapotranspiration . ETo (mm/period).

-Crop Kc - average values of crop coefficient for each time step.

-Effective rain (mm/period) - the amount of water that enters the soil.

-Crop water requirements . CWR or Etm (mm/period).

-Irrigation water requirements .IWR (mm/period).

-Total available moisture .TAM (mm).

-Readily available moisture. RAM (mm).

-Actual crop evapotranspiration . ETc (mm).

-Ratio of actual crop evapotranspiration to the maximum crop evapotranspiration -ETc/ETm (%);

-Daily soil moisture deficit (mm).

-Irrigation interval (days) & irrigation depth applied (mm).

-Lost irrigation (mm). Irrigation water that is not stored in the soil (i.e. either surface runoff or percolation);

-Estimated yields reduction due to crop stress (when ETc/ ETm falls below 100%).

The output of the program is tabulated in the table (2.3).

5. Irrigation Water Requirements Calculation

Crop water requirements (CWR) are calculated on the basis of monthly effective rainfall (P_{eff}) and reference evapotranspiration (ETo), the first being calculated from average rainfall following the USDA Soil Conservation Service method and the latter being calculated following the Penman-Monteith approach .For a given crop, i, and a given cropping period (Allen et al ., 2006):

$$CWR = \sum_{t=0}^{T} (Kci.ETo - Peff) \text{ .... (2.8)}$$

Where Kci is the crop coefficient of the given crop, i, during the growth stage, t, and T is the last growth stage. Each crop has its own water requirement. Net irrigation water requirement (NIWR) in a specific scheme for a given year is thus the sum of individual crop in a specific scheme for a given year are thus the sum of individual crop (CWRi) calculated for each irrigated crop, i (Allen et al ., 2006):

$$NIWR = \sum_{i=1}^{N} CWR_i .Si \text{ .... (2.9)}$$

Where Si is the area cultivated with the crop, i when dividing by the area of the scheme (S, in ha), a value of irrigation water requirements is obtained, expressed in m^3/ha or in mm (1 mm = 10 m^3/ha).

$$NIWR = \frac{\sum_{i=1}^{n} CWRi.Si}{S} \text{ .... (2.10)}$$

For computation of these units, the ***CROPWAT4*** software has been used.

6. Obtained Results for the Studied Area

The volume of water required for each crop in a cultivated area has been determined based on using prepared data (crops type) and ***CROPWAT4*** software. The results are shown in tables (2.3 and 2.5). Mentioned parameters were calculated using collected data from Ministry of Agriculture in Kurdistan region. It is to notice that, according the collected data the percentage of cultivated crop groups include Wheat 44 %, Barley 31 % Sunflower 13.5 %, Chickpeas 7 %, Maize 0.6 %, Tobacco 0.3 %, and Sweet Melon 0.12 %. The crop water and other parameters have been calculated based on these percentages and summarized in table (2.3) and Fig. (2.10).

7. Errors of Model

The ***CROPWAT4*** model is very sensitive to climatic and crop growth stages data. Hence, the input data of this model should have high accuracy. To run ***CROPWAT4*** model one needs to calibrate and validate the obtained results with local lysimeter measurements. Due to lack of these data, it was not possible to do calibration and validation of the results for the study area. Despite these issues, since this model is the best method among 20 main methods in the world (Behmanesh, 2003).

Table (2.3) Out put of *CROPWAT* 4 Model for Different Cultivated Crops in the Studied Area

Out put / Crop type	Barley	Wheat	Sunflower 1	Sunflower 1	Tobacco	Chickpeas	Sweet melon	Maize
ETo(mm/period)	754	897	724	906.1	783	551	849	842
CWR (ETm)(mm/period)	540	605	535	641.9	605	405	608	568
Actual crop Evapotranspiration(ETc) (mm/period)	707	711	629	755.2	697	477	715	669
Total Rainfall(mm/period)	621	621	145	10.6	3.7	57	57	50.4
Effective Rainfall (mm/period)	496	496	126	9.95	3.6	52	52	47
Field water supply(FWS) (l/s/ha)	0.24	0.24	0.57	0.8	0.9	0.65	0.71	0.64
Net irrigation requirement NIWRi (mm/period)	241	241	516	700	650	401	658	564
Net irrigation requirement NIWRi (m^3/ha)	2410	2410	5160	7000	6500	4010	6580	5640

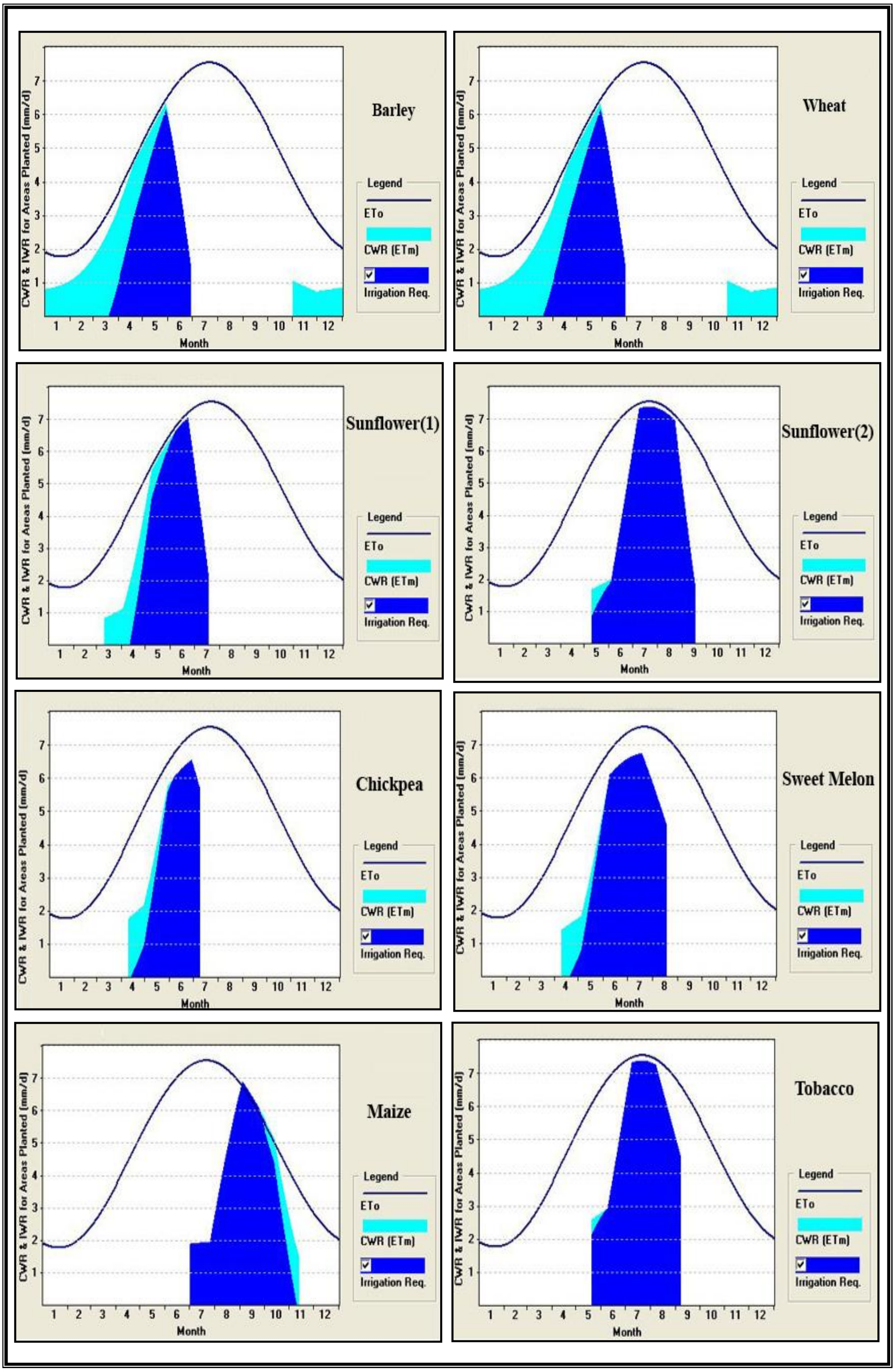


Fig. (2.10) Reference Evapotranspiration, Crop Water Requirements and Irrigation Requirement for Different Crops in the Studied Area

8. Water Resources for Irrigation

A. Surface Water

Qashan- and Dimana (Shaoor) streams are the surface water resources for irrigation in the studied area, they flow in the northwest direction into the Dokan Lake. The discharges of these two streams are gauged each one at one-gauge station, which are located at the beginning and inside of the irrigated area. The two streams were measured monthly for one year. The mean discharges of the (Qashan) and (Dimana(Shaoor)) streams are (2.0) and (0.78) m^3/s respectively. The monthly discharge recorded in the stations for the two streams are shown in table (2.4).

Table (2.4) Monthly Discharge of the two Main Streams in Rania Area in (m^3/sec) for Water Year (2005-2006)

Month Factor	Oct.	Nov.	Dec.	Jan.	Feb.	Mar	Apr.	May	Jun.	Jul.	Aug.	Sep.	Mean
Qashan	1.2	1.35	2.2	2.5	3	4.5	3.5	1.8	1.15	1	0.95	0.9	2
Dimana	0.608	0.635	0.7	0.745	1	1.1	1.15	0.95	0.639	0.63	0.625	0.615	0.783

B. Groundwater

In the studied area groundwater is used for irrigation including the major springs and wells .The springs which are used for irrigation are (Saruchawa,Qulai Kanimaran, and Qulai Rania) with mean discharges of (6.5,0.4, and 0.5 m^3/sec) respectively. The portions of their discharges used for irrigation are (80, 100, and 50 %) respectively .The number of wells which exploited for irrigation are nearly (50) wells. They are operate about (5) hours per day with an estimated discharge of about (6 l/sec/well).

Table (2.5) Net Irrigation Water Requirements, Surface Water Availability, and Groundwater Availability of Rania Area

Crop	Cultivated Area (ha)	%	NIWR m.c.m	Surface water availability(m.c.m)	Groundwater availability(m.c.m)
Wheat	9040	44	21.8	63.1	186.5
Barley	6393	31	15.4		
Sunflower	2787	13.5	16.9		
Chickpeas	1430	7	5.7		
Maize	114	0.6	0.64		
Tobacco	57	0.3	0.37		
Sweet Melon	25	0.12	0.164		
	19848		60.97	249.4	

2.10.2 Hydrometeorological Approach

Hydrometeorological approach for Water balance is widely used when the output of a small basin, within which urbanization occupies a part is known. Often, such output is not available and accordingly the empirical approaches are considered. Thus, the input parameters for such water balance are used to clarify a possible period of water surplus and deficit. These parameters are mainly of two groups, the first group represents the elements of water availability, while, the second group includes elements of water losses (Hassan, 1998, Chnaray, 2003).

1 .The Mehta's Simple Water Balance Model

This model is a modification of (Thornthwaite-Mather model, 1955) which is done by (Mehta et al., 2006), Fig. (2.11) summarizes a simple conceptual water balance model. Water is stored in the soil reservoir until the soil water content (SW) exceeds the available water capacity (AWC), at which point the excess goes into storage (S). The monthly stream flow is a simple linear function of (S). Determining the soil water budget requires keeping track of the accumulated potential water loss (APWL) and the amount of water in the soil (SW).

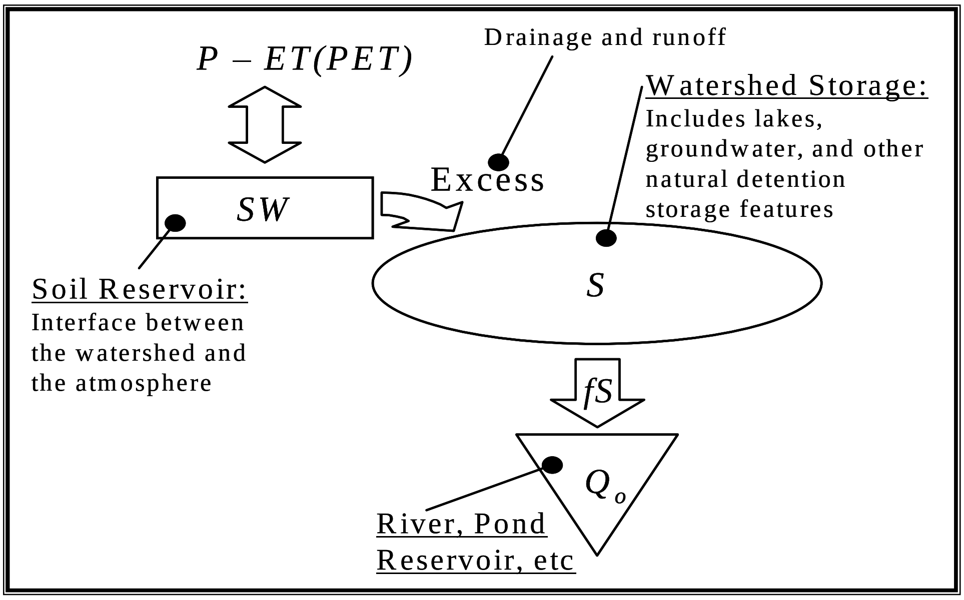


Fig. (2.11) Mehta's Conceptual Model (After Mehta et al., 2006)

All excess water, i.e., water above the AWC, goes into watershed storage (S), which in-turn, feeds river discharge (Qo) from the watershed.

$$S_t = S_{t-1} + Excess$$ ……….. (2.11) (Mehta et al., 2006)

Hydrologists commonly assume that discharge is a constant fraction of watershed storage, especially for groundwater discharge into rivers; this assumption is called the linear reservoir assumption.

$$Q_o = fS_t$$ ……….. (2.12) (Mehta et al., 2006)

Where f is the reservoir coefficient and 0 < f < 1. If data are available, f can be empirically determined.

2. Equations

Calculations to determine SW and APWL are performed for each time step using monthly precipitation (P) and potential evapotranspiration (PET). Excess water, i.e., net precipitation (ΔP) in excess of the soil's water holding capacity (AWC) leaves the soil and is stored in the watershed and eventually released to the river. Table (2.6) below summarizes the calculations.

Table (2.6) Equations of the Model (Mehta et al., 2006)

Situation in the Watershed	***SW***	***APWL***	**Excess**
• Soil is drying $\Delta P < 0$	$= AWC \exp\left(\frac{APWL_t}{AWC}\right)$	$= APWL_{t-1} + \Delta P$	$= 0$
• Soil is wetting $\Delta P > 0$ but $SW_{t-1} + \Delta P \leq AWC$	$= SW_{t-1} + \Delta P$	$= AWC \ln\left(\frac{SW_t}{AWC}\right)$	$= 0$
• Soil is wetting above capacity $\Delta P > 0$ but $SW_{t-1} + \Delta P > AWC$	$= AWC$	$= 0$	$= SW_{t-1} + \Delta P - AWC$

When P>PET, AET =PET

When P<PET, AET = dSW + P

3. Model Input

The required model input data are:

Rainfall (P): Accurate and local rainfall data, potential evapotranspiration (PET), available water capacity (AWC), rooting depth, reservoir coefficient 'f'.

4. Running the Soil Water Balance Model

The water balance is estimated based on long-term average climatic Variables for the period of (1984-2005) .Excel spreadsheet software which prepared by (Mehta et al., 2006) used to run the model and the results are summarized in the table (2.7), and the graphical presentation is denoted in Fig. (2.12). Instead of using the Thornthwaite method to calculate potential evapotranspiration, which is based on air temperature only, more realistic results can be obtained by applying a reference potential evapotranspiration calculated by the Penman- Monteith methods which take into account a more complete range of meteorological observations applied to a reference (grass). In addition, it will reduce the uncertainties that could occur by only considering temperature. Crop coefficient is also another variable introduced into the model. This model can give basic information for regional and sub-regional base line type study.

The available water content is (75 mm) estimated based on tables developed by (Tornthwaite and Mather, 1955) regarding the soil texture, crop type and percentage of each type of soil. The factor estimated to be (0.09).

Table (2.7) Monthly Soil Water Balance for Rania Area (Mehta et al., 2006 method)

Months Parameter	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Total
P	31.1	80.3	148.9	148.1	120.7	119.2	72.1	22.1	1.3	0	0	0	*743.8*
Eo	152.2	92.7	66.7	67.6	66.7	98	116	162	223	239	230	195.6	*1709.5*
Kc	0.72	0.72	0.72	0.72	0.72	0.72	0.72	0.72	0.72	0.72	0.72	0.72	
PET_{crop}	109.6	66.7	48	48.7	48	70.6	83.5	116.7	160.6	172.1	156.6	140.8	*1230.8*
APWL	0	0	0	0	0	0	-11.4	-106	-265.3	-437.4	-593.6	-734.8	
P-PET	-78.5	13.6	100.9	99.4	72.7	48.6	-11.4	-94.6	-159.3	-172.1	-156.6	-140.8	
SW	0	13.6	75	75	75	75	64.4	18.2	2.2	0.2	0	0	
dSW	0	13.6	61.4	0	0	0	-10.6	-46.2	-16.1	-2	-0.2	0	
AET	31.1	66.7	48	48.7	48	70.6	82.7	68.3	17.4	2	0.2	0	483.6
Deficit	78.5	0	0	0	0	0	0.8	48.4	143.2	170.1	156.4	140.8	738.3
Surplus	0	0	39.5	99.4	72.7	48.6	0	0	0	0	0	0	260.2
Storage	0	0	39.5	135.3	195.9	226.8	206.4	187.8	170.9	155.6	141.6	128.8	
Runoff	0	0	3.6	12.2	17.6	20.4	18.6	16.9	15.4	14	12.7	11.6	143
Detention	0	0	12.9	100	153.7	180	160.2	142.6	126.9	112.9	1.5	89.5	
Recharge	117.2												
Units	All Units in(mm)												

According to this model the total runoff is (143 mm) which is (19.2 %) of the total precipitation and the groundwater recharge is (117.2 mm) which is (15.75 %) of the total precipitation.

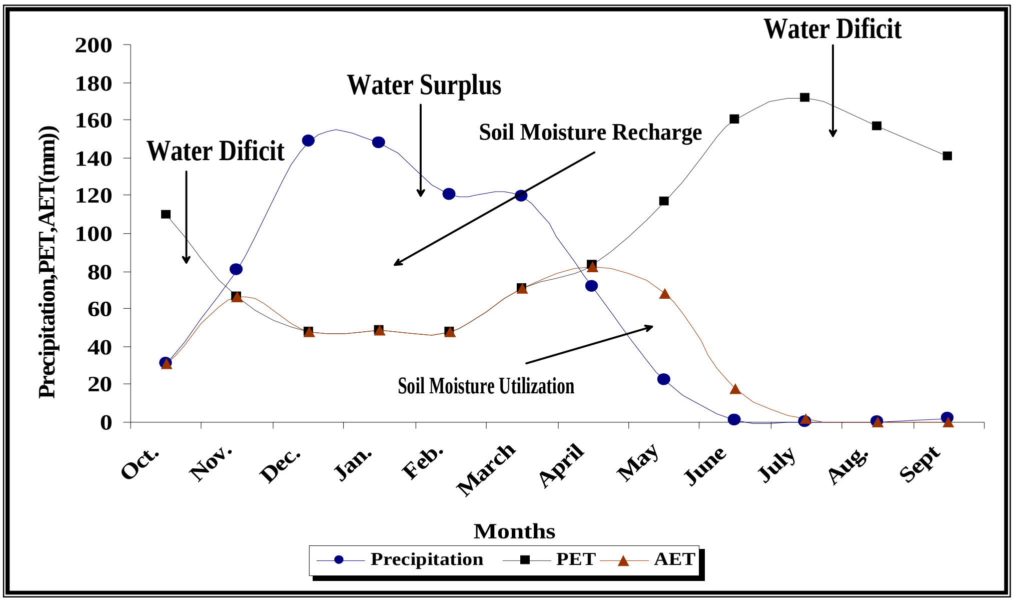


Fig. (2.12) Monthly Soil Water Balance (Mehta et al., 2006 Method)

Due to lack of information and absence of continuous daily discharge data, soil conservation service (SCS) method is used for estimating the runoff value.

2.11 Soil Conservation Service Method (SCS)

A combination of a hydrologic soil group (soil) and a land use and treatment class (cover) is a hydrologic soil-cover complex .This method was designed in order to compute surface runoff (Rs) values or create (Rs) values from available rainfall data (Hawkins, 2004). The empirical rainfall-runoff relation is:

$$Q = \frac{(P - 0.2S)^2}{(P + 0.2S)} \quad \ldots\ldots\ldots\ldots (2.13)$$

Where:

Q = runoff in (mm) of depth.

P = total precipitation (mm) (average monthly records used).

S = retention including the initial abstraction which is assumed to be (0.2 S)

$$CN = \frac{1000}{10 + \frac{S}{25.4}} \ldots\ldots\ldots\ldots (2.14) \text{ (S) in millimeter}$$

$$= \frac{1000}{10 + S} \ldots\ldots\ldots\ldots\ldots\ldots (2.15) \text{ (S) in inches}$$

CN = Curve number

Fig. (2.13) is a convenient way to estimate runoff from rainfall directly without having to calculate (S). The factor (S) is generally needed for other applications, such as the analysis of runoff data or the development of supplementary runoff relationships, the SCS method can be used when detailed data on soils and vegetation covers are available(Hawkins , 2004). The method was developed from various records of rainfall and runoff and numerous combinations of soils and covers.

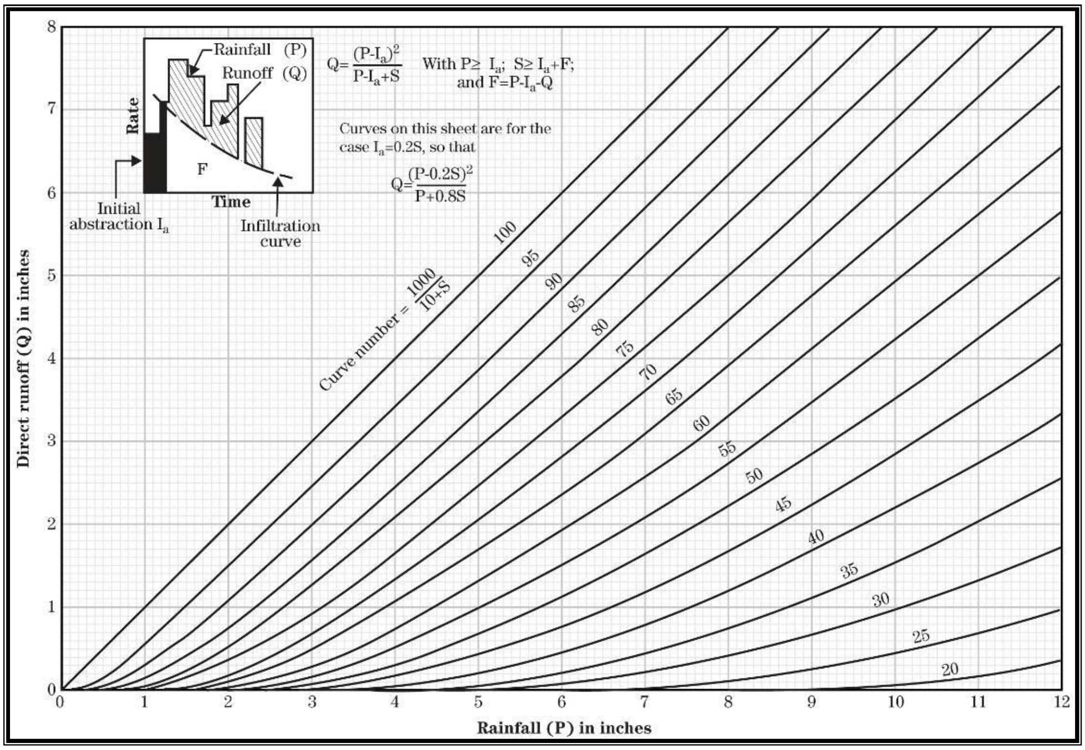


Fig. (2.13) Graphical Solution of the Equation $Q = \frac{(P - 0.2S)^2}{(P + 0.2S)}$ **(After Hawkins, 2004)**

Based on the land morphological features, the associated soil textures, the soils and land use/land cover, and the lithology of expected rock units, a map of hydrological cover conditions was prepared Fig. (2.14). From this map, the hydrological soil groups and the hydrological cover conditions (poor, fair and good) were determined to which CN were assigned using reference tables provided by the USDA-SCS method (Hawkins , 2004**)**. Since the Rania area has more than one CN value, a weighted CN value was calculated using equation (2.16) (Sharma et al., 1992).The weighted value (CN=59.5) was the one considered in the estimation of runoff using monthly rainfall data as shown in table (2.8). The mean monthly precipitation values (records) of Dokan meteorological station used for estimating (Rs) values from the standard graphs figure (2.13) as shown in table (2.9).

$$CN_{weighted} = \frac{A_1CN_1 + A_2CN_2 + \dots\dots + A_nCN_n}{A_1 + A_2 + \dots\dots + A_n} \qquad \dots\dots\dots\dots (2.16)$$

Where A_1, A_2, ..., A_n are the respective areas of hydrological groups and CN_1, CN_2 ..., CN_n are the corresponding curve members.

Table (2.8) Hydrologic Group and Weighted Curve Number for Rania Area

Area specification	**Area Km^2**	**CN**	**CN x Area**
Jurassic Rocks	212	70	14840
Bekhme or Kometan,Qamchuqa	321	55	17655
Soil(partially cultivated)	103.3	43	4442
Silty clay soil	135.9	48	6523
Sand +conglomerate	10.9	32	349
Urban area	25	78	1950
Sarmord	120	72	8640
Shiranish+Tanjero	53	75	3975
Total	**981**		**58374**
Weighted CN			**59.5**

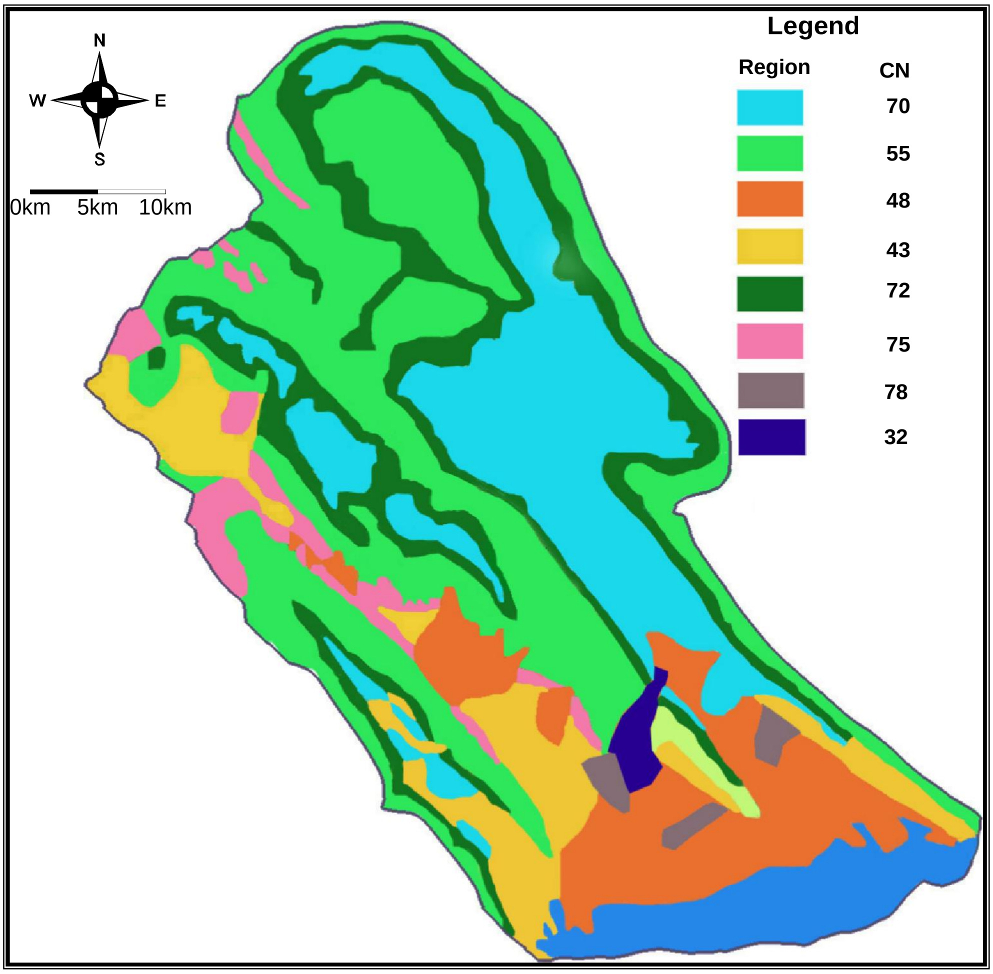


Fig. (2.14) Hydrological Cover Conditions in the Rania Area

Table (2.9) Runoff Values Calculated by SCS Method

Month **Factor**	**Oct.**	**Nov.**	**Dec.**	**Jan.**	**Feb.**	**Mar.**	**Apr.**	**May**	**Jun.**	**Jul.**	**Aug.**	**Sep.**	**Total**
P(mm)	31.1	80.3	148.9	148.1	120.7	119.2	72.1	22.1	1.3	0	0	1.4	743.8
Rs(mm)	0	9.8	46.1	45.6	29.1	28.3	6.9	0.9	0	0	0	0	166.6
$CN_{weighted}$	59.5												

2.12 Groundwater Recharge

Determining which of a wide variety of techniques is likely to provide reliable recharge estimates is often difficult. Various factors need to be considered when choosing a method of quantifying recharge. A thorough understanding of the attributes of the different techniques is critical. The space/time scales of recharge estimates are important because different study goals require recharge estimates over different space and/or time scales. Whereas some studies focus on recharge estimates for water resources assessment. (Scanlon et al. , 2002 ,Xu, and Beekman, 2003). Two techniques were selected for recharge estimation the first, is from *soil water balance model,* and the second is the *spring hydrographs analysis* method. The two methods applied for estimation of *diffuse recharge* (recharge refers to recharge derived from precipitation or irrigation that occurs uniformly over large areas).The first method described in the previous section and the detailed of second method is discussed in the following sections.

2.12.1 Spring Hydrographs Analysis

The recession curve analysis was performed according to the findings of base flow by Mijatovi (1970) in (Komac, 2001). Some basic karst spring characteristics may be presumed by accepting that the recession curve follows the equation:

$$y = e^{-\alpha(t-t_o)} \text{ .... } (2.17)$$

Where the coefficient **(α)** denotes the type of drainage according to certain characteristics of the karst aquifer, **(e)** is a natural logarithm, and to (**t**) is the time at the beginning (end) of the recession (time is usually measured in days. E.Maillet (1905) derived the general equation of the retardation curve expressing the discharge rate of a river under the exclusive influence of an aquifer.

$$\boldsymbol{Q_t = Q_o e^{-\alpha t}} \text{ .... } (2.18)$$

Where $\mathbf{Q_o}$ and $\mathbf{Q_t}$ are the discharge at the beginning of the measurement period and at time **t**, respectively, and **(α)** is the coefficient of recession or discharge coefficient. The coefficient, (**α)** will be a function of the aquifer transmissivity (T), storage coefficient(S) or (specific yield (Sy)), and the catchment geometry (Korkmaz, 1990), each exponential segment is interpreted to represent the depletion of an aquifer reservoir, with the rate of depletion of that reservoir being represented by the recession coefficient (αi). Accordingly, the segment with the greatest recession coefficient would represent the most rapid drainage of the karst network (presumably surface runoff or displacement of water into the largest conduits) and the recession segment with the smallest coefficient would represent the baseflow (i.e., the slow drainage of that portion of the aquifer with the lowest transmissivity). The latter is often termed the *diffuse flow* portion of the aquifer, while the most transmissive conduits are referred to as the *quick flow* portion of the aquifer. Intermediate segments of the total hydrograph recession are thought to represent the emptying of aquifer volumes having intermediate values of hydraulic conductivity (Doctor and Alexander 2006). Equation (2.18) describes the discharge characteristic of a linear reservoir, i.e. one in which the discharge, Q, is proportional to the storage, V, with Q = α V, rearranging and allowing for units gives:

$$V = \frac{86400Q}{\alpha} \quad \ldots\ldots\ldots\ldots \text{(2.19)}$$

Where V = storage capacity or dynamic reserve (m^3) Fig. (2.16).
Q = groundwater discharge ($m^3\ s^{-1}$); and
α = coefficient of recession (discharge coefficient) (day^{-1}).
In logarithmic form to the base 10, the exponential formula (2.18) is transformed into:

$$\boldsymbol{LogQ_t = LogQ_o - 0.4343\alpha t} \quad \ldots\ldots\ldots\ldots \text{(2.20)}$$

The discharge coefficient (α) may be obtained directly from equation (2.20), via the following equation:

$$\alpha = \frac{LogQ_o - LogQ_t}{0.4343\ t} \quad \ldots\ldots\ldots\ldots \text{(2.21)}$$

The recession curve, when placed on a Cartesian coordinate system with discharge (m^3/s) on the ordinate and time (day) on the absciss, has the form of hyperbola. However, when placed on a normal logarithmic scale, the diagram is no longer a curve but consists of linked straight lines,as shown in Fig. (2.15) the theory assumes that changes in the (α) reflect the changes of aquifer characteristics.

Equation (2.19) applies at each instant, so that Q in equation (2.19) is the same as Qt in equation (2.18). Thus:

$$\boldsymbol{V = 86400(Q_o / \alpha)e^{-\alpha t}} \text{ .... (2.22)}$$

For a given time period, $\Delta t = (t_o - t_m)$, quantitative data about the dynamic reserve Fig. (2.16) at the end of the period (t_m) may be calculated from the following equation:

$$\boldsymbol{V_m = V_o + R - Q} \text{ .... (2.23)}$$

Where Vm = dynamic reserve at the end of the period (t_m) (m^3);

Vo = dynamic reserve at the beginning of the period (t_o) (m^3);

R = groundwater recharge volume during the time period at (m^3);

and Q = groundwater discharge volume during the time period at (m^3).

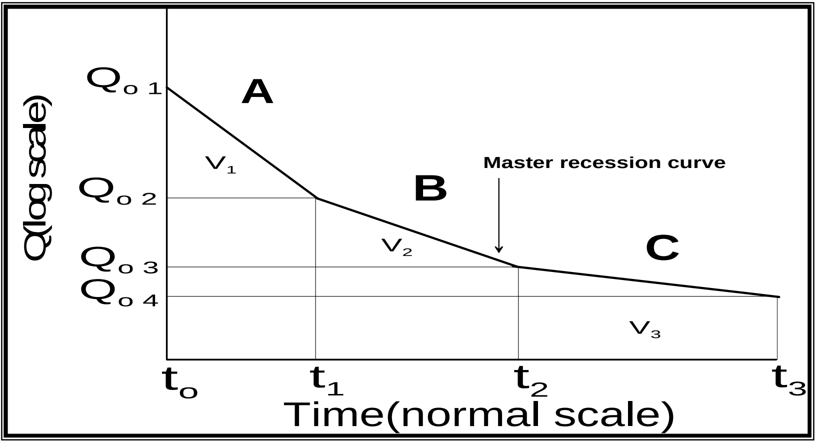


Fig.(2.15) the Recession Curve on Normal Logarithmic Scale (After Mijatovic, 1970)

The volume of groundwater discharge during a water year period may be estimated from the spring hydrograph. The difference between the dynamic reserve (Vm) at the end of a water year (tm), and the dynamic reserve at the beginning of a water year (to) is the dynamic reserve change (ΔV). The volume of groundwater recharge during a water year will be:

$$R = Q \pm \Delta V \quad \ldots\ldots\ldots\ldots (2.24)$$

Where R = groundwater recharge volume during the water year (m^3);

Q = groundwater discharge volume during the water year (m^3); and

ΔV = dynamic reserve change during the water year (m^3).

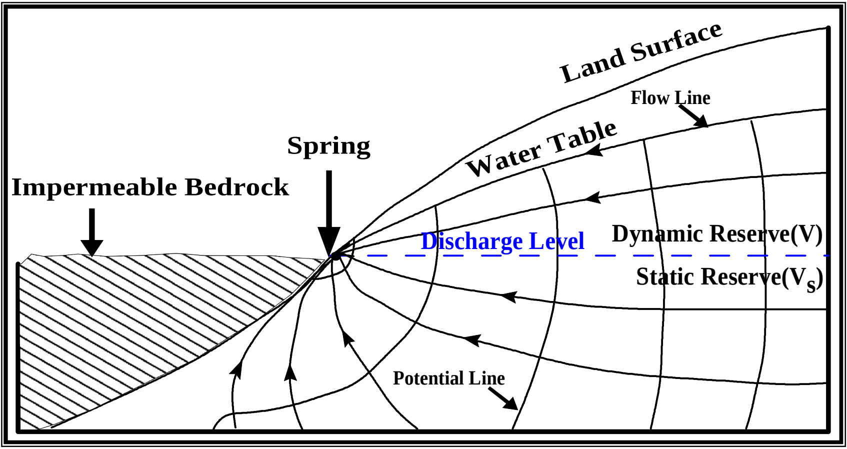


Fig. (2.16) Schematic Depiction of an Aquifer (After Korkmaz, 1990)

For estimation of recharge by the mentioned method daily discharge for four springs which are (Saruchawa, Qulai Kanimaran, Ganau, and Qulai Rania) used for the hydrologic year(2002), the recession hydrographs analysis denoted in the Fig.(2.17) and the results are summarized and tabulated in the tables (2.10 and 2.11).

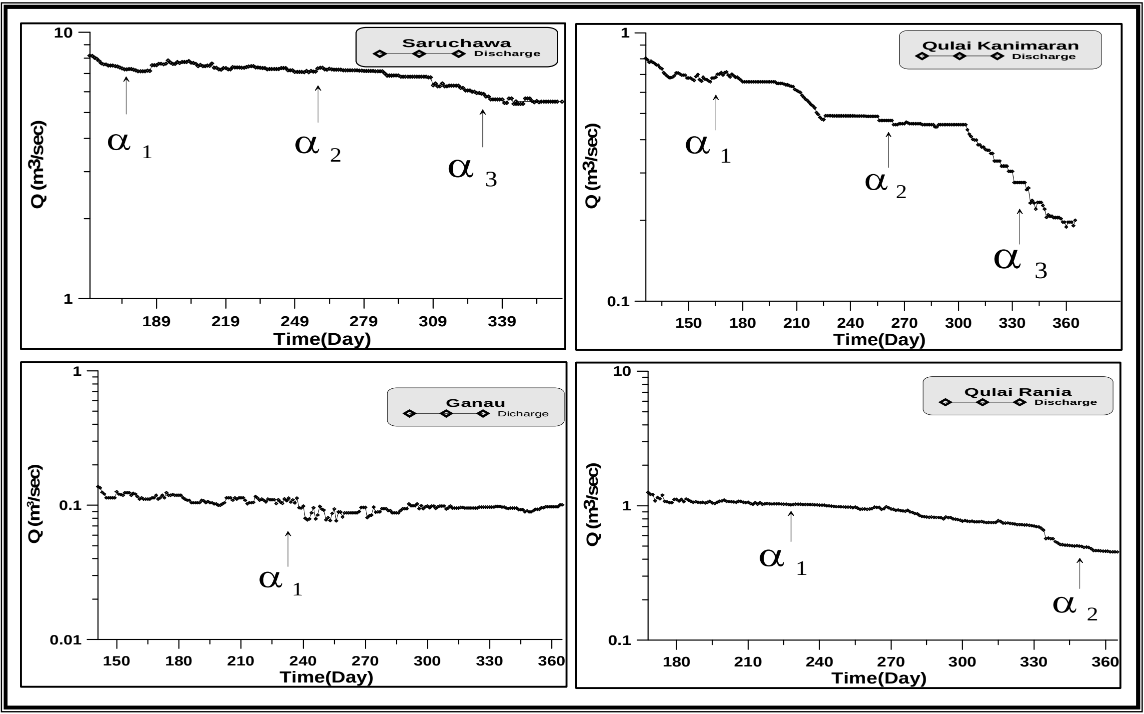


Fig. (2.17) Recession Hydrograph Analysis for the Main Springs in Rania District

Table (2.10) Spring Hydrograph Recession Analysis (2002)

Spring	Discharge coefficient α (Day^{-1})		Interval(day)	$Q_o(m^3/sec)$	$Q_t(m^3/sec)$
Saruchawa	α_1	0.005093	26	8.173	7.16
	α_2	0.001392	128	7.54	6.31
	α_3	0.002864	48	6.31	5.5
	average	**0.003116**			
Qulai Kanimaran	α_1	0.004922	100	0.803	0.491
	α_2	0.00099	77	0.491	0.455
	α_3	0.012334	60	0.419	0.2
	average	**0.006082**			
Ganau	α_1	**0.001387**	224	0.137	0.1006
Qulai Rania	α_1	0.003895	166	1.2555	0.658
	α_2	0.007663	30	0.57	0.453
	average	**0.005779**			

Table (2.11) Recharge Estimation based on Spring Hydrograph Analysis

Spring	October Discharge $Q_o(m^3/sec)$	September Discharge (m^3/sec)	Dynamic Reserve		Δv $10^6\,m^3$	Discharge $10^6\,m^3$	Recharge $10^6\,m^3$
			Vo $10^6\,m^3$	Vm $10^6\,m^3$			
Saruchawa	5.58	5.6	154.6992	155.2536	0.5545	205.436	**205.9905**
Qulai Kanimaran	0.221	0.2215	3.93496	4.005987	0.07103	16.15246	**16.22349**
Ganau	0.095	0.0998	6.0995	6.0995	0	3.19302	**3.19302**
Qulai Rania	0.497	0.4985	8.5219	9.8375	1.3156	24.65563	**25.97129**

CHAPTER THREE

HYDROGEOLOGICAL CONDITIONS

Hydrogeological Conditions

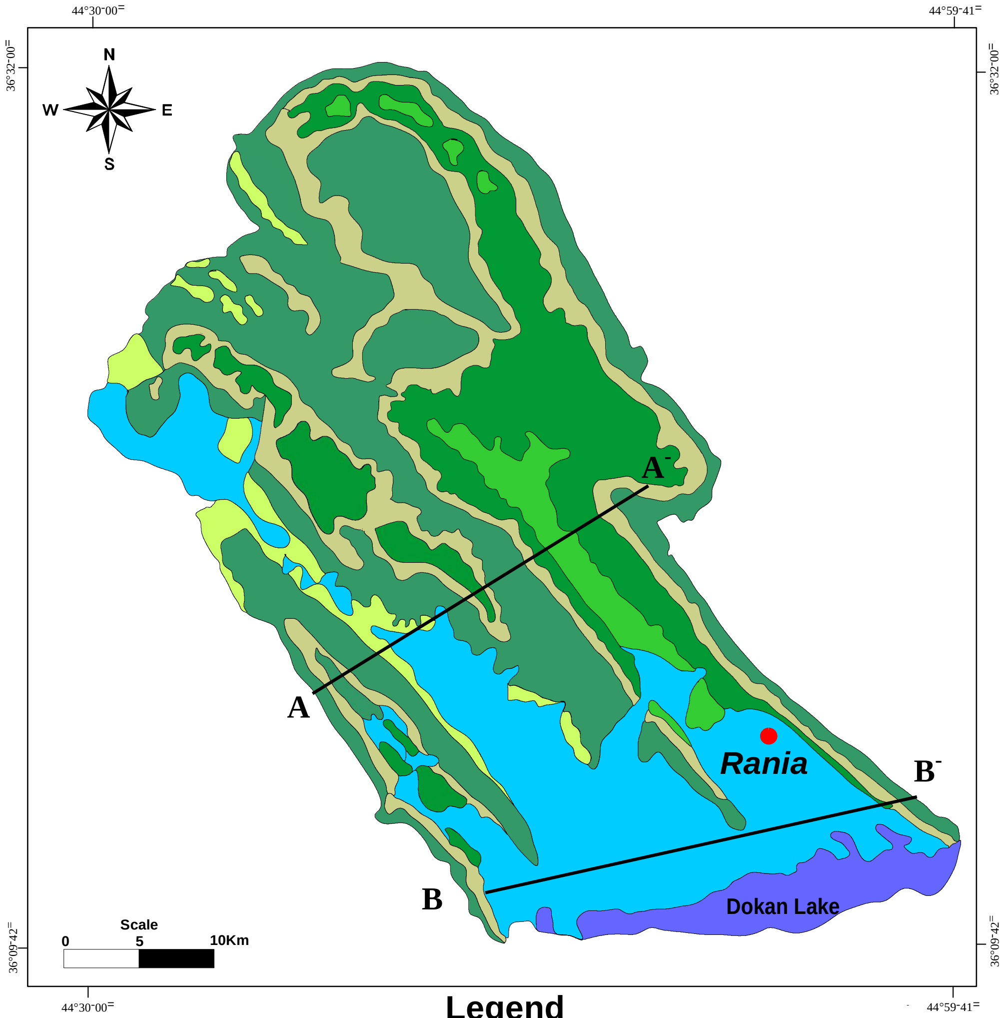
3.1 Hydrogeology of the Studied Area

A hydrostratigraphic unit is defined as a formation, part of a formation, or a group of formations in which there are similar hydrologic characteristics that allow for a grouping into aquifers and associated confining layers (Flora, 2004).

The geologic formations in the studied area are grouped into general hydrostratigraphic units, which in some cases are identified as local or regional aquifers in the area. There are four aquifer systems in the studied area belonging to different ages that are Jurrasic, early-late Cretaceous, late Cretaceous limestone and Quaternary systems Figs.(3.1 and 3.2). Groundwater flow occurs from the Rania plain, Makook ,Handreen and Pelewan anticlines from northwest toward the Dokan lake. The main aquifer in the Rania area is the Quaternary deposits, which are tapped by numerous supply wells to the surrounding communities. Ground water is locally used for domestic and irrigation purposes in the area whereas surface water is mainly used for irrigation. Below is a brief description of geological formations that make the aquifers systems in the studied area.

3.2 Jurassic Units

The Jurassic formations in the area are numerous: Sehkanyan ,Sarki, Chia Gara, Naokelekan, Barasrin and Sargelu. The first two: Sehkanyan and Sarki which consist of karstic fissured limestone and dolomite beds with shale layers are low productive aquifers. Chia Gara, Naokelekan, Barasrin and Sargelu rocks are complex karstic-fissured aquifer as well with low to medium productivity in carbonate rocks; yielding only small amounts of water to springs and seeps, while aquiclude in shale and Chert (Stevanovic and Markovic, 2004b). The thickness of Jurassic unit is about (300 m).



Legend

🟦 **Quaternary Aquifer**
Rock fragments,locally gravely,coverd by thin mantle of soil Deposits intergranular aquifer,Unconfined

🟨 **Aquitard**
well beded limestone and blue marl of Shiranish Fn.with Sandstone ,Siltstone and dark greysh marlof Tanjero Fn.,act as aquitard or aquiclude

🟩 **Bekhme Aquifer**
mainly massive limestone and dolomite of Qamchuqa Fn.,mainly well bedded to massive limestone of Bekhme Fn.locally with Kometan Fn.karstic fissuured aquifer,Semi-confined

🟫 **Aquiclude**
marly limestone and Dolomite with interbeds of marls of Balambo Fn.locally act as aquifer,marl and marly limestone of Sarmord Fn.act as aquiclude

🟩 **Upper Jurassic Aquifer**
mainly bedded to massive dolomite, limestone and marl,organic matter-rich limestom,coal,low to medium productive complex karstic aquifer,Confined

🟩 **Lower Jurassic Aquifer**
mainly limestone , and cherty shale of Sarki Fn. , dark dolomite of Sehkanyan Fn.low productive karstic fissured aquifer,Confined

Fig.(3.1) Hydrogeological Map of the Studied Area

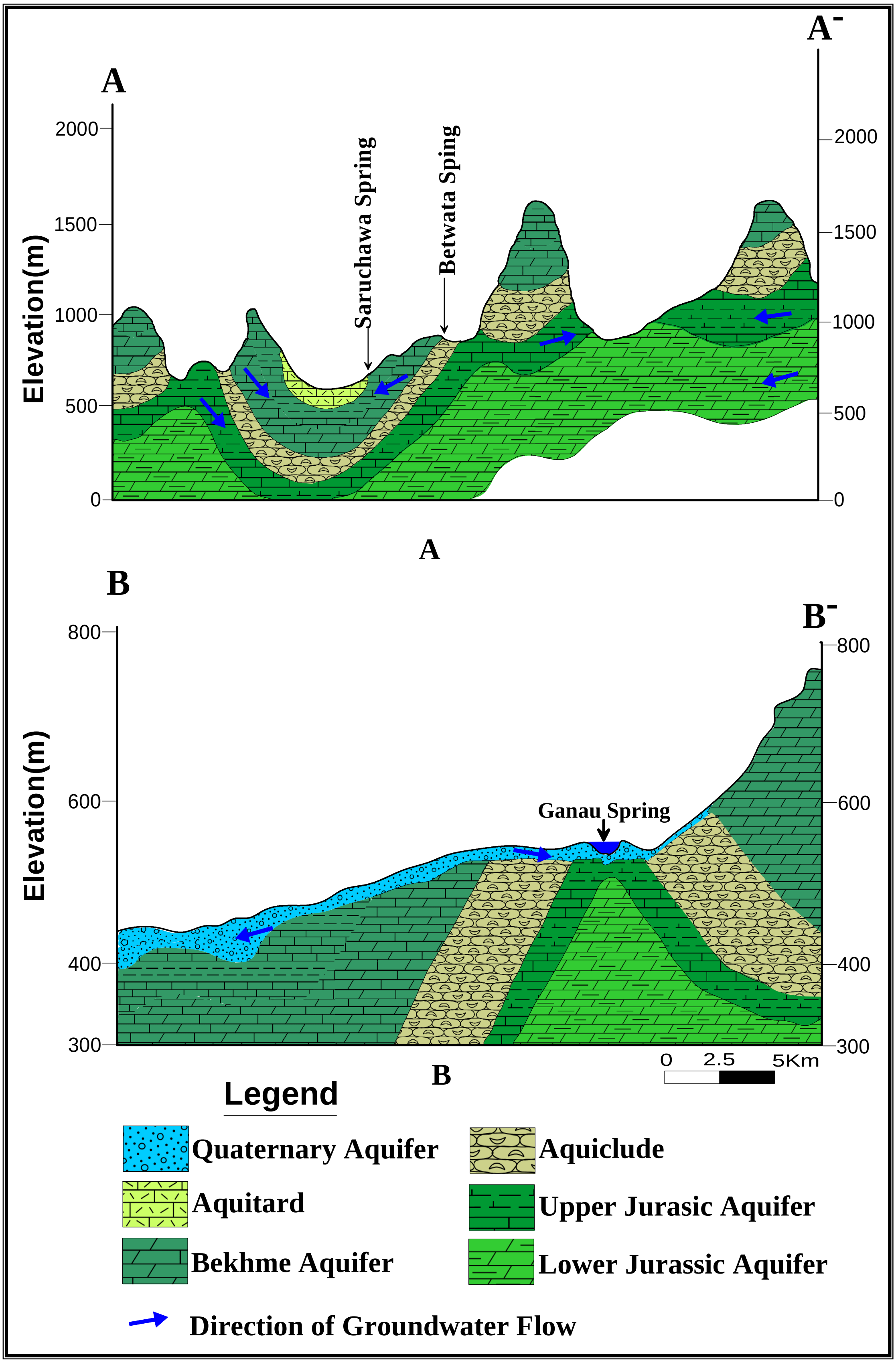


Fig. (3.2)A and B, Schematic Hydrogeological Cross Sections along the Studied Area (Modified from Sissakian, 1997)

3.3 Early-Late Cretaceous Limestone Units

The Cretaceous water bearing formations in the area are: (Kometan, Bekhme and Qamchuqa) they are Karstic aquifers with developed karstic features and fissure systems usually maintain the discharge of high yield springs (Stevanovic and Markovic, 2004b).The Sarmord Formation is belonging to this age but its lithology make it impermeable to semi-impermeable units acting as a barrier. Some springs exist at the boundary between Sarmord Formation and other limestone formations like Qamchuqa Kometan , and Bekhme (field observations).

These limestone units are significant water bearing units in the fractured and cavernous regions and are considered the main regional limestone aquifers and its thickness is approximately (450 m).

3.4 Late Cretaceous Limestone Units

Consist of Tanjero and Shiranish Formations Predominantly aquitard, clastic-flysch rocks, only locally developed fissured aquifer yielding only small amounts of water. It appears only in limited extends in the studied area. Shiranish Formation acts as a burier, some springs are merge at the contact between it and Cretaceous formations like Saruchawa spring that merges at the contact between Shiranish and Bekhme Formations.

3.5 Quaternary Units

The quaternary appears in the area as alluvial fans, alluvium, and river terraces. It forms intergranular aquifer medium to highly productive, unconfined locally disconnected with impermeable clay layers, partly semi-confined .The majority of drilled wells are benefiting from the water of this aquifer which is exploited for different purposes like domestic, agriculture, and industrial. The estimated thickness of this unit is more than (140m).

3.6 General Characteristics of the Aquifer Systems

3.6.1 Karst Aquifer “Bekhme”

Including Qamchuga, , Kometan, Bekhme, , Cretaceoues age formations developed mainly in carbonate facies (limestones and dolomites and their varieties).

It is a typical non-homogenous anisotropic aquifer, which contains large groundwater reserves, but varying in space and time. This aquifer is mostly characterized by great thickness and large surface area. The aquifer is highly fissured, well-karstified with many features, channels and caves that can be observed on the surface (Stevanovic and Markovic, 2004b).It features confined to semi-confined conditions when overlaid by the Shiranish Formation , but this condition exists less often in the studied area .Generally when out crops are exposed to the surface the aquifer features unconfined condition . Turbulent water-flow regime is one of the main characteristics of this aquifer. In general, the base of karstification (depth to the still fissured and porous level of the rock) is deeper than 100 m, which is very important for static water reserves accumulated in the deeper parts of the aquifer (Stevanovic and Markovic, 2004b).

The transmissivity values (approximated on the basis of recovery tests) which were performed by (FAO) on these aquifers in a neighboring area were very high (6-9 x 10^{-2} m^2/s) (Stevanovic and Markovic, 2004b).

3.6.2 The Intergranular Aquifer

It is a very productive aquifer that covers a surface of a several hundred square kilometers. Based on the results of previous investigations, including deep-well drilling, geophysical investigations (Aziz, 2002, Baban and Ali, 2002) the total thickness at the centre of the Rania and Chuwarqurna is assumed more than 140 m. From the surface down, the lithological column starts with altered impermeable clays or semi-permeable clayed-sand (1-15 m) and the lower layer consists of (gravel, sand, silt, and clay), more than100 m thick (main aquifer). In many cases the total length of well-screen (tapping only highly productive layers) is about 50-60 m. The cyclic nature of sediments, as well as the erosional and facial processes, alternate in the deposition environment and mark the discontinuities that limit the extension of some lithological units. Thus, the repetition of the fine, medium and coarse-grained textures, variation in permeability from one site to another within the same aquifer horizon, are typical characteristics of this aquifer (Stevanovic and Markovic, 2004b). This aquifer is underlain by Jurassic aquifer in Rania city, and in most of the area Chuwarqurna and Saruchawa is underlain by Shiranish Formation which is considered as an aquitard for its lower part and aquiclude for its upper part while in the remaining area of Chuwarqurna and Saruchawa is underlain by Bekhme aquifer. In all of these cases, it is reported that there is a hydraulic connection between the quaternary and the mentioned aquifers (Stevanovic and Markovic, 2004b).

This productive aquifer is tapped by many deep wells, which in turn provide large amounts of water for irrigation and water supply.

3.7 Aquifer Recharge

The effective infiltration capacity of the Bekhme karstic aquifer is high and a great part of rainfall contributes the groundwater recharge. The assessment of this infiltration rate relies on the occurrence of highly fractured, cavern and karstified rocks, lack of vegetation and a poorly developed hydrography (Stevanovic and Markovic, 2004b). During the wet season, the reduced evaporation rate, rainfall and even the layer slope contribute to the above-mentioned rate. Considering that the dip in the limestone beds and banks sometimes achieves 60-70° (almost sub-vertical), the intra-bed infiltration can increase significantly. Young (neo) tectonic uplifting of the Cretaceous limestone sequence, and associated sets of distension fractures, most likely reinforced the recharge potential. In areas where Bekhme layers are characterized by a reduced dip, or as observed the presence of a massive rock structure, fissures, joints and cavities represent the major factors contributing to aquifer recharge, plate (3.1). Topography might be a significant element controlling infiltration rate, however, depressions and sinkholes that are considered favorable factors, are rarely present at the outcropping surface of the “Bekhme” aquifer. However, the above-mentioned package of characteristics and factors should, in principle, guarantee the good recharge potential of the karstic aquifers. The condition above is less applied to Jurassic Karstic aquifer because it is characterized by less joints, fissures, and cavities also the dip amount is more gentle than that of Bekhme, but there is an important source for its recharge that is perennial streams because the rock units are exposed at the core of the anticlines where many streams like Shaoor stream flow over.

The main recharge of a shallow intergranular aquifer is usually by direct infiltration of precipitation and vertical percolation of surface waters from intermittent streams – wadies to the bottom aquifer like Shaoor and Qashan streams. In addition, there are many small depressions on the broad plains where rain water remains for sometime and slowly infiltrates and/or evaporates over time, plate (3.2).

Plate (3.1) Small Cavities in Limestone Rocks in the Studied Area

Plate (3.2) Small Depressions on the Plains where Rain Water Remains for Sometime

3.8 Aquifer Discharge

Out flow of aquifer storage has three forms in the area:

1-Drainage through springs (depletion).

2-Subsurface drainage (subsurface out flow).

3-Artificial drainage, by pumping from wells (draft).

3.8.1 Aquifer Discharge through Springs

Spring discharge represents the main groundwater outflow, especially in the case of karstic and karstic-fissured aquifers. Various factors, such as location of water bearing layer and impermeable rocks, presence and distribution of tectonic elements, influence the emergence of springs at particular locations, while climatic conditions and resources of the aquifer system actually dictate the amount of water discharged through outlet points. Numerous diffuse or concentrated springs with highly varying discharges have been reported in this region.

3.8.2 Subsurface Drainage

Subsurface water discharge indicates that there is a transfer of the majority or part of water from an aquifer to another type of aquifer, or directly into the river beds of surface streams. The possibilities for subsurface outflow depend on geometry (aquifer thickness and position of adjacent formations) and permeability of rocks. In hydrogeological practice, the occurrence of under groundwater discharge can be identified on the basis of simultaneous river gauging, thermometric and electric conductivity measurements of stream water and, whenever possible, by using certain geophysical methods.

Subsurface drainage is typical for karstic aquifers with deeper karstification. The conditions for karstification development are not uniform throughout the carbonate rocks. The dynamic of the karstic process is primarily controlled by complex geology, and less so by other factors such as landform slopes, paleogeographic features, climatic conditions, etc, this region is also characterised by holokarst development, i.e. karst landscape of fully developed surface and subsurface features (caves, sinkholes) (Stevanovic and Markovic, 2004b).

One of the typical stages in karstification is prevalence of karst over fluvial processes. The stream network in the carbonate rock complex was often completely disorganized and is actually represented mostly by dry and/or intermittent active river valleys. Clear example of subsurface drainage has been identified in Rania, where younger deposits are mainly recharged by subsurface seepage from Jurassic. Thus, several springs (including Qulai Rania,Kwera Kani, and Ganau) appear on a downstream discharge.

The subsurface drainage was verified through simultaneous river flow gauging on successive profiles in Qaladza – Rania basin. The measurements were conducted by the FAO staff of Dokan Dam facility during the low-water period of 1999. It was noticed that the stream flow almost doubles between two profiles table (3.1) as a direct consequence of subsurface drainage from the karstic aquifer at the edge of the southern basin, possibly augmented by drainage of recent valley deposits in the same basin (Stevanovic and Markovic, 2004b). This finding was established by the existence of a large submerged spring that emerged through alluvial deposits visible in Rania gorge only during very low water seasons like Quli Darban spring.

Table (3.1) Stream Flow Measured in Qaladza-Rania Basin (From Stevanovic and Markovic, 2004b)

Date	Qaladza (upstream) in m^3/s	Rania (downstream) in m^3/s
4 July 1999	13	24
1 August 1999	6.5	13.5
5 September 1999	5.8	11
6 October 1999	6	17
8 November 1999	10	17

Narrow gorge sections cut by the stream are sometimes characterised by concentrated or diffused subsurface discharge. The discharge is calculated by subtraction of stream flow recorded at the entrance (upstream), from stream flow recorded at the exit of the gorge area (downstream). This kind of assessment is not completely reliable, as a result of irregular stream geometry and turbulent flow particularly during discharge peaks. In addition, the delay in upstream – downstream peak transfer makes interpretation of daily discrete data difficult. For this reason, only data from the recession period were taken into consideration, while the maximum values during flood period were neglected (Stevanovic and Markovic, 2004b).

3.9 Water-Table Fluctuations

Groundwater levels rise and fall in response to many different phenomena. Fluctuations are not always indicative of groundwater recharge or discharge. Changes in water levels occur over different time scales. Long-term fluctuations, over periods of decades, can be attributed to naturally occurring changes in climate and to anthropogenic activities (e.g., changes in land usage, pumping, irrigation, and induced infiltration). Seasonal fluctuations in groundwater levels are common in many areas due to the seasonality of evapotranspiration, precipitation, and irrigation. Short-term water-table fluctuations occur in response to rainfall, pumping, barometric-pressure fluctuations, or other phenomena. (Al-Jabari,et al., 2000, Healy and Cook, 2002, Bradley, 2002).

A (1-year) programme including measurements of water tables was performed during the year 2002 by the FAO, while another was effectuated by the researcher in year 2006. The Variations in hydraulic head were monitored using a network of the two piezometers. Depths to water table were measured manually using an electrical sounder frequently every 7 days during 2002 and every 30 days during 2006.

The variations in the water table for two piezometers over the period 2002 and 2006 are shown in Fig. (3.3 and 3.4). It indicates the extent to which the water table responds to precipitation magnitude and its distribution. There were some differences in the response of individual piezometers to rainfall events, partly due to variations in the specific yield of alluvial deposits. Moreover, the variations between the two monitoring years are due to amount of precipitation in each year .From the water table hydrograph we concluded that there is a good response of water table to precipitation, this relation is an indicator of shallow water table and unconfined aquifer type.

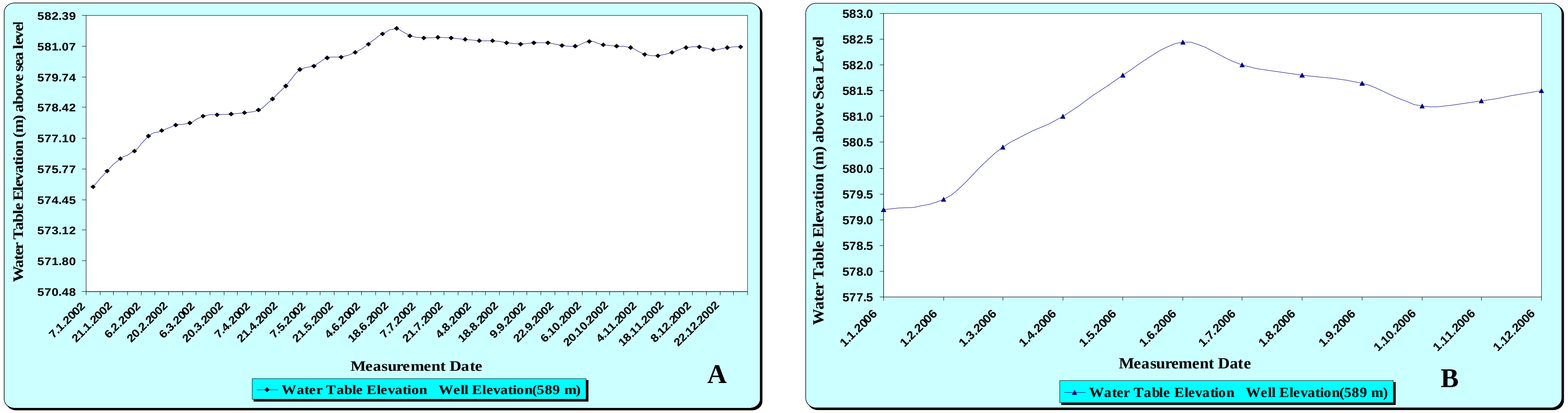


Fig (3.3) Water Table Hydrograph of Bosken Well (A) (FAO) for the Period (2002)(B) Present Study (2006)

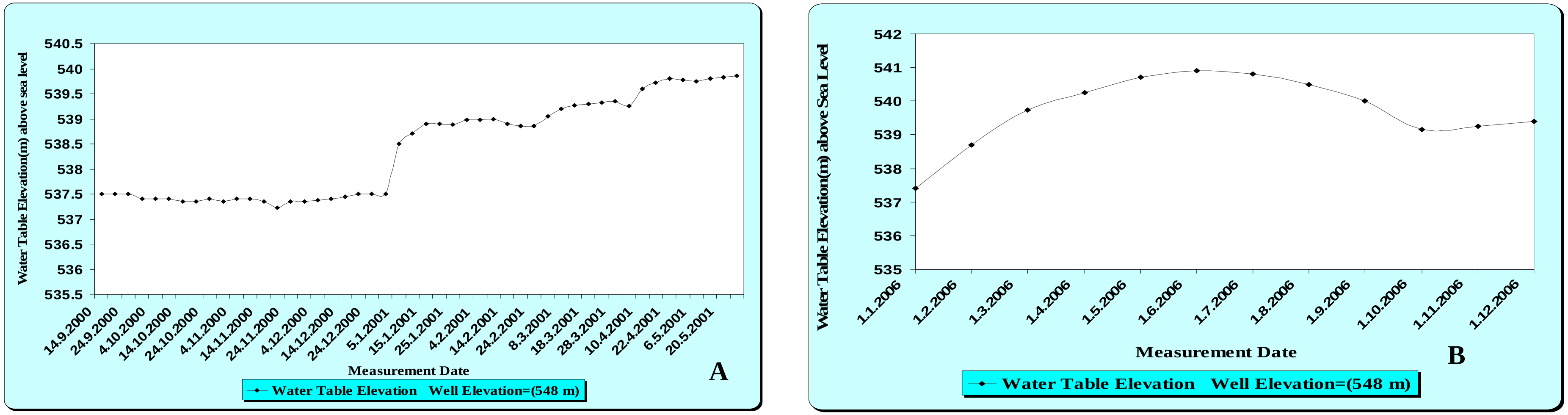


Fig (3.4) Water Table Hydrograph of Qulai Kanimaran Well (A) (FAO) for the Period (2000) (B) Present Study (2006)

3.10 Groundwater Flow

Groundwater movement which depends upon the hydraulic gradient and 'hydraulic conductivity, may be quantitatively appraised by graphical analysis of flow nets (Hassan, 1998, Chnaray, 2003).

The elevations of the wells for 27 wells of table (3.2) were determined by a (GPS) device, static water table above sea level was determined by subtracting the elevation of the wells from the depth of static water level, the depth to static groundwater table of some wells determined by electrical sounder and the records compared with that of Sulaimaniyah groundwater directories.

Table (3.2) Water Table Elevation above Sea level for Some Selected Wells in Rania Area

No.	Well	Longitude	Latitude	Elevation(m)	SWL(m)	W.T.A.S.L.(m)
1	**Azadi1**	44 °52' 20"	36 °15' 47"	599	38	561
2	**Nawroz**	44 °52' 16"	36 °15' 07"	598	32	566
3	**Hasan Agha**	44 °52' 37"	36 °16' 37"	581	38	543
4	**Peshwa**	44 °52 46"	36 °14' 52"	580	30	550
5	**Awarakan**	44 °52' 07"	36 °15' 49"	602	41	561
6	**Sarkapkan**	44 °49' 23"	36 °17' 06"	674	19.5	654.5
7	**Hospital**	44 °52' 49"	36 °16' 27"	590	0.39	589.61
8	**Rapareen3**	44 °52' 38"	36 °14' 26"	576	26	550
9	**Rapareen4**	44 °52' 51"	36 °14' 14"	574	30	544
10	**Rapareen1**	44 °52' 55"	36 °14' 42"	586	39	547
11	**Bosken**	44 °55 '12"	36 °14' 58"	589	6.25	582.75
12	**Camp13**	44 °50' 00"	36 °12' 27"	546	13	533
13	**Camp14**	44 °50 12"	36 °12' 28"	542	20	522
14	**17**	44 °50' 04"	36 °12' 36"	554	12	542
15	**16**	44 °50' 13"	36 °12' 42"	544	20	524
16	**Bn zeri**	44 °49' 18"	36 °12' 41"	550	13	537
17	**2**	44 °49' 21"	36 °12' 30"	545	10	535
18	**Rapareen**	44 °49' 14"	36 °12' 16"	553	16	537
19	**Grdjan**	44 °47' 20"	36 °12' 28"	545	13.8	531.2
20	**Mirabag**	44 °47' 03"	36 °14' 34"	593	65	528
21	**Kifradol**	44 °46' 36"	36 °14' 19"	578	37	541
22	**Tekosher**	44 °48' 02"	36 °13' 40"	583	43	540
23	**Industrial**	44 °47'16"	36 °14'01"	581	36	545
24	**Saruchawa(1)**	44 °44'32"	36 °15'17"	590	43.1	546.9
25	**Saruchawa(2)**	44 °44'15"	36 °15'00"	595	36	559
26	**Shkarta Camp**	44 °42'36"	36 °17'14"	673	28	645
27	**Qulai Kanimaran**	44°43' 34"	36 °12' 28"	548	10.9	537.1

A flow net map was constructed from the collected data Fig. (3.5) for unconfined aquifer, which shows that high groundwater level occurs in the northwest side of the area while the low groundwater level occurs in the southeast side of the area. This means that groundwater moves from northwest to southeast toward the Dokan Lake, so it flows in the same direction as regional groundwater flows. The central part is around Rania and toward the east and south east, became more flat with more groundwater contour spacing, which reflects a high aquifer transmissivity zone, and this in turn explains the location of the highest productivity wells in the area. One mound area appeared in the water table record in the east part of the area, which may represent local recharge areas.

In the case of the karstic and fissured-karstic aquifers available reports and documentation do not contain information on any kind of tracing tests performed in the area for Karstic aquifer, therefore there is no exact idea for groundwater movement but the tectonics and the position of regional and local base of erosion are the main factors to predispose and define groundwater directions in the area (Stevanovic and Markovic, 2004b) ,however, the position of the anticline limbs might be a local determinant in controlling flow orientation.

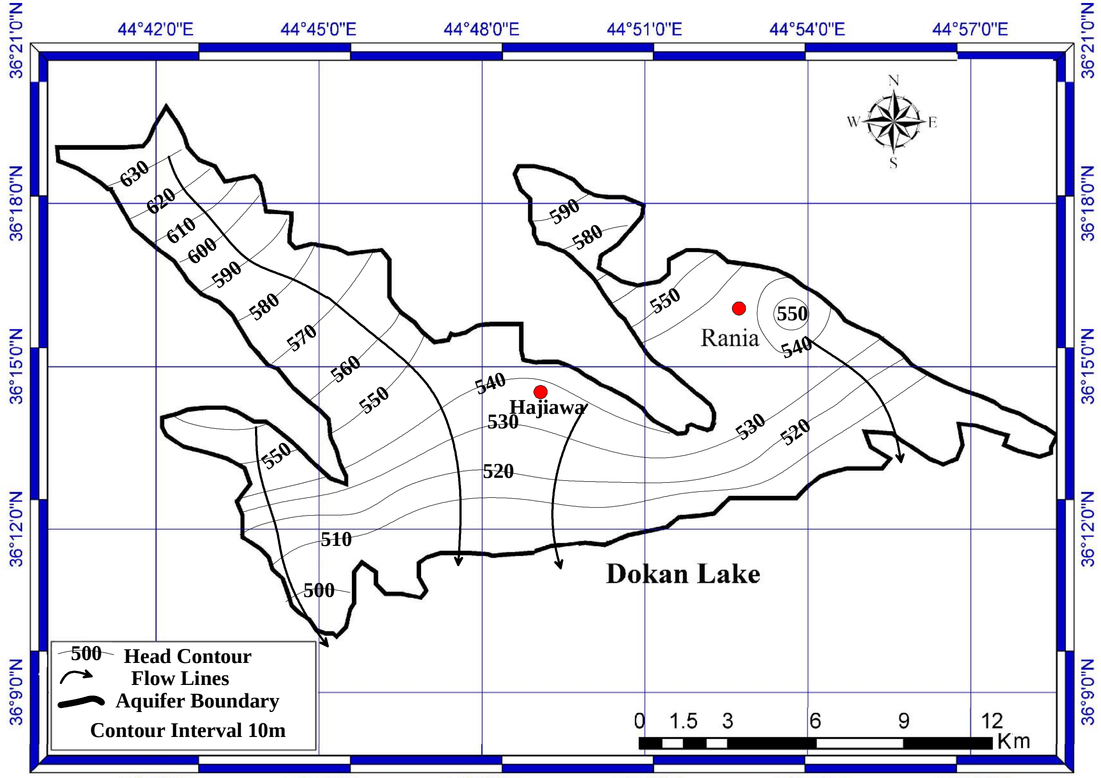


Fig. (3.5) Water Table Map of the Quaternary Aquifer for the Studied Area

3.11 Hydraulic Properties of the Quaternary Aquifer

Estimating the physical properties of water-bearing layers is an essential part of groundwater studies. One of the most effective ways of determining these properties is to conduct and analyze aquifer tests, which is a costly method. Alternatively it can be found a physical properties from single well test especially when observation wells are absent (Kruseman and de Ridder, 1994, Dellur , 1999, Schaaf, 2004) .This method had been used by many Iraqi and international researchers like (Chnaray, 2003, Schaaf, 2004).

The single well pumping test data are available for (11) wells drilled within the Quaternary (intergranular) aquifer in the studied area that are obtained from Sulaimaniyah groundwater directories. One well is monitored in an observation well by the researcher .These data introduced to (AQTESOLV 4.1, and Aquifer$_{\text{win32}}$ 3.0) software to calculate hydraulic properties of the aquifer. The detail data and results are listed in the appendix (4).The calculated hydraulic parameters are as follow:

3.11.1 Transmissivity (T)

Is the product of multiplying the average hydraulic conductivity by the saturated thickness of the aquifer. Consequently, it is the rate of flow under a hydraulic gradient equal to unity through the cross section of unit width over the whole saturated thickness of the water-bearing layer. (Kruseman and de Ridder, 1994, Dellur, 1999).

Cooper and Jacob (1946) method was applied for single well pumping test analysis, the transmissivity calculates by the following equation:

$$T = \frac{2.3Q}{4\pi\Delta s} \text{ .... } (3.1)$$

Where

Q: Constant rate discharge from the well measured in m^3/day

Δs: Difference of drawdown per log cycle (t) measured in m

The drawdown value to be used in the above equation must be corrected (Dellur, 1999); this correction is applied by the (AQTESOLV.4.1) software according to the following equations (Boonstra and de Ridder, 1981):

$$T = \frac{1.22Q}{\overline{S_w}} \text{ .... } (3.2)$$

$$\overline{S_w} = S_w - \frac{(S_w)^2}{2b} \text{ .... } (3.3)$$

Where $\overline{S_w}$:Corrected Drawdown, b: Saturated thickness

The result of transmissivity values is tabulated in the table (3.3), and the detailed data and graphs is listed in the appendix (4).

The transmissivity values determined for the intergranular aquifer have a very large variation. This is the result of regional and local hydrogeological conditions, variations of lithofacies, saturated thickness, and heterogeneity, though the effect of technical performance during drilling and testing cannot be neglected. In practical terms, the hydraulic losses and resistance of screen (intake) zones are sometimes very high as a result of improper well construction. Thus, presence of non-removed clayed components in the screen and gravel pack section and sometimes the intensive pumping rate, can stimulate clogging and significantly hinder well performance.

3.11.2 Hydraulic Conductivity (K)

The hydraulic conductivity of a soil or rock defines its ability to transmit a fluid, and it depends on a variety of physical factors, including porosity, particle size and distribution, shape of panicles, arrangement of particles, and other factors (Deming, 2002). It follows that (from the definition):

$$K = \frac{T}{b} \text{ .... } (3.4)$$

Where:

T = Transmissivity in (m^2/day)

b = Saturated thickness of the aquifer (m)

K = Hydraulic conductivity of the aquifer (m/day)

Using relation (3.4) the hydraulic conductivity of the aquifer was determined from data available in tables (3.3)

3.11.3 Storativity (S)

The storativity (S) of a confined aquifer (or aquitard) is defined as the volume of water released from storage per unit surface area of a confined aquifer (or aquitard) per unit decline in hydraulic head (Kruseman and de Ridder, 1994, Deming, 2002). Storativity is also known by the terms *coefficient of storage* and *storage coefficient*. In a confined aquifer (or aquitard), storativity is defined as:

$$S = S_s b \text{ .... } (3.5)$$

Where S_s is the specific storage [L^{-1}] and b is aquifer (or aquitard) thickness [L]. Specific storage is the volume of water that a unit volume of aquifer (or aquitard) releases from storage under a unit decline in head by the expansion of water and compression of the soil or rock skeleton. Storativity generally ranges between 0.00005 and 0.005 in confined aquifers. Specific storage is related to the compressibility's of the aquifer (or aquitard) and water as follows:

$$S_s = \rho g(\alpha + n_e \beta) \text{ .... } (3.6)$$

Where ρ is mass density of water [M/L^3], g is gravitational acceleration (= 9.8 m/sec^2) [L/T^2], α is aquifer (or aquitard) compressibility [T^2L/M], n_e is effective porosity [dimensionless], and β is compressibility of water (= $4.4x10^{-10}$ m sec^2/kg or Pa^{-1}) [T^2L/M].

In an unconfined aquifer (or aquitard), storativity is given by

$$S = S_y + S_s b \text{...........} (3.7)$$

Where S_y is specific yield which is defined as the volume of water released from storage by an unconfined aquifer per unit surface area of aquifer per unit decline of the water table. Because $S_s b$ is typically small in comparison to S_y, storativity in an unconfined aquifer is essentially equal to specific yield.

With single-well tests, basically the same procedures can be applied as with aquifer tests. The (r) value now represents the effective radius of the single well (Dellur, 1999, Schaaf, 2004). This is difficult to determine under field conditions; as a "best" estimate, the outer radius of the well screen is often used. A complicating factor is the phenomenon, that due to nonlinear well losses, the water levels inside the well can be considerably lower than those directly outside the well screen. Specific yield values based on this method should be treated with caution, because they are highly sensitive to the value of the radius of the effective pumped well (Dellur, 1999, Todd, 2005).

The procedure with single-well tests was applied to determined specific yield using Cooper and Jacob (1946) method as follows:

$$S = \frac{2.25Tt_0}{r^2} \text{...........} (3.8)$$

Where S is specific yield, t_0 is the intercept of the fitted line on the time axis; r is the effective radius of the single well.

The result of specific yield values for quaternary aquifer is tabulated in the table (3.3), and the detailed data and graphs is listed in the appendix (4).

Specific yield calculated also According to (Johnson, 1955) the can be determined approximately by the equation below:

$$S_y = \frac{b}{1000} \quad \text{...........} (3.9)$$

Where Sy: specific yield (unitless), b Saturates thickness (m).

the results shown in table (3.3).

Table (3.3) Transmissivity, Specific Capacity and Hydraulic Conductivity Values of Some Selected Wells in Rania Area

Well	T (m^2/day)	Sy (well test)	Sy (b/1000)	K (m/day)
Girdjan	600.8	0.0063	0.0812	7.40
Camp 13	44.6	0.067	0.087	0.51
Camp 14	124.5	0.09	0.1	1.25
Rapareen	199.3	0.079	0.084	2.37
Saruchawa1	169.6	0.053	0.081	2.09
Saruchawa2	82.14	0.05	0.086	0.96
Mirabag	245.3	0.079	0.058	4.23
Kifradol	235.7	0.087	0.078	3.02
Tekosher	152.8	0.15	0.092	1.66
Industrial	154.7	0.09	0.084	1.84
Bosken	4260	0.0031	0.0725	58.76
Qulai Kanimaran	---	---	0.0691	---
Min.	**44.6**	**0.0031**	**0.058**	**0.51**
Max.	**4260**	**0.15**	**0.1**	**58.76**
Median	**169.6**	**0.079**	**0.084**	**2.09**

3.11.4 Specific Capacity (Sc)

Specific capacity is the ratio of the obtained rate of the discharge to the drawdown, which is required to produce the obtained discharge and expressed in cubic meter per day for each meter of drawdown (Fetter, 1994):

$$S_c = \frac{Q}{s_w} \text{..........} \quad (3.10)$$

Sc: Specific capacity measured in m^2/day.

Q: constant rate discharge from the well measured in m^3/day

s_w: Total drawdown measured in the well measured in meter

According to (Fetter, 1994), specific capacity expresses the productivity of the productive well and decreases with the period of pumping because the drawdown continually increases with time as the cone of influence of the well expands. For this reason it is important to state that the duration of pumping period for which a particular value of specific capacity is computed.

The specific capacities of the well in the studied area were calculated by the equation (3.10), table (3.4).

It concluded that there is an inverse relationship between specific capacity and drawdown (Todd, 1980).

Table (3.4) Specific Capacity Values Relationship

Well	Q (m^3/day)	s (m)	T.D (m)	SWL (m)	b (m)	Sc(Q/s) (m^2/day	T (m^2/day)
Girdjan	907.2	1.1	95	13.8	81.2	824.7	600.8
Camp 13	1199	10	100	13	87	119.9	44.6
Camp 14	1296	4.4	120	20	100	294.5	124.5
Rapareen	1900	4	100	16	84	475	199.3
Saruchawa1	950.4	2.9	126.5	43.1	81	327.7	169.6
Saruchawa2	1166	6	122	36	86	194.3	82.14
Mirabag	583.2	1.13	123	65	58	516.1	245.3
Kifradol	1166	2.3	113	37	78	507	235.7
Tekosher	1166	2.8	135	43	92	416.4	152.8
Industrial	654	3.17	120	36	84	206.3	154.7
Bosken	1089	0.119	79	6.5	72.5	9151.3	4260

3.12 Karst Springs

Within the group of karst springs, the major outlets were considered to be draining both Bekhme and Jurassic aquifers. Karst springs often associated with faults locations and fracture systems, and border massif carbonate rocks at their contacts with non-carbonate rocks. Many karst springs are mainly related to their favorable geologic-geomorphologic setting.

1-Geological factors – comprise main geologic elements that control the karst spring location.

2-Lithologic control - changes in aquifer lithology or contacts with less permeable layers such as in case of Qamchuqa – Sarmord and in case of Bekhme, Kometan– Shiranish Formations .

3-Regional or local faults/fractures.

4-Combination of plunge of the anticline dissected by transversal fractures/faults the most frequently occurring feature for some large springs. Among the well-known examples, for the most outstanding discharges, are the Sarwchawa.

5- Geomorphologic factors -

A-*Base of karstification* – generally the lowest point the karstification process occurs, represents the discharge point of the karst system for gravity springs. However, the same does not apply for artesian springs, for which the base of karstification is below the discharge point; hence, many systems are eventually drained through alluvial deposits or into/under riverbed as in (Qulai Rania and Ganau submerged springs).

6- Hydrogeological factors – As for the surface streams the discharge of karst springs is related to the catchment area in addition, to the drained volume of the water-bearing layers. Thus the geometry of the aquifer is one of the most important aspects determining its capacity.

3.13 Main Karst Systems

The concept of system is used to define the framework for any aquifer and represents a transfer (whether fast or very slow), between an input or recharge to an output or discharge. In this regard the karst systems cover the intricate net of different size fissures and voids developed by dissolution within the carbonate rock bodies, between the diffuse or concentrate (swallets) recharge areas and the spring/group of springs. Therefore a part from the spring name, whenever possible the karst system name could suggest the inferred zone of recharge. The main karst systems in the studied area are as follows:

3.13.1 Saruchawa - Mackok System

This system contains many springs like Saruchawa, Betwata, and Shkarta. Authors of the study undertaken by Parsons Company (1957) were the first to describe some of the principal springs in Sulaimaniyah Liwa. The largest spring is Saruchawa spring, which yields an estimated annual average discharge for the year (2002) of (6514 l/sec). It is reported that 500 families are supplied with water by this spring for both domestic and irrigation needs. The source of Saruchawa spring is mostly groundwater flow from limestone. Five small springs just southeast of Saruchawa spring have an estimated combined annual average flow of about (708 l/sec). These springs are the result of the intersection of ground surface and water table in the valley alluvium (Stevanovic and Markovic, 2004b).The entire group of springs is related to the boundary between Kometan (Bekhma aquifer) and Shiranish Formation Fig. (3.6). The plunging of the limb of the structure to the plain dictates the location. The spring area mainly includes several strong artesian springs and some 3-4 different other groups of springs emerging in a concentrate manner or as diffuse springs collected by concrete or improvised canals , plate (3.3A). The minimum discharge recorded in 2001 was 1750 l/s, while in 2002 the minimum discharge was three times greater, at 5500 l/s (Stevanovic and Markovic, 2004b).

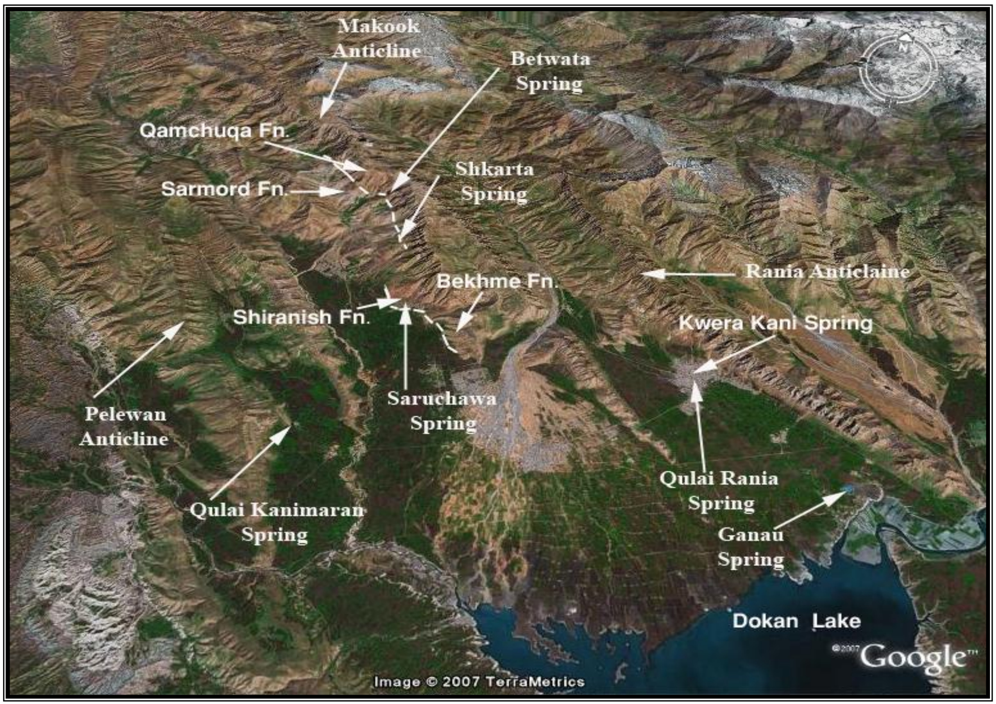


Fig. (3.6) Occurrence of (Saruchawa, Betwata, and Shkarta) Spring due to Stratigraphic Condition

An interesting hypothesis suggests possible underground connection between the spring and Shaoor stream stretching northeast of the spring. The direction of major structures is reflected in the geomorphological features of the whole area, which is NW-SE. Two anticlines and a syncline as well as Shaoor stream anticline and a hanged valley located almost at the top of Mackok Mountain (representing the southern limb of the anticline) comply with this direction. Still the plunge of the anticlinorium structure corresponds to a sudden change of the valley’s direction to SW.

Betwata spring Fig. (3.6) and plate (3.3 B) is located near the Betwata sub-district; yielding an estimated annual average of (60 l/sec). It is reported that most families of Betwata are supplied with water by this spring for both domestic and irrigation needs. The spring issues at the contact between Qamchuqa and Sarmord formations. (Stevanovic and Markovic, 2004b) reported that the spring is the result of a fault that exists in the area, however, during fieldwork such a fault was not recognized. The location of the spring is; therefore, attributed to the presence of an impermeable boundary between Sarmord and Qamchuqa Formations. This hypothesis is supported by a similar occurrence of Shkarta spring, which is also located at the contact of the two mentioned formations Fig. (3.6) and plate (3.3 C). The discharge of Shkarta spring is about (30 l/sec) and it is used to supply Shkarta village which has about (50) families (personal communication).

3.13.2 Qulai Rania System

It is another large spring located at the centre of Rania city. Its annual average yield for the year (2002) is estimated at (780 l/sec). Reports mentioned that most of the families in the city of Rania are supplied by this spring for their domestic and irrigation needs. The spring emerges in a concentrated manner and collected by concrete or improvised canals Fig. (3.6) and plate (3.3 D). There are two other springs: Kwera Kani and Darbandi Raina located to the NW and SE and having the same trend which are thought to be belong the same karstic system Fig. (3.6). The first is intermittent with a discharge of about (60 l/sec) disappearing during the low water season plate (3.3 E).Its water ,however, is not exploited ending in the sewage system, whereas the Darbandi Raina spring is disappeared during high water season because it is flow by the water of Dokan lake. The entire group of springs is related to the boundary between Quaternary deposits and the Jurassic rocks with that located in the core of Rania anticline for which the base of karstification is below the discharge point, hence eventually drained through alluvial deposits and thought to be contributed to spring's recharge.

3.13.3 Qulai Kanimaran System

This system is karstic-fissured. It is a large spring located near Qulai Kanimaran village; it yields an estimated average of (0.513 m^3/sec). It is reported that its water supply the domestic needs in Qulai kanimaran and Kanimaran villages. Moreover, it is used for both livestock and irrigation needs. The spring is merging from the contact of Jurassic rocks with the alluvium deposits in the plunge of Pelewan anticline. The controlling factor is the structure like joints that appear in the strata, and all waters are flowing from these joints Fig. (3.6) and plate (3.3 F).

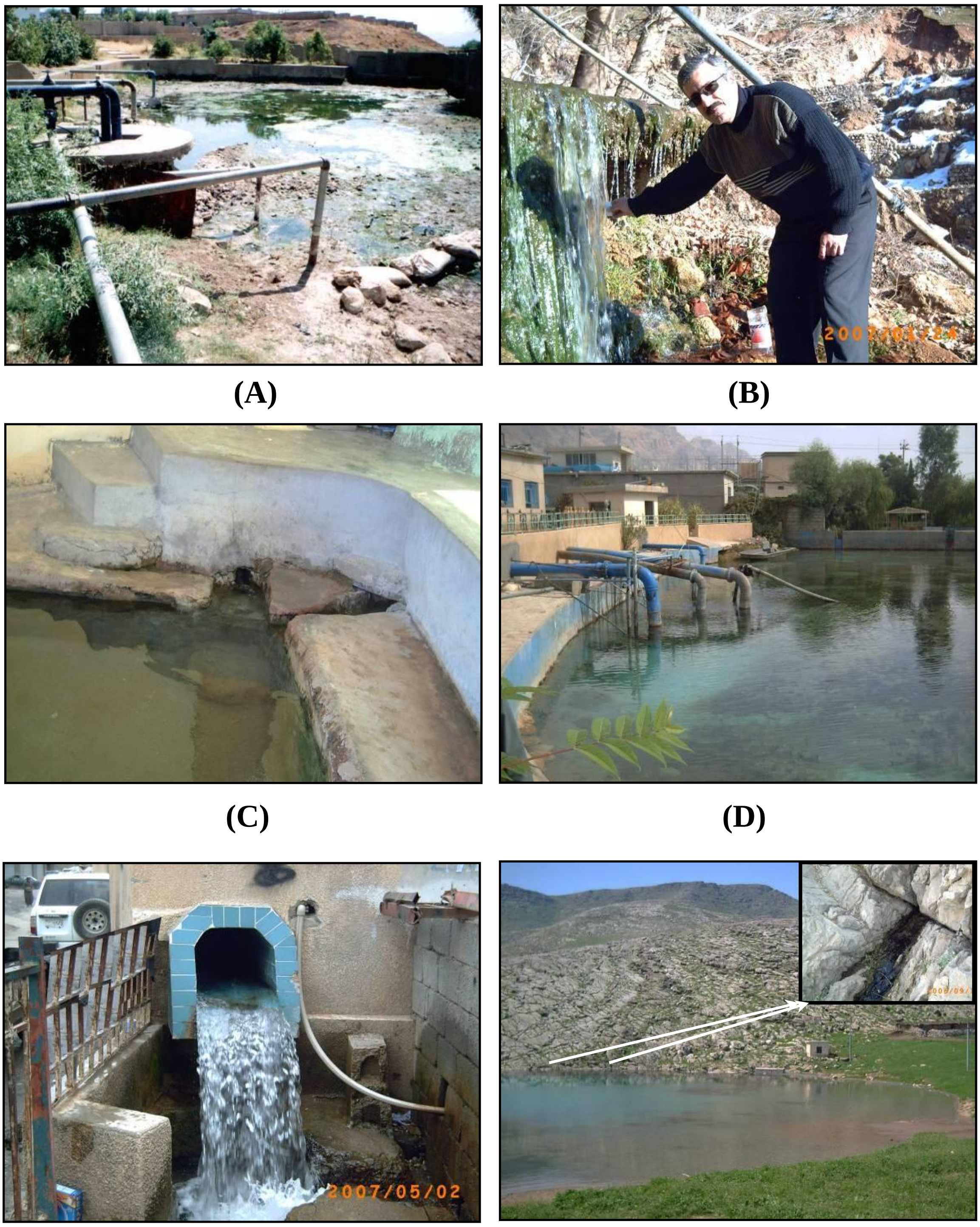

(A) (B)
(C) (D)
(E) (F)

Plate (3.3) A-Saruchawa Spring B- Betwta Spring
C- Shkarta Spring D- Qulai Rania Spring
E- Kwera Kani Spring F- Qulai Kanimaran Spring

3.13.4 Ganau System

It is an amazing sulphide spring located near the Dokan Lake south east of Rania city. Its average yield during the year is estimated at (101 l/sec). A circular lake of about 500m diameter is found in the spring surrounding Fig. (3.6) and plate (3.4 A). Spring water which flows toward the Dokan Lake was never exploited for any purpose due to its high content of dissolved solids and (H_2S) gas , plate (3.4 A). The spring is thought to be issued in the Late Triassic terrain (Kurra China and Baluti) Formations by a probable fault, and hence is eventually drained through the alluvial deposits, the high content of chloride, sulphate, and (H_2S) gas is from dissolution of gypsum which exists in the mentioned formations . The large lake is formed as a result of collapsing in the alluvium caused by weak acid nature of the spring that forms cavities on the bottom of the alluvium, plate (3.4 B).

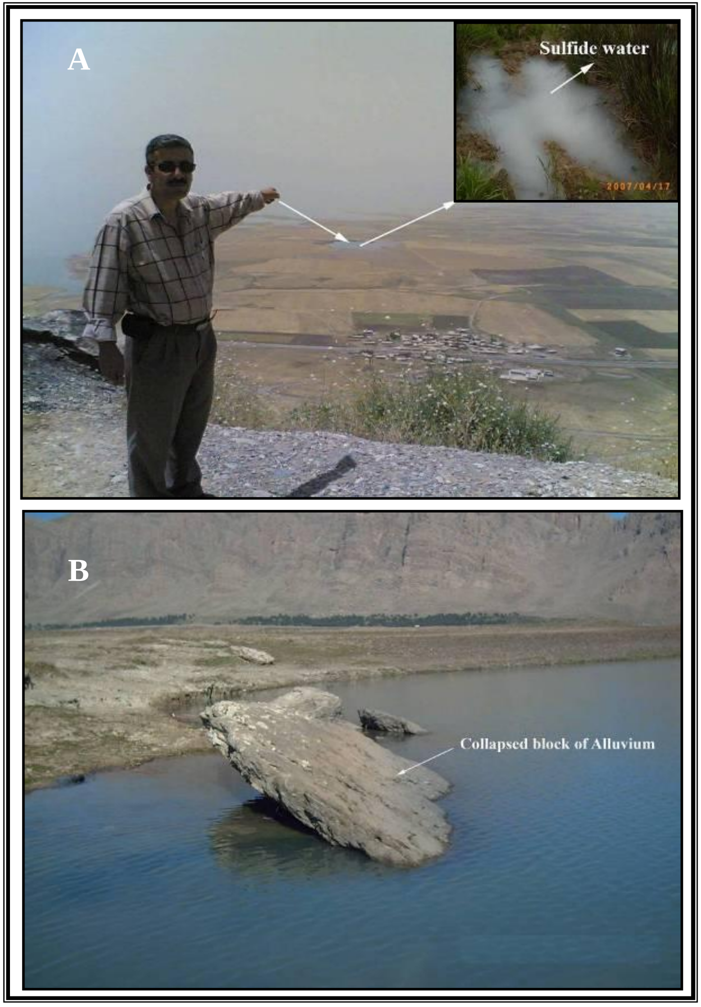


Plate (3.4) Ganau Spring (A) Showing the Spring Location and Sulphide water (B) Showing Collapsed Blocks of Alluvium

3.14 Springs Classification Systems

3.14.1 Significance of Classifying Semi-Arid Springs

Physical parameters of springs up to their point of discharge have historically been classified (Bryan 1919 and Meinzer 1923), but few studies have classified springs beyond their point of discharge. Meinzer (1923) described 11 physical and chemical classifications for springs, table (3.5) and eight classes based on the quantity of discharge for the spring appendix (2). Clarke (1924) considered three criteria to be most important for spring's classification: geologic origin, physical properties, and geochemistry. Types of springs have typically been based on the geologic origin by which the groundwater discharges at the surface (Fetter, 1994). Wallace and Alfaro (1994) recently updated many historical classifications for springs, but these and previous classifications of springs describe certain types of springs and do not consider many ecological characteristics of the spring after the point of discharge. Springer, et al. (2004) put a broad classification of springs which are listed in the appendices (1, 2, 3), the classification is a collection of many previous works. For the classification of existing springs in the studied area Springer,et al. (2004)classification is used as tabulated in the tables (3.6 & 3.7).

Table (3.5) Meinzer (1923) 11 Physical and Chemical Classifications for Springs

No.	Classification
1	Character of openings through which the water issues.
2	Rock structure and resulting force that brings the water to the surface
3	Lithologic character of the aquifer
4	Geologic horizon of the aquifer
5	"Sphere" into which the aquifer is discharged
6	Quantity of water discharged
7	Uniformity in the rate of discharge
8	Permanence of the discharge
9	Quality of the water
10	Temperature of the water
11	Features produced by the springs or otherwise related to them

Table (3.6) Physical and Geomorphic Springs Classification for the Rania Springs Based on Springer et al. (2004). Classification

Name	Hydrostratigraphic Unit	Emergence Environment	Aperture Geomorphology	Sphere of Discharge	Spring Channel	Forcing Mechanisms
Qulai Rania	Sed.(Qamchuqa+Bekhma +Alluvium)	Subaerial- floodplain	Seepage or filtration spring	Limnocrene - emerges from lentic pools	Spring-dominated stream	Increased pressure due to gravity driven head pressure differential
Saruchawa	Sed. (Bekhme Fn.)	Subaerial – Mountainside	Contact spring	Limnocrene - emerges from lentic pools	Runoff-dominated stream	Gravity driven springs
Qulai Kanimaran	Sed. Jurassic	Subaerial – Mountainside	Fracture spring	Hillslope spring	Runoff-dominated stream	Gravity driven springs
Ganau	Sed. Late Triassic	Subaerial- floodplain	Seepage or filtration spring	Limnocrene - emerges from lentic pools	Runoff-dominated stream	Springs due to pressure produced by other forces
Kwera Kani	Sed.(Qamchuqa+Bekhma +Alluvium)	Subaerial- floodplain	Seepage or filtration spring	Limnocrene - emerges from lentic pools	Spring-dominated stream	Increased pressure due to gravity driven head pressure differential
Betwata	Sed.(Qamchuqa+Bekhme)	Subaerial – Mountainside	Contact spring	Hillslope spring	Spring-dominated stream	Gravity driven springs
Shkarta	Sed. Qamchuqa	Subaerial – Mountainside	Contact spring	Hillslope spring	Spring-dominated stream	Gravity driven springs

Table (3.7) Hydrological and Geochemical Classification for the Rania Springs Based on Springer et al. (2004) Classification

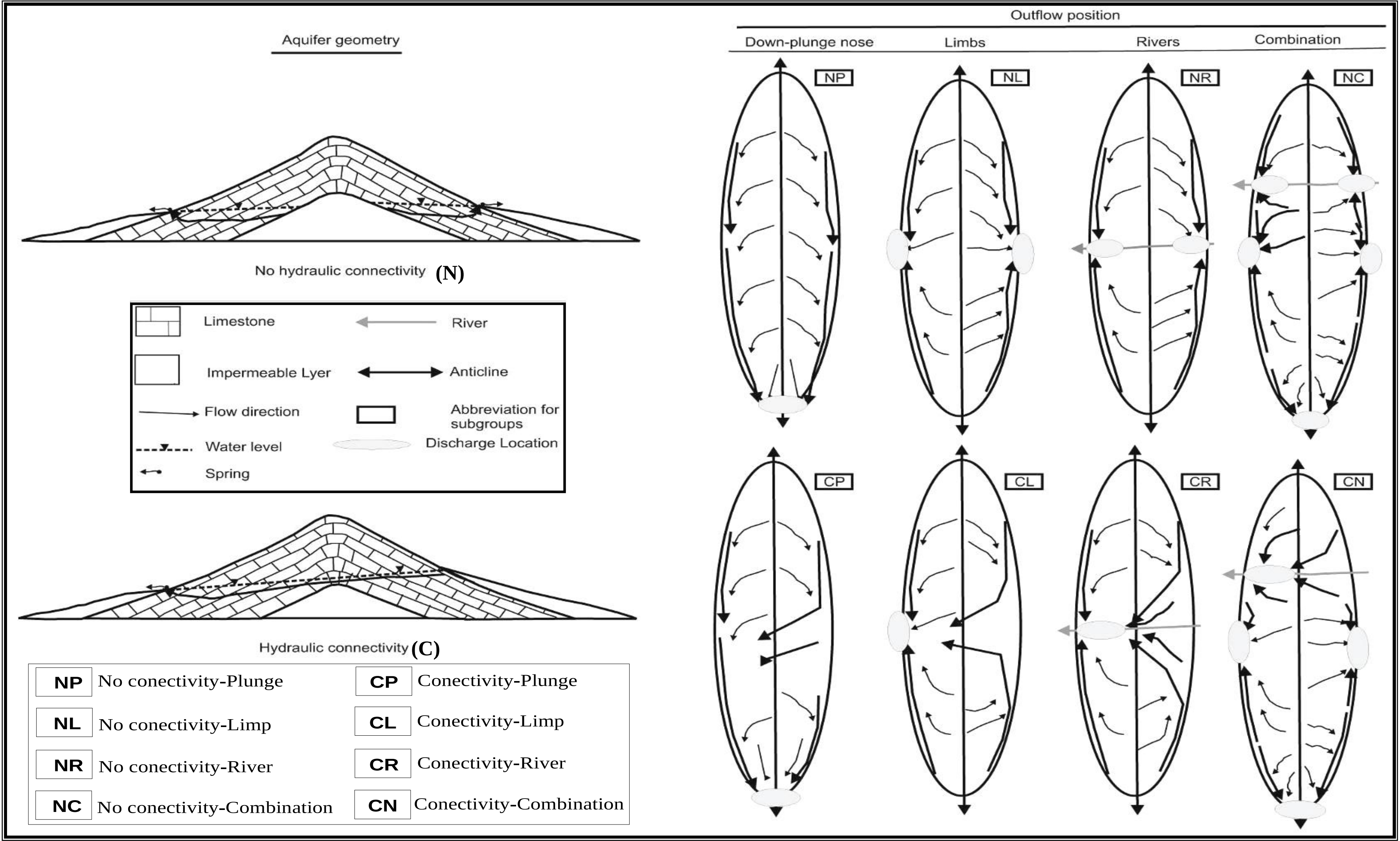
Name	Flow Consistency	Flow Rate	Temperature	TDS	pH	Dominant Cation	Dominant Anion
Qulai Rania	Perennial	Sixth	Cold	Fresh	Neutral	Calcium type	Bicarbonate type
Saruchawa	Perennial	Seventh	Cold	Fresh	Neutral	Calcium type	Bicarbonate type
Qulai Kanimaran	Perennial	Sixth	Warm	Fresh	Neutral	Calcium type	Bicarbonate type
Ganau	Perennial	Sixth	Warm	Brackish	Neutral	Calcium type	Chloride type
Kwera Kani	Intermittent-erratic	Fifth	Cold	Fresh	Neutral	Calcium type	Bicarbonate type
Betwata	Perennial	Fifth	Cold	Fresh	Moderately Basic	Calcium type	Bicarbonate type
Shkarta	Perennial	Fifth	Warm	Fresh	Neutral	Calcium type	Bicarbonate type

3.15 Ashjari Conceptual model for Output Location of Springs

Ashjari Conceptual model (2006) is a model to describe the influences of anticlinal structure on regional flow and occurrence of karst springs.
Geometrically, the studied area has anticlines are cylindrical forms, which plunge down beneath younger sediments at SE ends. The young sediments, which overlaid karstic aquifers, are permeable. Sediments form a thick cover over the synclines between anticlines. Only the top of the anticlines are bare containing exposed carbonate formations and in some cases with quaternary deposits. At their bottom the karst aquifers are bounded by impermeable formations (mostly marls and shales). Considering the aquifer geometry, there are two cases:

A)If the elevation of the impermeable formation under the crest of an anticline is appropriately higher than the foot of the anticline most of the recharged water of each limb can flow towards the foot of the same limb Fig.(3.7) (Ashjari, 2006). In this manner, the hydraulic connectivity of the limbs is disconnected and each limb becomes an independent sub-aquifer. The main source of recharge is direct precipitation on the karstic aquifer body. The recharge is mainly autogenic. A combination of joints and bedding planes plays a role in transferring the ground water through the vadose zone to the phreatic zone. The impermeable formation below the karstic aquifer can block ground-water flow in a vertical direction. The steep slopes of the anticline limbs direct the flow toward the foot of the anticline via available pathways.

B)If the elevation of the impermeable formation under the crest of the anticline is lower than the karst-water level, resulting in the absence of any barriers, the karst water of one of the anticline limbs (donor limb) can flow towards the adjacent limb (receiver limb). Usually the contact elevations of karst formations with the adjacent non karstic formation or alluvium are higher around the donor limb than around the receiver limb. In other words, hydrological base level is located at the foot of the receiver limb and the easiest way for ground water to flow from donor limb to receiver limb, because the hydraulic gradient is steeper toward this limb. The hydraulic connection between the two limbs is often restricted to small areas of the donor limb. So, the infiltrated water flows first parallel to strike in a donor limb, towards a connection area, and then flows to the receiver limb at the connection area. A main conduit system may develop at the foot of the anticline, parallel to strike where the branches of diffuse flow or small-conduit flow join each other. The direction of flow in the main conduit systems at the feet of anticlines depends mainly on the location of discharge zones. Thus, anticlines of both groups can be further classified into four subgroups in which karst water discharges , (I) Down-Plunge nose: only from one plunge apex or both plunge apexes; (II) Limbs: only from limbs; (III) Rivers: to a river traversing the karstic aquifer; and (IV) Combination: a combination of more than one of these subgroups Fig. (3.7). Therefore, the appropriate conceptual model defining regional flow in anticlinal aquifers is based on the presence or absence of hydraulic connectivity between limbs of anticlines and on the location of discharge zone, leading to eight alternative types of flow patterns.



NP	No conectivity-Plunge	**CP**	Conectivity-Plunge
NL	No conectivity-Limp	**CL**	Conectivity-Limp
NR	No conectivity-River	**CR**	Conectivity-River
NC	No conectivity-Combination	**CN**	Conectivity-Combination

Fig (3.7) Conceptual Model based on Geometry and output Location of Springs (after Ashjari 2006)

3.15.1 Springs Output According to Ashjari (2006) Conceptual Model.

The output location of the studied area springs are as follows:

A) No Hydraulic Connectivity between Limbs

In aquifers of this group, the elevation of the aquifer bottom (impermeable formation) under the crest of an anticline is higher than the feet of the anticline (i.e., most of the recharged water on each limb can flow towards the foot of the same limb). Two subgroups have been distinguished considering the position of outlets Fig. (3.8).

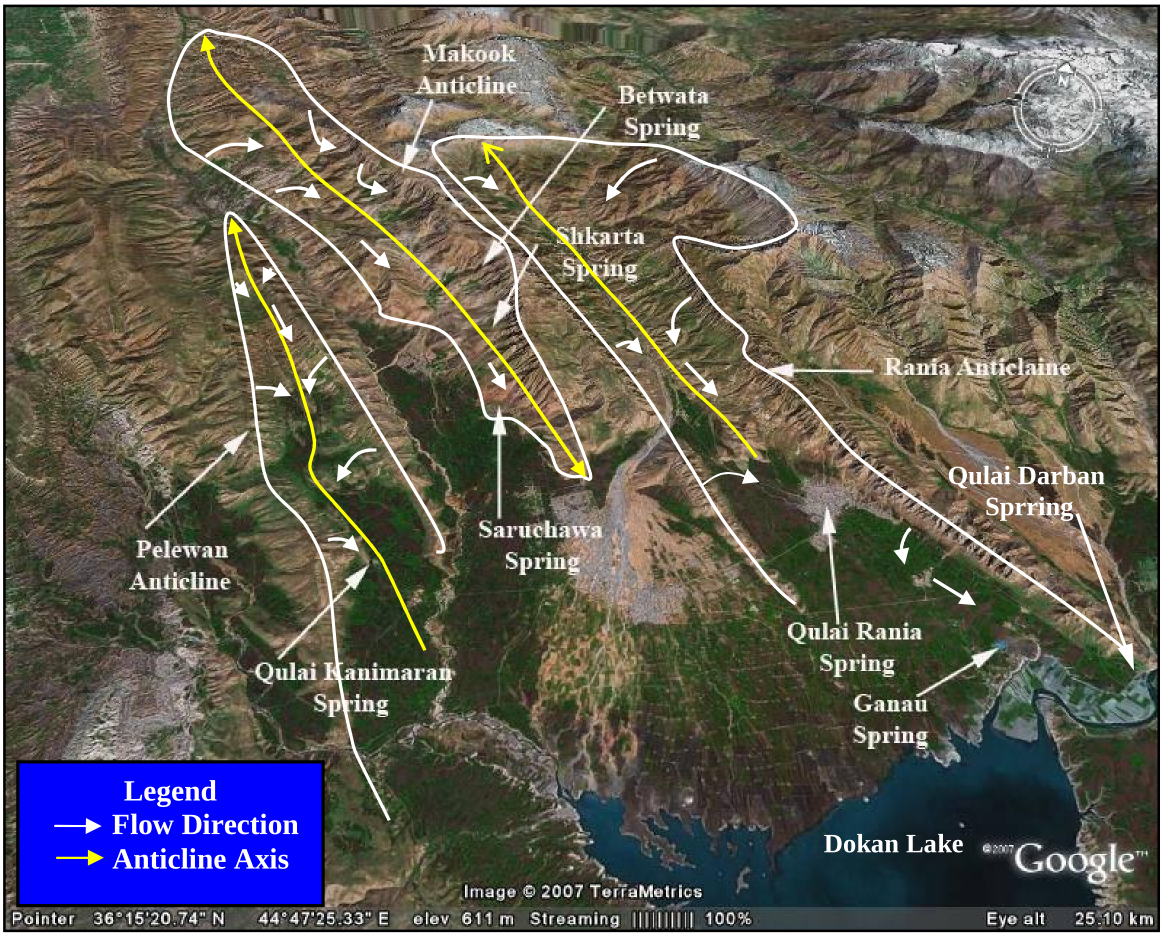


Fig. (3.8) Illustration of springs output According to Ashjari (2006) Conceptual Model

1. Discharge from the Plunge of the Fold (NP)

In one separate case ground water is discharging from the plunging end of an anticline, and the Makook anticline is discussed as the type case of this subgroup. The doubly plunging Makook anticline is composed of the karstic Bekhme-Qamchuqa Formations which are overlain and underlain, respectively, by the impermeable Sarmord and Shiranish Formations in the south-eastern plunge apex, also in the same direction is in direct contact with the adjacent alluvium. The elevation of the impermeable Sarmord Formation under the crest of the anticline is noticeably high, disconnecting the hydraulic connectivity of both limbs The main source of recharge is diffuse infiltration, karst water joins a main conduit system at the foot of the anticline, parallel to the strike, extending from the high elevation plunge apex and leading to the plunge apex related to the local base level. As the main conduit system gets close to the discharging plunge apex, it collects more water from the limb area. The karst water emerges as Saruchawa spring or flows to adjacent alluvium Fig. (3.8).

2. Karst Water Discharge from Limbs (NL)

Makook anticline was taken as a good example for this type. The presence of Sarmord Formation causes the emergence of two springs at the northern lime of Makook anticline which are Betwata and Shkarta Fig. (3.8). Karst water of the limb area joins the main conduit system parallel to the strike at the foot of the anticline .Each limb may be only one subaquifer with one interconnected main conduit system at the foot of the anticline with numerous overflow discharge zones, or it may consist of several subaquifers with independent conduit systems.

B) Northern and Southern Limbs are Connected

In this situation karst water of one of the anticline limbs (the donor limb) flows towards the adjacent limb (receiver limb) either through a restricted number of link areas or all along the anticline. After the transfer of karst water to the receiver limb, the flow patterns are similar to anticlines which have no connectivity between limbs. For this reason, the group is further classified into four similar subgroups as the cases with separate limb hydraulic Fig. (3.8).

1. Karst Water Discharges only from one Limb of the Anticline (CL)

Pelewan anticline is the type case of this subgroup Fig. (3.8). The core of anticline consists of the Jurassic Formations surrounded by impermeable Sarmord Formation. The geological setting indicates the northern limb is higher than the southern limb. The karst water of the northern limb flows towards the foot of the southern limb and emerges as Qulai Kanimaran spring in contact with alluvium, a part of this alluvium which located above the outlet of the spring has water supply contribution to it. The karst water of the northern limb flows towards the foot of the southern limb.

2. Groundwater Discharges from a Combination of Limb, Plunge Apex and River (CN)

A typical example of this subgroup is the Rania anticline Fig. (3.8), which displays a combination of limb and river discharge zones. Karst water of the Rania anticline discharges from three springs on the northern limb and river. The Rania anticline is a long anticline and divided into eastern, central, and western parts. There is hydraulic connectivity between the southern and northern limbs in most parts of the anticlines, in the western part composed of Sarmord and Qamchuqa Formations. In the central part its core is exposed and composed of Jurassic rocks, while in the eastern part it is composed of Quaternary and part of them is submerged by Dokan Lake.

Water discharging at the core of the anticline which is collected from both limbs of the anticline as karst springs flowing to the adjacent alluvium. A part of this alluvium which located above the outlet of the spring has water supply contribution to it. The Qulai Rania and Kwera Kani springs are examples of this situation as some of this water is moving toward the Lesser Zab river ,Qulai Darband spring is a good example of such situation.

3.16 Time Series Analysis of Main Springs Discharges

3.16.1 Stochastic Properties of Time Series

3.16.2 Theoretical background

Time series, a common term in hydrologic studies, is simply a series of a time-dependent hydrologic variable such as the flow rate of a stream or a spring. When analyzing a time series in practice, we deal with a limited amount of recorded data sample. This sample, regardless of its size (e.g., one or one hundred years of data), consists of a limited number of realizations (one or hundred) of the same hydrologic event (Kresic, 1997).A time series can be continuous (such as the flow rate of a perennial stream) or discrete (such as daily precipitation). For practical and computational purposes, most continuous time series are converted into discrete time series by introducing the recording (or modeling) time interval - 1 day, 1 week, 6 hours or so.

A good example is a time series of monthly precipitation at a certain location in a moderate climate. Our long-term experience can tell us that, for example, April through June is the wet period, and July through September is the dry period of the year. Accordingly, we can with a high probability, expect that in the near future (say, next year) these two periods will again last about the same time. However, no one can state with 100% accuracy that this will indeed happen (for example, June may be an unusually dry month next year). In addition, it is impossible to accurately predict the annual or monthly amount of precipitation using some physical laws of nature.

We can only apply tools of statistics and make predictions about the future using probabilistic models based on past data. A time series studied in this way is called a *stochastic time series*, its parameters described with statistic, and probabilistic terms are called stochastic parameters (properties).If the chosen mathematical function ignores the physical laws that govern the transformation of input (s) into output (s), the model is a *pure stochastic* one. If, in any form, the mathematical function incorporates physical laws, the model is called a *stochastic-conceptual model*. In groundwater studies, we can use three types of conceptual models (Rahnemaei et. al, 2005):

1- *Continuum model*: this assumes that the aquifer acts similar to porous media (alluvium).

2-*Discrete model*: assumes water flows more in fractures and separate conduits

3- *Dual porosity model*: it attempts to characterize groundwater flow in individual conduits or fractures as well as in the matrix portion of the aquifer

Stochastic models can be used to:

1-predict the frequency of occurrence of a certain hydrologic variable (for example, the maximum water table elevation).

2- Issue a short-term forecast with confidence limits (for example, with 90% accuracy we state that the flow at the spring will be (3.5 m^3/s tomorrow).

3- Extend a short time series using correlation with another time series that has a longer recording period (an example would be the extension of the "recording" period at one gauging station using data from nearby stations that were operating longer).

4-Generate a synthetic time series to study the characteristics of a hydrologic variable (for example, a stochastic model can generate several thousand time series of the flow in a river which can then be used to find probability of occurrence of a 10,000-year flood).

A very important factor that limits a wider use of stochastic models in hydrogeology is the lack of recorded data. Since these models are based on statistical and probabilistic calculations, very short time series do not allow for meaningful derivation of model parameters. One of the techniques often used is multiple (linear) regression. If a hydrologic system of interest is not linear, an attempt is usually made to linearize the corresponding time series and use linear rather than more complicated non-linear regression. For example, the impact of precipitation on groundwater levels is more or less delayed and attenuated by porous medium. Accordingly, the influence of antecedent precipitation may be more important for today's water table elevation than yesterday's rainfall. A simple operator (function) applied to precipitation data, such as the moving average, can significantly improve the stochastic model in such cases (Kresic, 1997).

3.16.3 Autocorrelation

Autocorrelation is the correlation between successive values of the same variable. Fig. (3.9) illustrates its principle.

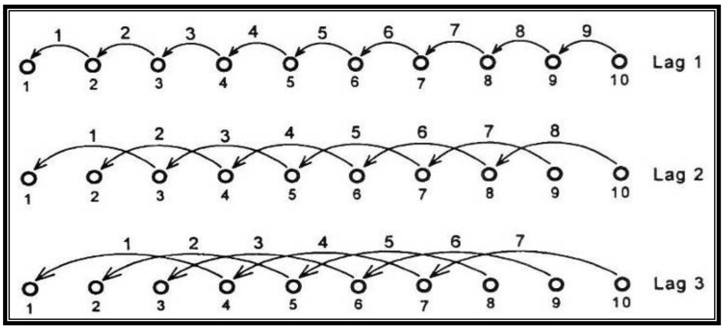


Fig. (3. 9) Principle of Autocorrelation for a Sample of a Discrete Time Series. For lag 1 the Number of Pairs in Autocorrelation is N-l (10-1=9). For lag 2, this Number is 8, for lag 3 it is 7 and so on.

If a hydrologic variable is measured on a daily basis (as is the spring discharge in our case), for lag 1 autocorrelation we pair values recorded at days 1 and 2, days 2 and 3, days 3 and 4, and so on. The number of pairs in the autocorrelation is N-l where N is the number of data. For lag 2 we pair days 1 and 3, days 2 and 4, and so on. Consequently, the number of pairs in correlation decreases again and is N-2 (Kresic, 1997). Autocorrelation is measured by the autocorrelation coefficient, also called serial correlation coefficient, whose estimate for any lag k is(Kresic, 1997):

$$r_k = \frac{\frac{1}{N-k}\sum_{i=1}^{N-k}(x_i - \bar{x})(x_{i+k} - \bar{x})}{\frac{1}{N}\sum_{i=1}^{N}(x_i - \bar{x})^2} \quad \ldots\ldots\ldots\ldots (3.10)$$

Where

N: is the total number of data in the sample,

x_i :is the value of the variable (spring discharge in our case) at time t=i,

x_i +k: is the value of the variable at time t=i+k,

$\bar{x}$:is the average value of the sample.

The autocorrelation coefficient is in practice estimated from a sample, for small sizes, the variance will change for different lags and the following equation is accurate estimate of the autocorrelation coefficient:

$$r_k = \frac{\sum_{i=1}^{N-k} x_i . x_{i+k} - \frac{1}{N-k}(\sum_{i=1}^{N-k} x_i)(\sum_{i-1}^{N-k} x_{i+k})}{[\sum_{i=1}^{N-k} x_i^2 - \frac{1}{N-k}(\sum_{i=1}^{N-k} x_i)^2]^{1/2} . [\sum_{i=1}^{N-k} x^2{}_{i+k} - \frac{1}{N-k}(\sum_{i=1}^{N-k} x_{i+k})^2]^{1/2}} \ldots\ldots\ldots (3.11)$$

r_k can have values between 1 and -1. For lag 0 it is always 1 since the correlation between two completely identical samples is "absolute".

Autocorrelation coefficients are calculated for various lags and then plotted on a graph called autocorrelogram. The number of lags (autocorrelation coefficients) should be approximately 10 % of the total number of data for smaller samples. For large samples, such as daily values over one or several years, the number of lags can be up to 30 % (Kresic, 1997).

If there is some predictability from the past of a series to its present values, the series is autocorrelated. Terms that are also often used to describe an autocorrelated series are persistence and memory. If a series is not autocorrelated it is called independent (i.e., persistence is absent; the series is without memory). The hypothesis that a time series is dependent (autocorrelated) is tested by various statistical tests. One of the simpler tests is proposed by Bartlett (Gottman, 1981 sited in Sahu, 2004). To be significantly different from zero at the level of confidence 0.05 (i.e., with 95% probability), the autocorrelation coefficient must exceed $2/\sqrt{N}$.

$$r_k > \frac{2}{\sqrt{N}} \ldots\ldots\ldots\ldots (3.12)$$

Where N is the total number of data in the sample. This test is in hydrologic practice often performed just for the first, or the first two lags, which is not recommended. It is more correct to perform a test for the entire correlogram introducing limits of confidence. This may uncover possible delayed or periodic components in the time series that would otherwise be considered as independent if, say, lag 2 was found to be not significantly different from zero.A test proposed by Anderson gives limits of confidence for the entire correlogram (Kresic, 1997, Samani, 2001):

$$LC(r_k) = \frac{1 \pm Z_a.\sqrt{N-k-2}}{N-k-1} \;........... \;(3.13)$$

Where

N: is the sample size, k is the lag,

Z_a is the value of the normally distributed standardized variable at the (α) level of confidence. Values of Z for various levels of confidence can be found in statistical tables and those used most often are given in table (3.8).

Table (3.8) Values of Z for the Most Often Used levels of Significance a (Spiegel and Meddis, 1980 sited in Kresic, 1997).

Level of significance α	0.10	0.05	0.01	0.005	0.002
Z level for one-tail set	1.28±	1.645±	2.33±	2.58±	2.88±
Z level for two-tail set	1.645±	1.96±	2.58±	2.81±	3.08±

3.16.4 Cross-Correlation

The principle of cross-correlation is illustrated in Fig. (3.10) where daily spring flow is represented by the Y series and daily precipitation by the X series. In this case, Y is the dependent variable (it is influenced by X) and it lags behind X.

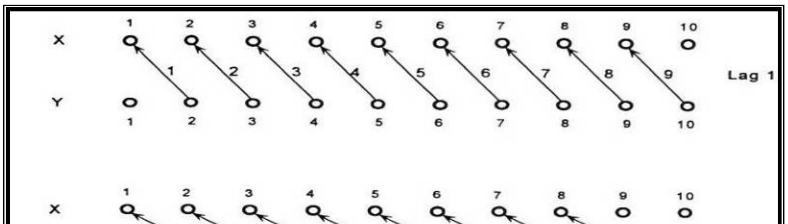


Fig. (3.10) Principle of Cross-Correlation between two Discrete Time Series Medium

The time-dependent relationship between the two series is analyzed by computing coefficients of cross-correlation for various lags and plotting the corresponding cross-correlogram. The cross-correlation coefficient for any lag k is given as (Sahu, 2004):

$$r_k = \frac{COV(x_i, y_{i+k})}{(VAR_{xi}.VAR_{yi})^{1/2}} \text{ .... } (3.14)$$

In practice, it is estimated from the sample using the following equation:

$$r_k = \frac{\sum_{i=1}^{N-k} x_i . y_{i+k} - \frac{1}{N-k}(\sum_{i=1}^{N-k} x_i)(\sum_{i-1}^{N-k} y_{i+k})}{[\sum_{i=1}^{N-k} x_i^2 - \frac{1}{N-k}(\sum_{i=1}^{N-k} x_i)^2]^{1/2} . [\sum_{i=1}^{N-k} y^2{}_{i+k} - \frac{1}{N-k}(\sum_{i=1}^{N-k} y_{i+k})^2]^{1/2}} \text{ .... } (3.15)$$

3.16.5 Simple Spectral Analyses

Simple spectral analysis is complementary to correlation analysis. The spectral density function corresponds to a change from a time mode to a frequency mode through a Fourier transformation of the auto-correlation function. The interpretation of the spectral density function, S (*f*), through the identification of the different peaks representing periodical phenomena, leads to the characterization of the system. In the case of an infinite series, Jenkins and Watts (1968) show that the spectral density is:

$$S(f) = 2\left[1 = 2\sum_{k=1}^{m} D(k) r(k) \cos(2\pi fk\right] \text{ .... } (3.16)$$

$$D(k) = \frac{\left(1 + \cos \pi \frac{k}{m}\right)}{2} \text{ .... } (3.17)$$

Where *f*=j/2m, j = 1 to m, *f* is the frequency in cycles per day and D(k) ensures that the S(*f*) estimated values are not biased. If the time series, such as precipitation or discharge, contains distinct periodic terms, the spectral density of these terms will appear as high and sharp peaks in the estimated spectrum (Samani, 2001).

3.16.6 Cross-Spectral Analyses

The cross-spectral density function, $S_{xy}(f)$, corresponds to the Fourier transformation of the cross-correlation function. It is expressed as a function of the cospectrum, $h_{xy}(f)$ and the quadrature spectrum, $\lambda._{xy}(f)$. The asymmetry of the cross-correlation function makes it necessary to express the spectral-density function with a complex number (Sahu, 2004).

$$\lambda_{xy}(f) = 2\left[r_{xy}(0) + \sum_{1}^{m} (r_{xy}(k) + r_{xy}(k))D(k)\sin(2\pi fk) \right] \text{...........} \quad (3.18)$$

Various functions may be derived from the cross spectrum among which the amplitude, phase, coherence and gain functions were used for this study.

3.16.7 Amplitude

In polar coordinates, the cross-spectrum can also be expressed as a function of the amplitude| S_{xy} (*f*) |and phase $\theta_{xy}(f)$:

$$S_{xy}(f) = \left| S_{xy}(f) \right| e^{-i\theta xy(f)} \text{...........} \quad (3.19)$$

From the standpoint of its application to hydrologic series in general and this study in particular, the *cross-amplitude function*, $\left| S_{xy}(f) \right|$, can be associated with the duration of the impulse response function, and indicates the filtering of the periodic components of the input signal, precipitation or recharge for example. This function characterizes the modulating effect of the aquifer in the short, medium and long term, and with respect to the purpose of this study, contains information about the aquifer properties. In the frequency domain, it represents the input-output covariance (Box and Jenkins, 1976, Sahu, 2004).

3.16.8 Coherence and Gain Functions

The coherence function shows whether the input series contains the same type of periodic components in the output series, and thereby indicates the correlation between the periodic variables. It is expressed as:

$$CO_{xy}(f) = \frac{S_{xy}(f)}{\sqrt{S_x(f)S_y(f)}} \text{...........} \quad (3.20)$$

The plot of coherence function against frequency is the coherency diagram. The values of COxy vary between unity and zero, where unity indicates that the two series are fully dependent, and zero shows two independent series (Sahu, 2004, Panagopoulos and Lambrakis, 2006).The gain function expresses an amplification (>1) or an attenuation (<1) of the output signal in comparison with the input signal. In a karstic environment, this phenomenon can be related to the storage of water during the high rainfall period and the release of water during the dry period (Padilla, et al., 1995):

$$g_{xy}(f) = \frac{S_{xy}(f)}{S_x(f)} \quad \ldots\ldots\ldots\ldots \ (3.21)$$

A (STATISTICA) version 6. software was used to calculate these statistical parameters.

The objective of applying this method is to test whether the mentioned statistical parameters analyses are valuable tools when used with spatially distributed time series data such as discharge hydrographs and precipitation data, which provides valuable information on the hydrodynamic characteristics of the aquifer, hydrogeology, aquifer boundaries, transmissive properties (e.g., the time lag and attenuation between input and output) , specific storage , porosity of the aquifer, flow regime, recharge extent of karstification degree, and infiltration velocity through fractured hard rocks (Sahu, 2004, Rahnemaei, 2005, Ali, et al., 2007). The available data were the results of one year (2002) of monitoring discharge (done by FAO) of four springs which are (Saruchawa, Qulai Kanimaran, Ganau, and Qulai Rania springs). For the study, the following two sets of data were analyzed:

(a) Daily precipitation data monitored at Dokan Dam weather station.
(b) Daily discharge data (one water year 2002).

3.17 Results and Discussion

3.17.1 Relationship between Precipitation and Springs Discharge

The relationship between precipitation (the system input) and springs discharge (the system output) Fig. (3.11) is of great interest because precipitation is readily measured and springs discharge is the variable of interest for management and springs vulnerability assessment. At the sections below will show, the two time series contain much information about the spring’s system.

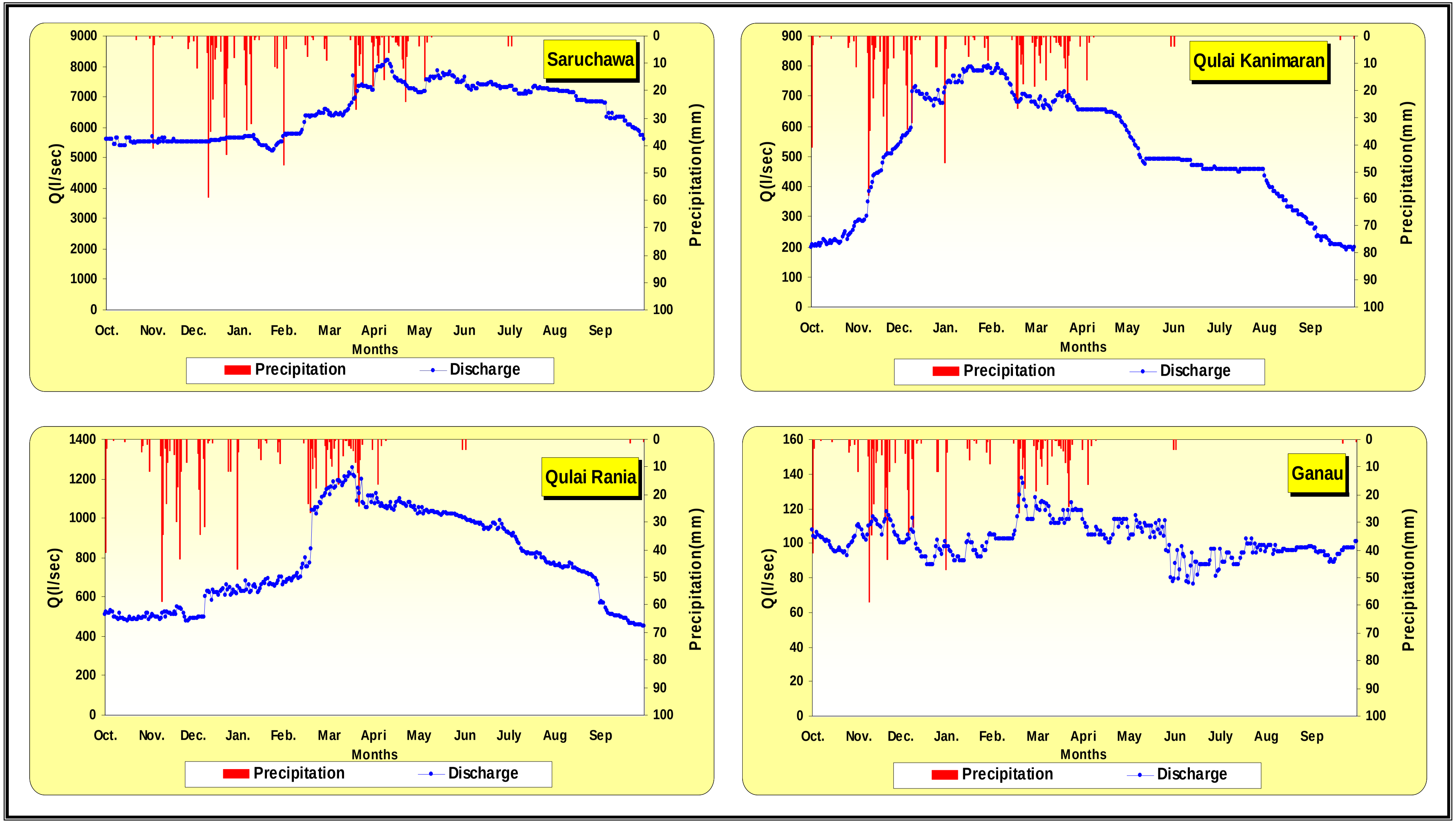


Fig. (3.11) Relationship between Discharge for the Main Springs and Precipitation

3.17.2 Auto-Correlogram

The autocorrelogram exceeds the confidence limits for approximately (85, 60, 35, and 82) days for (Saruchawa, Qulai Kanimaran, Ganau, and Qulai Rania) respectively Fig. (3.12) indicating that the autocorrelation coefficients for this period are significantly different from zero and that the process of springs discharge is not independent. In other words, the system has a long memory except for Ganau spring, with dominant large channels and relatively poorly developed matrix porosity, and has a low storage. A physical explanation is that the aquifer storage is significant and that it releases water gradually (Jemco, 2006, Panagopoulos and Lambrakis, 2006, Ali, et al., 2007). This may also indicate that the network of fine fissures and possibly the matrix porosity are the main constituents of effective porosity. In addition, the very slow decline of the autocorrelograms show a relatively stable discharge regime, conditioned by the limited dimensions of the karst channel and revealing the presence of periodic component, also it concluded that the flow regime is of diffuse type.

3.17.3 Cross-Correlogram

Cross-correlograms for spring flow and precipitation are statistically insignificant for the (Saruchawa, Qulai Kanimaran, and Qulai Rania) springs Fig. (3.12) which indicates the antecedent precipitation beyond this period has no direct influence on stream discharge. For the Ganau spring, cross-correlation shows a very minor level of significance from 3 to 9 days which is due to direct precipitation on the area of spring lake, but after that changes are insignificant. Low cross-correlation values for both of these springs show that the influence of infiltration is significantly attenuated by the porous media (Jemco, 2006). Dynamic resources are the consequence of a significant role of matrix porosity (slow subsequent water release following desaturation of larger fractures). Additionally, the presence of storage in the epikarstic zone certainly has a great influence on karst hydrogeological system behavior. Regarding the potential for groundwater tapping based on ‘‘ ’’ of deeper inflow of runoff water from precipitation to the area of the lake which formed by the spring.

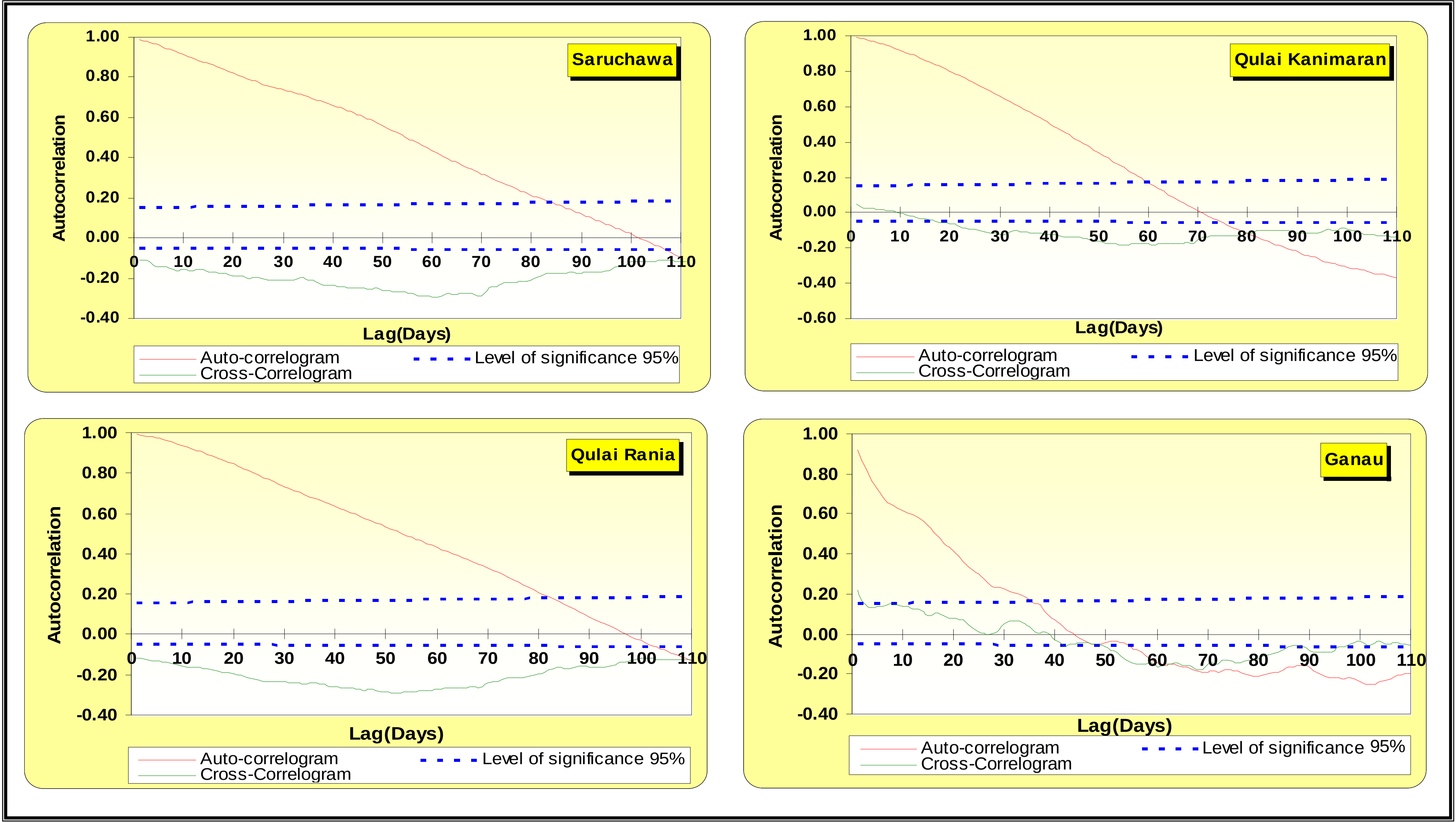


Fig. (3.12) Auto-Correlogram and Cross-Correlogram for the Main Springs

3.17.4 Spectral Density Function

The spectral density function of the springs discharge exhibits its highest peak at low frequencies (0.0028, 0.0028, 0.0055, and 0.0028) cycles per day, equivalent to (364, 364, 182, and 364) day periodicity for (Saruchawa, Qulai Kanimaran, Ganau, and Qulai Rania) respectively Fig.(3.13). This confirms the presence of a seasonal recharge and discharge cyclicity for all springs. Considerable peak at the middle frequencies (about 17 days) for Ganau spring show relatively low densities. This analysis confirms the existence of inflow of runoff water from precipitation to the area of the spring lake which formed by the spring.

3.17.5 Cross-Amplitude Function (CAP)

The cross-amplitude function (CAP) relating precipitation and discharge Fig. (3.14) shows a clear decrease in the middle and high frequencies in favor of the low ones. The system notably filters the input signal (precipitation) at higher frequencies (above 0.1, 0.1, 0.17, and 0.13 or periods of less than 10, 10, 6, and 7.5 days) for (Saruchawa, Qulai Rania, and Qulai Kanimaran) respectively Fig. (3.14) and there is a significant increase in the signal at low frequencies. Many times the function approaches near zero, for the above frequencies, but never vanishes. When the amplitude function of a time series data becomes noticeable or positive at higher frequencies, it indicates the presence of a quickflow component in the system; whereas a zero or near zero amplitude function or one that approaches zero indicates a baseflow component. This phenomenon indicates that there is a quick flow component inside the aquifer system, although there is also a noticeable base flow component.

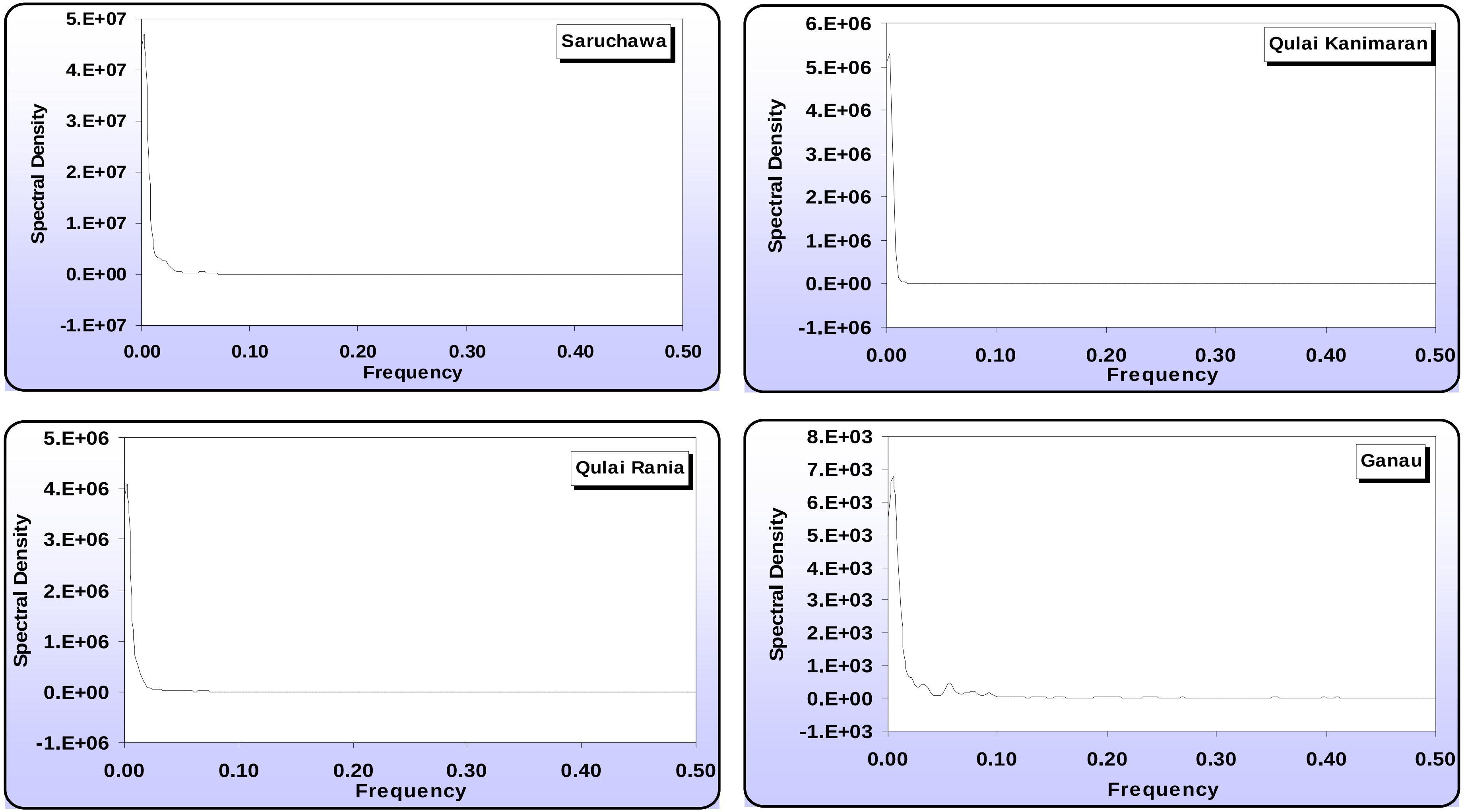


Fig. (3.13) Spectral Density for the Main Springs

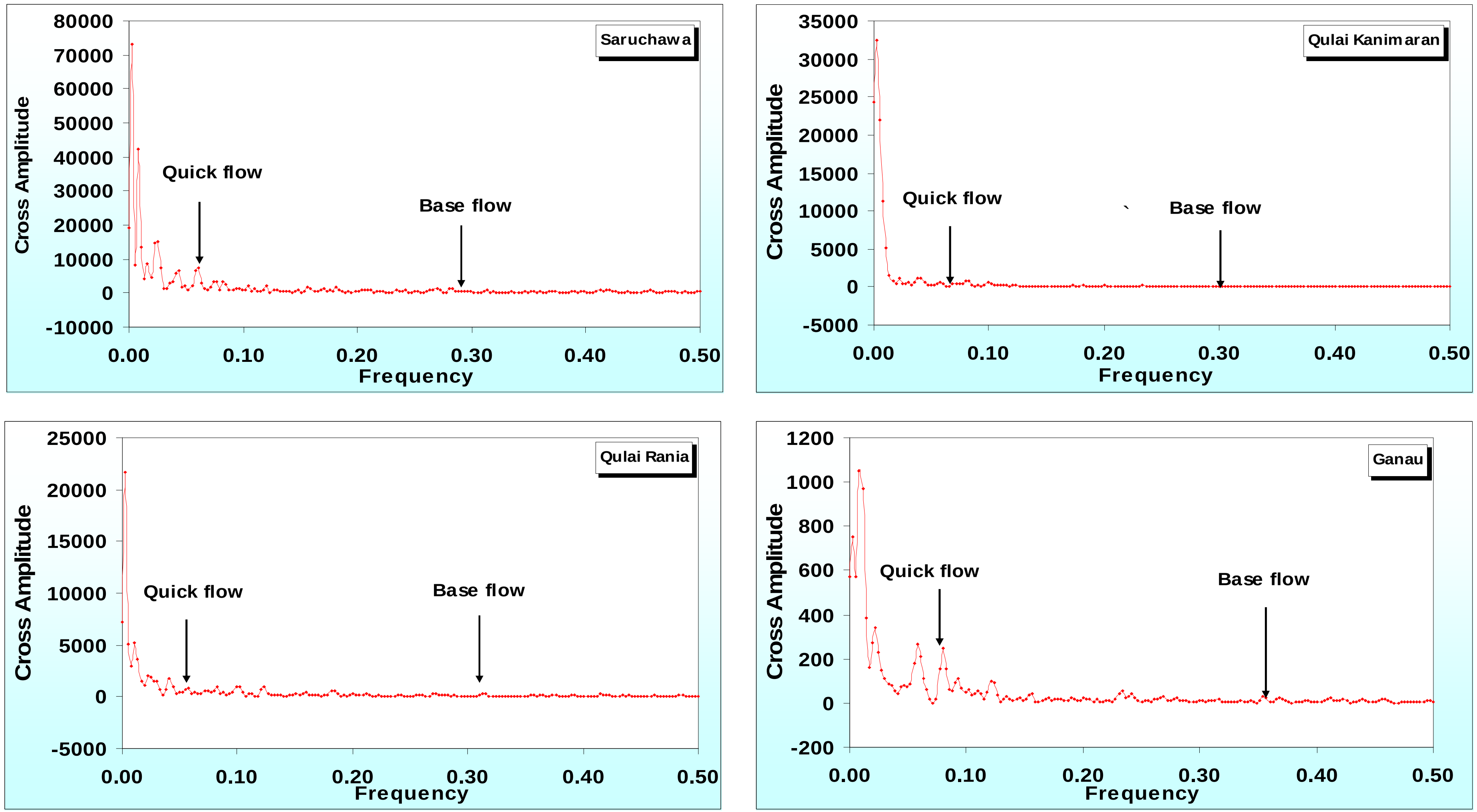


Fig. (3.14) Cross-Amplitude for the Main Springs

3.17.6 Gain Function (GAP)

The strong filtering of the input signal can also be seen from the gain function (GAP) Fig. (3.15). The frequency corresponding to a gain of 1 represents the duration of baseflow in the aquifer, and the frequency for which the gain begins to take values of less than 0.4 corresponds to duration of the quick flow (Padilla et al., 1994). Values between 1 and 0.4 are considered to be intermediate flow, i.e. having characteristics between baseflow and quickflow.

In a karst aquifer, the level of amplification of the input signal is related to the delay. The signal is attenuated when the discharged water comes with a lower delay from the release of storage water. The observed attenuation is another indication of the aquifer's small to moderate storage capacity, for (Ganau and Qulai Kanimaran).The low storage of the system could be explained by the presence of many large tunnels which directly contribute to the aquifer discharge and low effective porosity. In contrast, the results for (Saruchawa, and Qulai Rania) is showed that there is a quick flow and there is no attenuation, therefore it’s a good indication for large storage capacity.

3.17.7 Coherence Function (COF)

The coherence function (COF) Fig. (3.16) shows less consistency between the input (precipitation) and output (discharge) signals. The presence of different coherence at different frequencies is consistent with the existence of both quick flow (high coherence) and base flow (lower coherence) components in the system. The high coherence at low frequencies is expected, as seasonally high rainfall is likely to be associated with seasonally high discharge. The highest coherence function observed between precipitation and discharge is (0.95, 0.93, 0.91, and 0.83) (Saruchawa, Qulai Kanimaran, Ganau, and Qulai Rania) respectively. On the basis of statistical parameters and physical properties of springs ,and with reference to (Jacobson and Langmuir, 1974) the flow regime of Ganau and Qulai Kanimaran is diffuse flow (low portion) and conduit flow (high portion), and Saruchawa,Qulai Rania is diffuse flow (high portion)and conduit flow (low portion). With regard to water electrical conductivity each of the above spring is belong to different aquifer system due to variations of (EC) values which are (540, 514, 2000, and 614 μs)for (Saruchawa, Qulai Kanimaran, Ganau, and Qulai Rania) respectively.

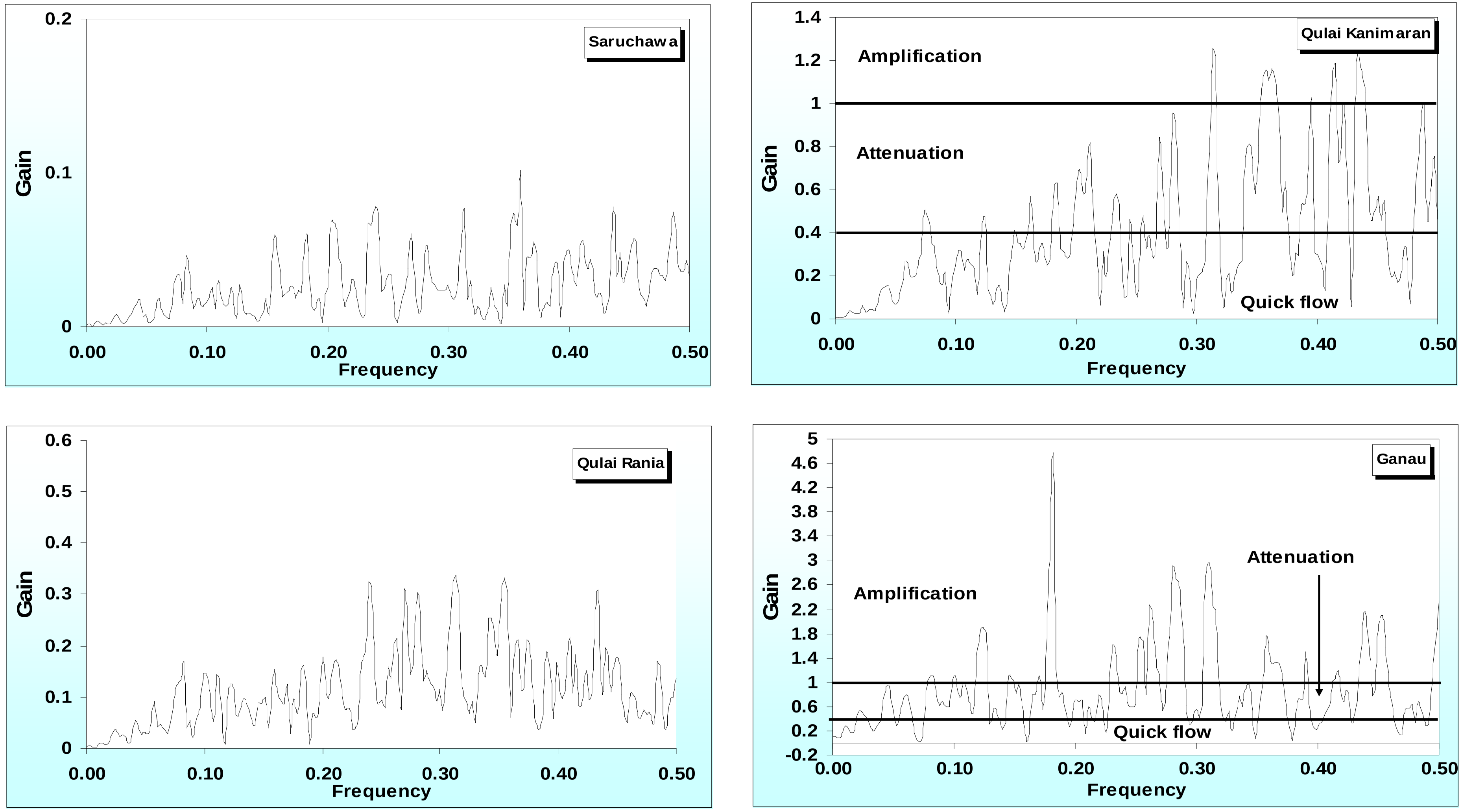


Fig. (3.15) Gain Function for the Main Springs

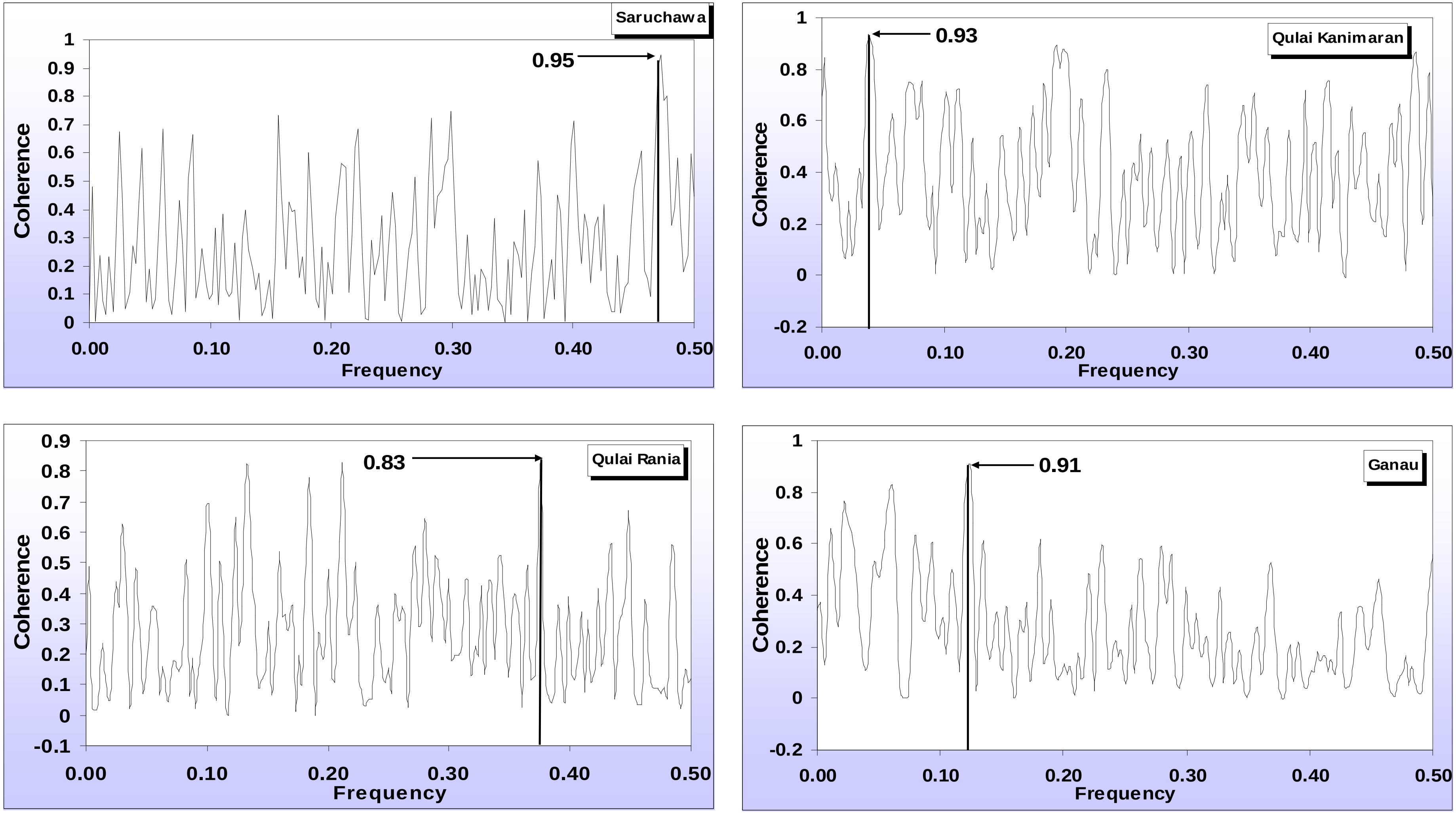


Fig. (3.16) Coherence Function for the Main Springs

CHAPTER FOUR
ENVIRONMENTAL ISOTOPES

Environmental Isotopes

4.1 Environmental Isotopes

Environmental isotopes (^{18}O and/or ^{2}H) are particularly suitable for tracing the origin of water in the hydrological cycle because they are constituents of water molecules and do include isotopes introduced into the system artificially. The environmental isotope tracers, in combination with conventional hydrological methods, provide additional information on investigated systems. For instance, they serve for determining the origin of water, the storage properties; water dynamics, or relations between surface and groundwater, migration of water such as travel times and groundwater, groundwater pollution (IAEA, 1993, Clark and Fritz, 1997, Mook and Vries, 2001, Aggarwal, et al., 2005). The isotope data can quantitatively be interpreted only with the aid of adequate mathematical models.

4.2 General Review of Environmental Isotopes

4.2.1 Stable Isotopes

Isotopes of the same chemical element have almost identical physical and chemical properties. However, because of their small mass differences, they have different reaction rates and different abundances in two chemical compounds or phases that are in isotopic exchange. Also physical processes such as diffusion, evaporation, condensation, melting, etc. produce isotopic differentiation. All these variations in the isotopic composition, produced by chemical or physical processes, in compounds or phases, present in the same system, are called ***isotopic fractionation*** (Clark and Fritz, 1997). The atomic ratio R of the less frequent to the abundant isotope changes of a sample (spl) is usually determined by mass spectrometer and expressed as delta value (**δ**) referring to a certain reference material (standard, std) (Clark and Fritz, 1997):

$$\delta = \frac{R_{sp1}}{R_{sdt}} - 1 \qquad (\times 1000\ \text{‰})\ldots\ldots\ldots\ldots\ (4.1)$$

The most important atomic constituents of the water molecule are (^{16}O, ^{18}O), and (^{1}H, ^{2}H). These have the widest field of application in groundwater studies, for instance, tracing the origin of the water, the mode of recharge of groundwater, determining the age (short-term due to the seasonal variation and long-term due to the distinction between Holocene and Pleistocene groundwater. One has to keep in mind that the ^{18}O value is very small and ‰ is no unit, ‰ means 1 over 1000. Hence, the delta values are always smaller than 1, although numbers in connection with per mill, e.g. 25‰, are large: 25‰ is equivalent to 0.025 (Mook and Vries, 2001).

4.2.2 Stable Isotopes of Water

Stable oxygen (^{16}O & ^{18}O) and hydrogen (^{1}H & ^{2}H) isotopes are highly effective tracers of mixing between different water sources because they constitute and move with water molecules. The different masses of the water molecule species causes them to have different reaction rates, which can lead to isotopic fractionation as water cycles through the environment (Aggarwal, et al., 2005). Oxygen and hydrogen isotope data are generally reported in delta (ä) notation in parts per thousand (‰) relative to the standard VSMOW (Vienna Standard Mean Ocean Water (Clark and Fritz, 1997). The ä ^{2}H and $\delta^{18}O$ signatures of continental rainfall derived from oceanic moisture generally correlate with the straight line relationship (Craig, 1961a) referred to as the Global Meteoric Water Line (GMWL) which is the relation between the ä H^{2} and ä O^{18} values of precipitation from various part of the world (eq.4.2 and Fig.4.1). Water with less deuterium than VSMOW has a negative δD and is isotopically depleted with respect to the standard, whilst water with more deuterium than VSMOW has a positive δD and is considered isotopically heavier than the standard (Gardi, 2002). A similar relationship applies to $\delta^{18}O$.

The variation is useful for interpreting the origin of the water, or the type of water/rock interaction that has occurred along the flow path.

$$\delta^{2}H = 8.13 \times \delta^{18}O + 10.8 \qquad ‰,\ VSMOW \ldots\ldots\ldots\ (4.2)$$

Craig's line is only global in application, and is actually an average of many local or regional meteoric water lines which differ from the global line due to varying climatic and geographic parameters. Local meteoric water lines (LMWL) will differ from the global line in both slope and deuterium intercept. Nonetheless, Craig's paper is perhaps the most often cited in environmental isotope hydrology as his global meteoric water line (GMWL) provides a reference for interpreting the provenance of ground waters.

A key observation made by *Craig* was that isotopically depleted waters are associated with cold regions and enriched waters are found in warm regions. This partitioning was soon recognized as a tool for characterizing groundwater recharge environments, and is now the basis of groundwater provenance studies (Mook and Vries, 2001).

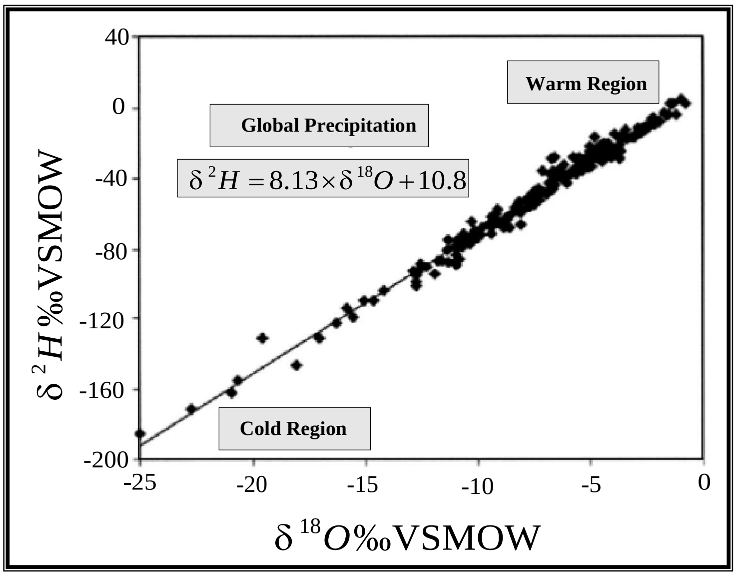


Fig. (4.1) the Meteoric Relationship of ^{2}H and ^{18}O (After Craig, 1961a in Clark and Fritz, 1997)

The isotopic abundance is generally reported as the deviation of the isotopic ratio of a given sample (spl) relative to that of a *standard* (std), for example for (O) defined as follow (Alsaaran, 2006, Chen, et al., 2006):

$$\delta^{18}O = \frac{{}^{18}O/{}^{16}O_{(sample)} - {}^{18}O/{}^{16}O_{(standard)}}{{}^{18}O/{}^{16}O} \times 1000\ ‰ \ldots\ldots\ldots\ldots (4.3)$$

Most freshwaters have negative values (‰) tracers.

Moisture recycling by evaporation causes differential enrichment in ^{2}H and ^{18}O causing water to deviate from the GMWL (equation). Deuterium excess is an index (*d excess*, equation, (Dansgaard, 1964) often used to identify different sources of evaporated water by way of departure from the GMWL. The *d excess* ! of the GMWL is 10 (equation).

$$d - excess = \delta^2H - 8 \times \delta^{18}O \ldots\ldots\ldots\ldots (4.4)$$

Interaction between surface water and groundwater can often be traced using the stable isotopes of water because water that remains at the surface for any length of time is usually subjected to evaporation and is consequently enriched in ^{2}H and ^{18}O relative to groundwater. The stable isotopes of the water molecule can also be useful for distinguishing the sources of surface water following a storm. Potential sources include overland flow, through flow, and groundwater discharge, different sources of groundwater may have characteristic isotopic signatures depending on the altitude where recharge occurred (Aggarwal, et al., 2005).

Water which is recharged in arid or semi-arid regions can have long residence times in the top few meters of soil. Kinetic effects by vapor diffusion can be greater during extensive evaporation from the unsaturated zone than evaporation from surface water (Epstein, et al.,1953, Gammons,et al., 2005). Therefore, evaporation from the unsaturated zone and the water table is often characterized by stronger evaporative enrichment with a lower slope. Allison *et al.* (1984) showed that groundwater recharged under such conditions of direct infiltration often have a δ ^{18}O-δ ^{2}H composition that plots below, but parallel to the meteoric water line. The rate of evaporation from bare soil surfaces can be calculated from the shape of the isotope profile.

4.3 Rainout Effect

In precipitation, the initial liquid phase of rain is enriched in ^{18}O and ^{2}H as compared to the later precipitation. Consequently, in rain events, the precipitation gets lighter as the rain continues, a phenomenon known as "rainout effect" or "amount effect" Fig.(4.2) Similarly, the center of a large land mass or continent has precipitation that is depleted in ^{18}O and ^{2}H, a phenomenon known as the "continental effect." Isotopically enriched rain forms and falls from a diminishing vapor mass, and the residual vapor becomes isotopically depleted with respect to earlier rains from the same cloud (Sahra, 2006). Rainout consequently evolves to colder, isotopically-depleted precipitation: cold climates plot at the depleted end of the GMWL and warm environments plot at the upper end (Sahra, 2006).

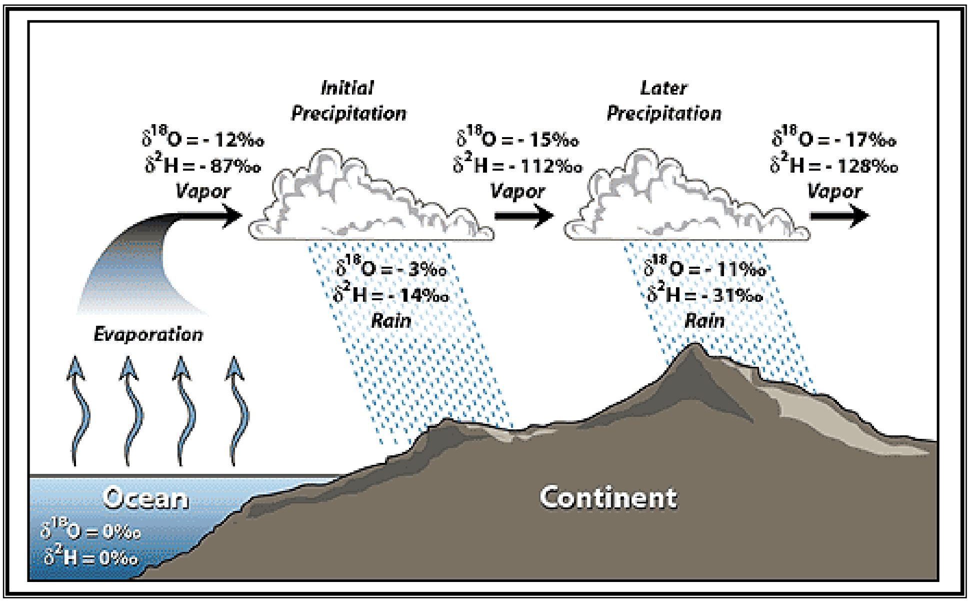


Fig. (4.2) Rainout Effect on δ^{2}H and δ ^{18}O Values (Based on Hoefs, 1997 and Coplen et al., 2000)

This progressive depletion of ^{18}O and ^{2}H is typically described using a Rayleigh distillation. The Raleigh equation applies not only to the temperature-isotope evolution during rainout, but the progressive partitioning of heavy isotopes into a water reservoir as it diminishes in size (Gupta et al., 2005):

$$R = R_o f^{(a-1)} \quad \text{...........} \ (4.5)$$

Where (Ro) is the initial isotope ratio, (R) is the ratio after the process occurs, (f) is the residual component, and (a) is the equilibrium fractionation factor.

4.4 Oxygen ($^{18}O/^{16}O$) and Hydrogen ($^{2}H/^{1}H$)

4.4.1 Physical Fundamentals

Oxygen has three stable isotopes, ^{16}O (99.76 %), ^{17}O (0.04) and ^{18}O (0.2 %), the isotope ratio $^{18}O/^{16}O$ is the ratio, which is normally determined in Oxygen isotope. $\delta\ ^{18}O$ values show natural variation of about 100 ‰, half of this range occurring in meteoric water, it is often enriched in saline lakes and have a high degree of evaporation, while high altitude and cold climate precipitation are depleted in $\delta\ ^{18}O$ ‰ (Mook and Vries, 2001). Generally in the hydrological cycle in temperate climates the range of $\delta\ ^{18}O$ values does not exceed 30 ‰. Natural variation of the oxygen isotopic composition of water, when combined with hydrogen isotopes, can be used for determining precipitation sources as well as evaporation effects. In addition the oxygen isotope ratio of solid phases (e.g. carbonate minerals) can record paleoclimate and paleohydrologic information. Those of hydrogen, ^{1}H (99.9844 %) and ^{2}H (or deuterium; D) (0.0156 %), combine and produce water molecules of differing molecular mass between 18 and 22, of which the most abundant are $^{1}H_2\ O^{16}$, $^{1}H\ ^{2}H\ ^{16}O$, and $^{1}H_2{}^{18}O$. As constituents of the water molecules, they can act as conservative. As with ^{18}O, high ^{2}H concentrations are observed in strong evaporated surface water, while low ^{2}H contents are found in polar ice. Variations of bout 250 ‰ are present in certain parts of the hydrological cycle. (Faure, 1986, Clark and Fritz, 1997, Mook and Vries, 2001, Al-Zubi, 2000)

4.5 Processes that Affect Stable Isotopic Composition of Water

There are deviations from the meteoric water line (MWL) indicating various processes of isotopic exchange and fractionation. The best know examples are departures due to evaporation observed in brines from sedimentary marine aquifers, exchange of oxygen between water molecules and silicate minerals observed in geothermal systems with active exchange of oxygen between water molecules and silicate minerals, and mixing between meteoric groundwaters and fossil residual brines in crystalline rocks. For water, the higher the mass number, the lower vapor pressure. Thus, ^{16}O and ^{1}H preferentially enter the vapor phase, whereas ^{18}O and ^{2}H preferentially concentrate in the liquid phase. Consequently, in evaporation, water vapor is enriched in ^{16}O and ^{1}H, whereas the remaining liquid water is enriched in ^{18}O and ^{2}H. More specifically, $H_2{}^{18}O$ is enriched in liquid water by 1% relative to its concentration in water vapor at the same temperature. Factors such as humidity, salinity, and temperature affect kinetic fractionation of water during evaporation. The lower relative humidity, the faster evaporation rate and the greater kinetic fractionation. Humidity affects oxygen and hydrogen differently such that the slope of the evaporation line will vary due to changes in relative humidity (Clark and Fritz, 1997 ,Hill,1998,and SAHRA, 2006) Fig. (4.3).

There is another process that affects stable isotope which is the *Altitude effect,* since temperature usually decreases with increasing altitude, the delta values will correspondingly drop. Gradients in $\delta\ ^{18}O$ of (-0.15 to -0.40 ‰) /100 m are observed, while the gradients for $\delta\ ^{2}H$ are about 8 times larger. With the aid of the altitude effect recharge areas of spring water can be localized. The elevation of the recharge areas for springs has been estimated from the orographic $\delta\ ^{18}O$ gradient. It is important to note that the hydrogeologically estimated altitude of the catchment is compared with the $\delta\ ^{18}O$ value of the corresponding spring water rather than the altitude of the spring-discharge site (Mook and Vries, 2001).

Continental effect is also another process **.**On their track across a continent clouds produce rain; the heavier molecules preferentially enter the condensed phase. The δ ^{18}O and δ ^{2}H correspondingly decrease towards the interior. Complex isotopic patterns are established that reflect the morphology of the landscape and the pathways of cyclones. Present-day precipitation and palaeowater are isotopically different, insofar as the climatic situation has changed. By the continental effect, diffuse direct recharge of groundwater is distinguished from groundwater recharged in restricted recharge areas (Faure, 1986, Mazor, 1990, Clark and Fritz, 1997).

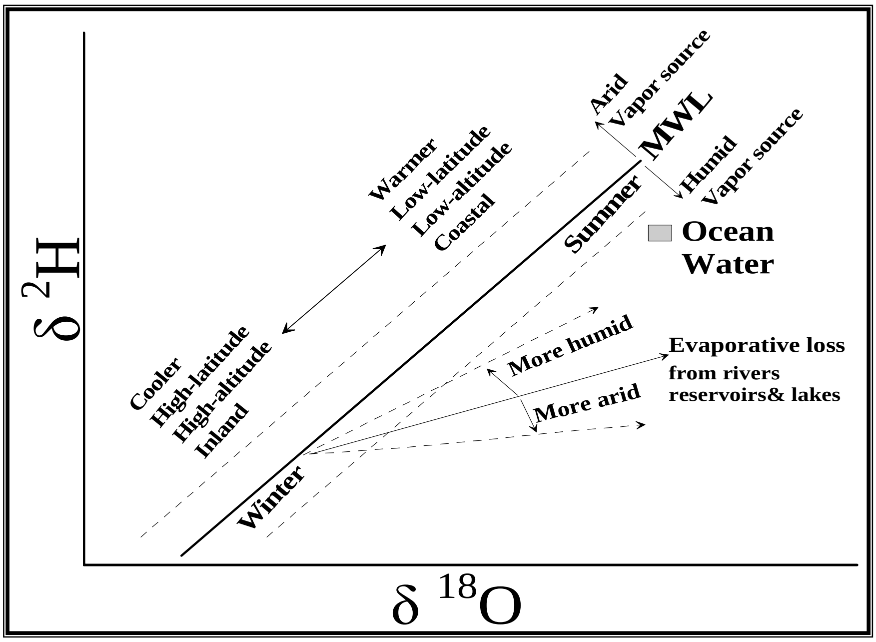


Fig. (4.3) Summary Diagram of How Hydrologic Processes Affect Oxygen and Hydrogen Isotopic Composition of Water (After SAHRA, 2006)

4.6 Isotopic Composition of Precipitation in the Studied Area

The understanding of isotopic composition of precipitation is the key tool for any interpretations of isotopic analysis in hydrological science because one can not simply compare the results with only the (GMWL), which could lead to a big mistake. A local meteoric water line (LMWL) must be constructed by way of analyzing the precipitation monthly in some stations. These analysis were not possible to make in the studied area due to some technical limitations, instead the study of (Mawlood, 2003) which was done on the nearby Erbil - Haji Omran area was of a great aid since both areas are under the same Mediterranean whether system. That study utilized the analyses of (22) groundwater samples and depended, on the two isotopic stations located at Iraq's neighboring countries, Halab station in Syria and Adana station in Turkey. The data of these two stations were extrapolated according to (Rayleigh) isotopic fractionation processes resulting in the equation below for (LMWT). This study has adapted the same equation of (LMWL) for the present studied area knowing that this practice is acceptable and has been applied in many sites in the world where isotopic stations are absent (Gardy,2002,Kortelainen and Karhu,2004, Alsaaran, 2006).

$$\delta^2 H = 8 \times \delta^{18} O + 20 \quad \text{...........} \ (4.6) \qquad \text{(from Mawlood, 2003)}$$

4.7 Isotopic Composition of Groundwater for the Studied Area

The average isotopic composition of the groundwater samples collected at various sites of the study area are summarized together with deuterium excess (d-parameter), altitude temperature and electrical conductivity (EC μS/cm) in table (4.1).

The stable isotope composition of the groundwater wells and springs samples of the study area are characterized by ^{18}O values (-6.27‰ < δ^{18}O < -7.75‰) with average (-7.04), and ^{2}H values (-40.2‰ < δ^{2}H < -32.6‰) with average (-36.56).

Table (4.1) Environmental Isotopes Data of Selected Wells, springs, and Shaoor River for the Studied Area

	Name	Coordinate		Elevation	T°C	EC µS/cm	^{18}O ‰	^{2}H ‰	D-excess ‰
		Lat.	Long.						
Wells	**Azady**	361532	445228	591	13.9	483	-7.36	-38.10	20.78
	Azady 2	361547	445220	599	9.7	476	-7.35	-37.90	20.9
	Sarkabkan	361706	444923	674	15.9	543	-7.05	-36.30	20.1
	Qurgo	361335	445649	540	14.8	506	-6.75	-34.60	19.4
	Rapareen 4	361414	445251	574	18.7	550	-6.63	-33.60	19.44
	Rapareen 1	361442	445255	586	18	536	-7.40	-39.00	20.2
	Bn Zery	361241	444931	550	12.2	390	-7.13	-36.90	20.14
	Hajy Homeran	361257	444938	560	12.3	394	-7.26	-36.90	21.18
	Electric Station	361314	444950	557	12.9	401	-7.09	-37.80	18.92
	Shilanay	361237	444922	544	12.2	390	-7.27	-37.90	20.26
	Tekoshar l	361343	444743	568	15.9	492	-6.91	-35.70	19.58
	Tekoshar 2	361340	444802	582	15.1	447	-7.11	-37.10	19.78
	Razga	361449	444745	618	15.3	473	-7.12	-37.30	19.66
	Merabag	361434	444703	593	17.3	604	-6.55	-34.50	17.9
	Kifra dol	361430	444620	574	12.9	675	-6.96	-36.60	19.08
Springs	**Qulai Rania**	361523	445307	564	14.7	512	-6.60	-34.10	18.7
	Saruchawa	361633	444521	585	15.1	558	-7.43	-38.30	21.14
	Shkarta	361823	444316	723	18.4	442	-6.27	-32.60	17.56
	Quali Kani maran	361228	444334	541	18.7	665	-6.81	-35.80	18.68
	Betwata	362033	444233	1047	13.6	372	-7.75	-40.20	21.8
	Shaoor river	362018	444656	766	10.2	610	-7.22	-36.40	21.36
	Max.						**-6.27**	**-32.6**	**21.8**
	Min.						**-7.75**	**-40.2**	**17.56**
	Average						**-7.04**	**-36.56**	**19.76**
Note: Shaoor River excluded from min,max and average values									

4.8 Relationship between δ ^{18}O ‰ and δ ^{2}H ‰

The δ^{2}H ‰ and δ^{18}O ‰ isotope composition of the different groundwater wells , springs samples as well as the Shaoor river sample are plotted on δ^{2}H ‰ - δ^{18}O ‰ diagram as shown in Fig. (4.4), the following remarks can be deduced.

-All water samples fall between the global meteoric water line (GMWL) and Eastern meteoric water line (which is the meteoric line of Mediterranean precipitation) (EMWL). The regression line for the δ^{2}H ‰ and δ^{18}O ‰ was calculated to be:

$$\delta^{2}H= (5.1329) \times \delta^{18}O-0.373 \ldots\ldots\ldots\ldots (4.7)\ (n=21)$$

The correlation coefficient between δ^{2}H and δ^{18}O was found to be high (0.93).

-Wells (Bn zery, Rapareen 4, Rapareen 1 and Shilanay), Betwata and Saruchawa springs and Shaoor stream are located above the local meteoric water line (LMWL) obtained by (Mawlood, 2003), which may be attributed to the following:

1-There are three sources of recharge, first is direct (focused) from coarse texture ephemeral stream beds (transmission losses) like Shaoor stream, the second is diffuse recharge spatially distributed through soil matrix from direct precipitation, and the third is from macro-scale openings such as fractures, solution holes. Saruchawa is thought to be recharged by source one from the Shaoor stream and the source two as mentioned in the chapter (3). Due to isotopic kinetic fractionation during water phase change, evaporation results in greater relative enrichment in ^{18}O than ^{2}H in residual water, which alters the ^{2}H-^{18}O relationship (Einsiedl, 2005, Hunt, et al., 2005, Guay et al., 2006). However, the degree of kinetic fractionation is higher when evaporation occurs from unsaturated soil rather than from free water surfaces or saturated soils. This means that the groundwater that was recharged by diffuse recharge is more enriched in stable isotopes than that which is recharged by direct recharge (Alsaaran, 2006, Pilla, et al., 2006, Kebede, et al., 2008).

The case is different for Betwata spring; the depletion here is an indication of recharge from the distant mountainous areas located higher in altitude than the studied area.

This differential fractionation has been used to delineate the mechanism of groundwater recharge qualitatively and quantitatively by many authors in the world like (Adar et al., 1998, Winograd et al., 1998, Bajjali and Al-Hadidi, 2005, Alsaaran, 2006).

-The values of (D-excess) indicate the same assumptions above. There are two groups of it one is greater than (20 ‰) and the other is less than (20 ‰). The (D-excess) values of wells (Bn zery, Rapareen 4, Rapareen 1 and Shilanay), Betwata and Saruchawa are all greater than (20 ‰).

-Groundwater recharge in the basin originates only from heavy downpours that are depleted in the heavy isotopes (δ^2H and δ^{18}O), as has been suggested for other arid and semi-arid regions (Alsaaran, 2006, Yu Lu, et al., 2008).

-Wells with lower temperature values contain more depleted stable isotopes; this means that the water table is shallow and it is affects by ambient temperature and direct recharge from precipitation (Pilla,et al., 2006).

4.9 Relationship between δ^{18}O ‰ and Elevation

The δ^{18}O contents of the samples are plotted in Fig. (4.5) against the elevation. The calculated regressions indicate two lines:

1- $Elevation = -8.8755X\ \delta^{18}O + 506.93$ $R^2 = 0.01378$(n=17)........... (4.8)

2- $Elevation = -201.69X\ \delta^{18}O + 623.94$ $R^2 = 0.5423$ (n=4)............. (4.9)

This means that there is depletion in δ^{18}O content of the water samples with the increase in elevation for the second line ,but the relation of the first group is very weak because the elevation variations is small. The two lines of calculated regression confirm the suggestion that; there are different recharge sources of groundwater.

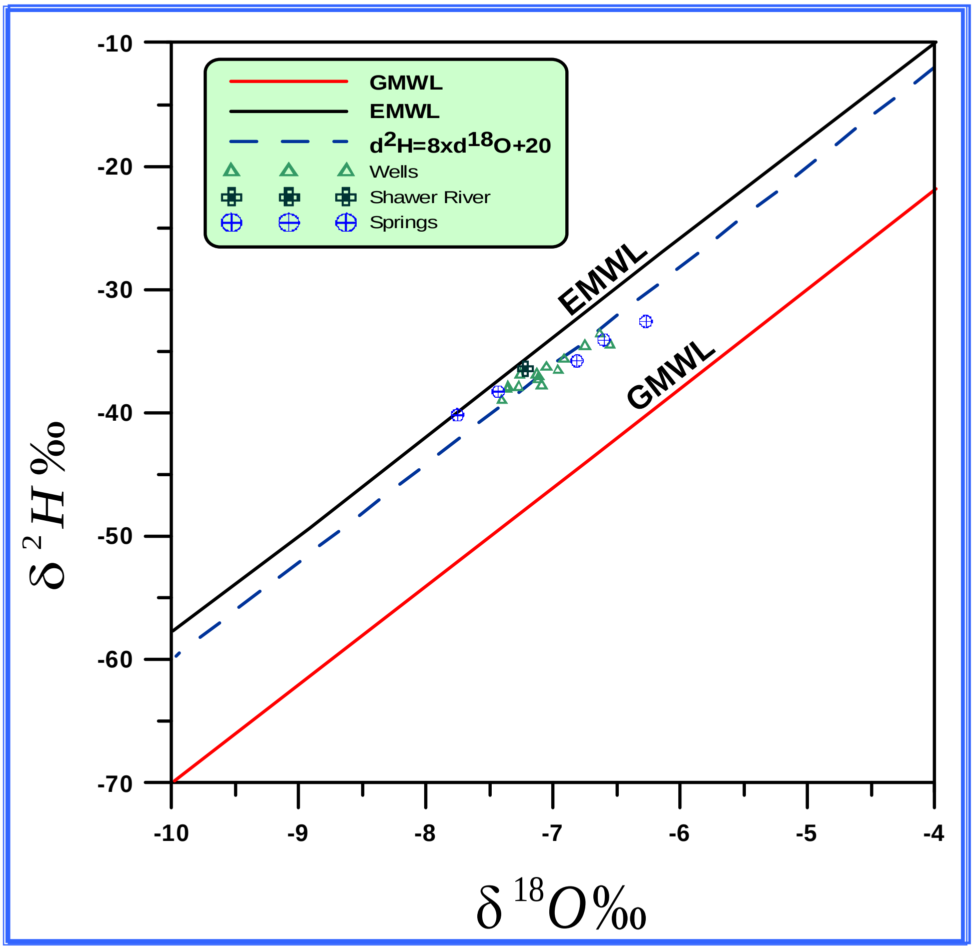


Fig. (4.4) δ^2H and δ^{18}O Diagram of the Water Samples of the Studied Area

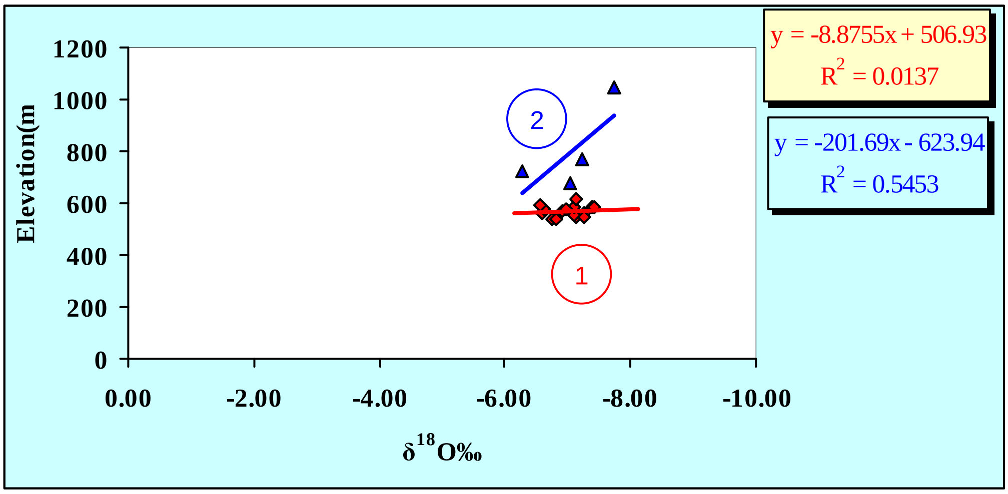


Fig. (4.5) Relationship between Elevation and δ^{18}O of the Water Samples of the Studied Area

CHAPTER FIVE
HYDROCHEMISTRY

Hydrochemistry

5.1 Introduction

As a resource, groundwater is gaining increasing importance in the supply of water to sub districts in the drier regions of Kurdistan where surface waters are very scarce or absent or unsafe for drinking purpose. The combination of population growth, economic and agriculture development, and an arid climate results in overexploitation of the water resources in the region. The continuous high water demand leads to a rapid degradation of the quality of fresh-water resources .Understanding the groundwater characteristics are crucial for groundwater management in the studied area.

The interest of society in groundwater geochemistry is mainly to ensure good quality drinking water. Although drinking water can be manufactured in a chemical plant, as for example in desalinization plants; this is a very costly affair. Preservation of good ground-water resources, therefore has a high priority for environmental authorities (Adams, et al 2001).

5.2 Uncertainty Measurement of Chemical Analysis

Every measurement is subject to an element of uncertainty, which may be reduced by improving the method or repeating the measurement but can never be entirely eliminated. This uncertainty consists of two contributions: random error (*precision*) and systematic error (*Accuracy*) (Gill, 1997, Appelo and Postma, 1999, Rao, 2006).

5.2.1 Precision (Random Error) of Chemical Analysis

The term precision refers to the closeness of agreement between results obtained by repeating an analytical procedure several times under the same conditions. Precision may be expressed in two alternative ways, as repeatability or reproducibility, according to the circumstances under which the measurements are replicated (Al-Manmi, 2002).

How precise an analysis can therefore be quantified in terms of the standard deviation obtained from replicate measurements: the smaller the standard deviation, the more precise the analysis. For any normal distribution there is a 95% probability (i.e. a 19 in 20 chance) of an individual reading lying within ±2σ of the mean value (Gill, 1997). According to (Stoodly, 1980), precision is also named "***Coefficient of Variation***" which represents standard deviation of a group data comparing with mean %.

$$CV(precission)\% = \frac{2SD}{\bar{x}} \times 100$$ .... (5.1) (95 % confidence) (Maxwell, 1968)

(Acceptance limit 5-25 %)

The accuracy of analysis calculated according to equation (5.1). Two samples were taken for this purpose (one for wells and the other for springs). Each sample was divided into three equal portions, and then analyzed separately. The results were found to fall within the accepted limit which would mean they can dependable for hydrochemical interpretations table (5.1).

5.2.2 Accuracy (Systematic Error) of Chemical Analysis

Accuracy or *systematic errors* display systematic deviations due to faulty procedures or interferences during analysis. Systematic errors can be tested only by analyzing reference samples and by inter laboratory comparison of the results. At low concentrations, due to lack of such samples, the accuracy of the analysis for major ions can be estimated from the *Electroneutrality (E. N.)* condition since sum of positive and negative charges in the water must balance (Gill, 1997, Appelo and Postma, 1999):

$$Electroneutrality(EN\%) = \frac{sum\,cations - sum\,anions}{sum\,cations + sum\,anions} \times 100 \ldots\ldots\ldots\ldots \quad (5.2)$$

The accepted limit or (certain) is between 0-5 %, 5-10 % should be carefully dealt with or (probable certain) and >10 % (uncertain) is not useful for geochemical interpretation.

Another useful technique to check the accuracy is by dividing the electrical conductivity (EC) by 100 which yield a very good estimate of the sum of anions and cations both in (meq/l) (Rao, 2006):

$$\sum anions = \sum cations (meq/l) = \frac{EC}{100} (\mu S/cm) \ldots\ldots\ldots\ldots \quad (5.3)$$

When the above methods are applied to the water samples, it is found that the results for both two seasons are within the acceptable limit, table (5.2 and 5.3).

Table (5.1) Precision of the Hydrochemical Analysis of Water Samples

No.	Parameter	Dry season (October)			Wet Season (April)		
		Mean	SD	C.V (95 %)	Mean	SD	C.V (95 %)
1	Ca^{2+}	86.2	0.28	0.64	79.5	0.71	1.78
2	Ca^{2+}	70.2	0.28	0.8	66.5	0.71	2.2
1	Mg^{2+}	7.54	0.2	5.26	6.75	0.35	10.48
2	Mg^{2+}	19.1	0.14	1.48	17.6	0.57	6.4
1	Na^{+}	48.7	0.94	2.6	43.5	0.71	3.26
2	Na^{+}	6.42	0.05	1.62	5.85	0.07	2.4
1	K^{+}	3.26	0.07	4.34	3	0.14	9.4
2	K^{+}	0.79	0.01	2.64	0.77	0.01	1.84
1	Cl^{-}	34.5	0.5	2.88	37.5	0.71	4.64
2	Cl^{-}	21.8	0.36	3.32	19.8	0.35	3.6
1	SO_4^{2-}	41.5	0.71	3.4	37.5	0.71	3.78
2	SO_4^{2-}	34.5	0.71	4.08	30.6	0.64	4.16
1	HCO_3^{-}	268.5	0.71	0.52	274	1.4	1
2	HCO_3^{-}	279	1.4	1.02	283.5	0.71	0.5
1	NO_3^{-}	29.3	0.32	2.78	29.1	0.14	1
2	NO_3^{-}	15.2	0.02	0.28	14.7	0.14	1.92
1	PO_4^{3-}	0.098	0.004	6.52	0.088	0.003	8.08
2	PO_4^{3-}	0.08	0.003	9.12	0.07	0.003	10.4
1:Deep Well 2:Spring							

Table (5.2) Accuracy of the Hydrochemical Analysis (Springs)

	Dry Season			Wet Season			
No.	**EN%**	**EC/100**	**Type**	**No.**	**EN%**	**EC/100**	**Type**
Betwata	4.49	5.14	certain	Betwata	6.65	4.88	P.certain
Qulai Kanimaran	4.06	5.48	certain	Qulai Kanimaran	5.55	5.30	P.certain
Shkarta	2.19	6.72	certain	Shkarta	0.36	6.66	certain
Qulai Rania	1.10	3.84	certain	Qulai Rania	1.13	3.71	certain
Saruchaua	3.82	6.13	certain	Saruchaua	5.64	6.13	P.certain
Ganau	4.63	5.12	certain	Ganau	7.29	4.86	P.certain
Kwera Kani	4.65	20.50	certain	Mzgauti Gawra	8.05	20.00	P.certain

Table (5.3) Accuracy of the Hydrochemical Analysis (Wells)

	Dry Season			Wet Season			
No.	**EN%**	**EC/100**	**Type**	**No.**	**EN%**	**EC/100**	**Type**
1	7.00	6.16	P.certain	1	3.26	6.01	certain
2	5.54	4.83	P.certain	2	9.62	4.69	P.certain
3	5.09	4.72	P.certain	3	6.73	4.62	P.certain
4	5.71	5.12	P.certain	4	5.72	5.00	P.certain
5	5.86	5.08	P.certain	5	7.37	5.01	P.certain
6	5.56	5.07	P.certain	6	6.11	4.99	P.certain
7	4.26	4.50	certain	7	4.92	4.44	certain
8	6.30	5.29	P.certain	8	6.90	5.20	P.certain
9	5.87	5.60	P.certain	9	6.06	5.49	P.certain
10	6.36	6.03	P.certain	10	5.97	5.96	P.certain
11	5.72	4.60	P.certain	11	7.17	4.45	P.certain
12	5.37	5.61	P.certain	12	5.41	5.47	P.certain
13	5.62	5.50	P.certain	13	6.06	5.36	P.certain
14	5.98	5.18	P.certain	14	5.71	5.08	P.certain
15	5.26	5.25	P.certain	15	6.62	5.20	P.certain
16	-4.89	5.10	P.certain	16	4.36	5.02	certain
17	5.13	3.74	P.certain	17	6.74	3.69	P.certain
18	5.73	3.62	P.certain	18	5.90	3.54	P.certain
19	5.42	3.80	P.certain	19	5.71	3.71	P.certain
20	4.81	3.84	certain	20	6.06	3.76	P.certain
21	0.07	3.79	certain	21	0.09	3.72	certain
22	2.37	3.88	certain	22	3.50	3.74	certain
23	3.15	3.82	certain	23	3.39	3.69	certain
24	6.29	3.77	P.certain	24	7.52	3.68	P.certain
25	0.23	5.00	certain	25	0.32	4.92	certain
26	8.46	4.10	P.certain	26	8.16	4.02	P.certain
27	4.27	3.68	certain	27	6.02	3.60	certain
28	3.79	3.95	certain	28	4.80	3.88	certain
29	6.59	3.91	certain	29	8.44	3.80	certain
30	3.67	5.87	certain	30	5.31	5.78	P.certain
31	6.29	4.16	P.certain	31	7.49	4.00	P.certain
32	6.01	4.55	P.certain	32	6.84	4.43	P.certain
33	6.46	4.42	P.certain	33	6.46	4.35	P.certain
34	4.26	4.87	certain	34	5.14	4.80	P.certain
35	5.18	4.38	P.certain	35	3.68	4.28	certain
36	5.34	6.28	P.certain	36	5.80	6.18	P.certain
37	0.55	6.49	certain	37	2.06	6.32	certain
38	3.00	5.04	certain	38	5.01	4.96	P.certain
39	2.53	4.22	certain	39	1.91	4.18	certain
40	4.75	4.47	certain	40	4.93	4.38	certain
41	6.41	4.88	P.certain	41	7.88	4.75	certain

5.3 General Evaluation of the Water Analysis

The results of chemical analysis of water samples for two seasons tabulated in the appendices (5 to 13) and the range and median values tabulated and represented in the table (5.4) and Fig. (5.1).Median value taken because it is more reliable for samples have outlier values (Hasan, et al. 2007).

Table (5.4) Range and Median Values of Hydrochemical Parameters for Water Samples in Rania Area

Variables	**Dry season(October)**				**Wet season(April)**			
	Wells		**Springs**		**Wells**		**Springs**	
	Range	**Med.**	**Range**	**Med.**	**Range**	**Med.**	**Range**	**Med.**
Ca^{2+} mg/l	41.6-96.0	60.8	48.0-248.0	73.6	40.0-90.0	58.0	47.0-238.4	69.0
Mg^{2+} mg/l	7.7-30.7	15.4	11.5-39.0	19.0	7.0-29.8	14.7	10.0-30.0	17.0
Na^{+} mg/l	1.4-49.3	11.5	1.41-52.0	24.0	1.3-44.0	11.0	1.3-50.0	22.5
K^{+} mg/l	0.79-3.31	1.16	0.75-27.0	1.08	0.7-3.1	1.1	0.77-24	1.0
Cl^{-} mg/l	14.0-70.0	38.0	21.8-305.0	50.4	12.5-63.1	32.0	19.2-300.0	45.0
SO_4^{2-} mg/l	5.9-84.0	42.0	14.0-257.0	44.0	5.3-77.0	38.0	13.0-248.0	38.0
HCO_3^{-} Mg/l	129.0-290.0	202.0	177.8-402.0	270.0	132.0-296.0	205.0	179.0-410.0	273.0
NO_3^{-} mg/l	5.48-46.0	16.8	6.8-58.5	15.2	9.3-42.0	16.1	6.1-57.0	14.8
PO_4^{3-} mg/l	0.01-0.4	0.07	0.08-0.8	0.1	n.d-0.3	0.06	n.d -0.6	0.09
T.H mg/l	167.0-319.0	214.0	183.0-780.0	256.0	158.0-299.0	202.3	179.0-719.0	241
TDS mg/l	232.0-415.0	302.1	246.0-1312.0	350.7	226.6-404.5	295.7	237.4-1280.0	339.0
EC µS/cm	362.0-649.0	472.0	384.0-2050.0	548.0	354.0-632.0	462.0	371.0-2000.0	530.0
pH	6.65-8	7.37	6.7-8.14	7.25	6.8-8.12	7.4	6.8-8.21	7.35
H_2S mg/l	N.D.	-	7.5	-	N.D.	-	7.0	-
Turbidity NTU	0.2-2.3	0.9	2.2-10	2.7	0.2-2.5	1.0	2.4-11.0	3.0
$T^{o}C$	16.0-24.5	20.0	15.0-22.5	16.5	14.7-22	18.6	13.2-21.5	15.2
N.D. =Not detected								

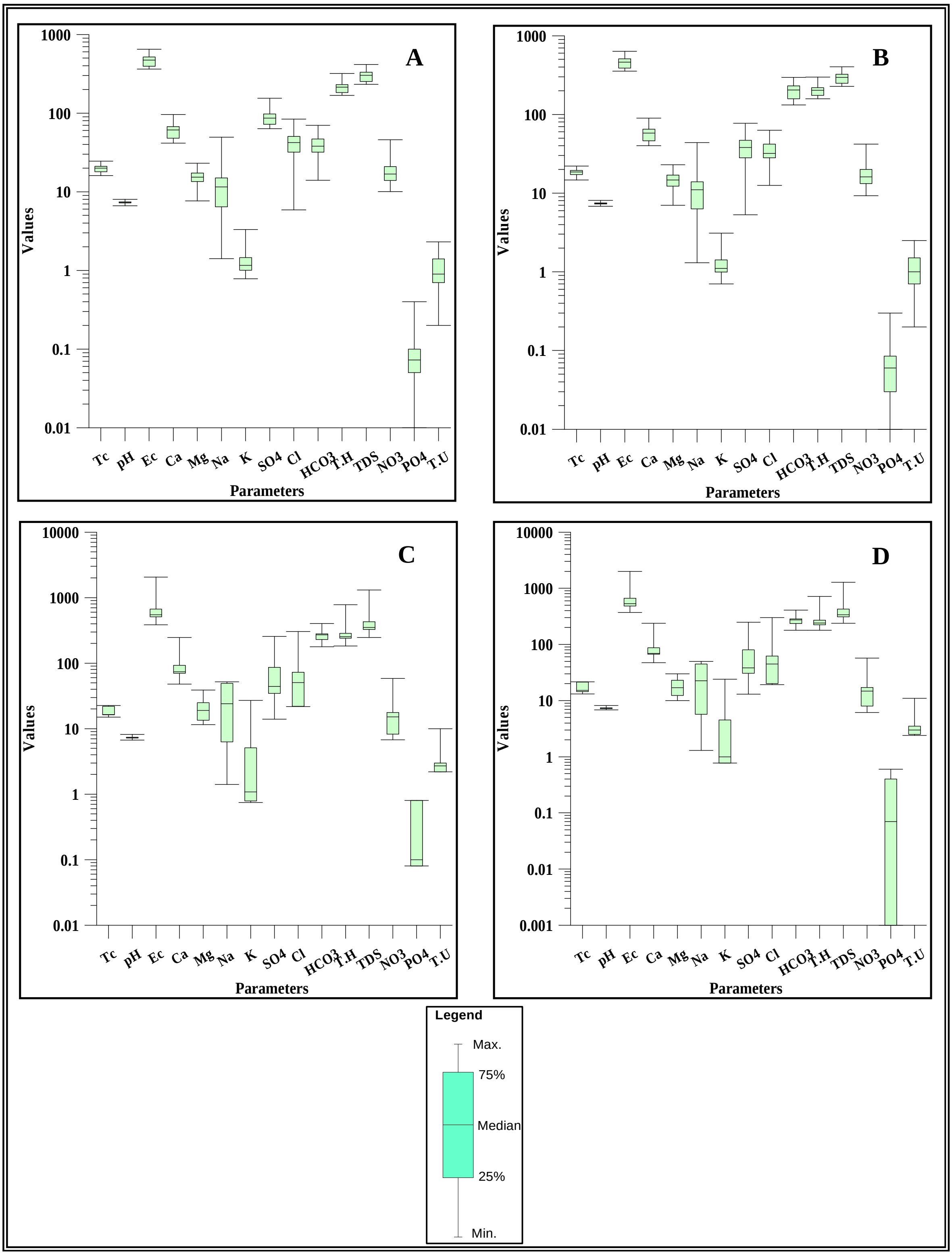


Fig. (5.1) Box- Whisker Plot of Hydrochemical Parameters (A) Wells (Dry Season) (B) Wells (Wet Season) (C) Springs (Dry Season) (D) Springs (Wet Season)

5.4 Physiochemical Parameters of Groundwater

The main goals of studying the physiochemical characteristics of groundwater are to determine the origin of water and the degree of pollution (Detay, 1997).

1. Color, Odor and Taste

The colored water may be caused by increasing concentration of dissolved (Fe and Mn) ions, algae, and humic compounds (Pierce et al., 1998, Al-Manharawi and Hafiz, 1997). Odors release from any water may be related to decreasing of dissolved oxygen (D.O_2), presence of organic pollution and hydrogen sulfide (H_2S). Taste of water may be a result of increasing carbonate hardness, total dissolved solids (TDS), decreasing dissolved oxygen (D.O_2), and excessive bacterial activity. All water samples collected from wells and springs were colorless, tasteless, and odorless except the sample from (Ganau) spring which has the odor of (H_2S) gas and has milky color due to the process of (H_2S) oxidation and which later precipitate as (S).

$$H_2S + O_2 \longrightarrow H_2O + S \downarrow$$

2. Temperature (T^oC)

Temperature will impact on the acceptability of a number of other inorganic constituents and chemical contaminants that may affect taste (WHO, 2006). Temperature effects the geochemical and chemical reactions (Mather in Saether, 1997). The temperature values of water samples were as the table below:

Dry Season (October)				**Wet Season (April)**			
Wells		**Springs**		**Wells**		**Springs**	
Range	**Med.**	**Range**	**Med.**	**Range**	**Med.**	**Range**	**Med.**
16-24.5	20.0	15-22.5	16.5	14.7-22	18.6	13.2-21.5	15.2
Units (^oC)							

There is no abnormal temperature value recorded.

3. Hydrogen Ion Concentration (pH)

The pH is defined as the negative, base-10 logarithm of the hydrogen-ion activity. Most reactions in gas/water/rock systems involve or are controlled by the pH of the system (Langmuir, 1997).The pH value for all water samples was in the optimum range of pH (6.5-8.5). According to (WHO, 2006) some water samples were described as alkaline water, and the others are near neutral. The pH values of water samples were as the table below.

Dry Season (October)				**Wet Season (April)**			
Wells		**Springs**		**Wells**		**Springs**	
Range	**Med.**	**Range**	**Med.**	**Range**	**Med.**	**Range**	**Med.**
6.65-8	7.37	6.7-8.14	7.25	6.8-8.12	7.4	6.8-8.21	7.35

It is obvious that the values of wet season are slightly greater than dry season, this is attributed to recharge mechanism, because when there is excess of rainfall there is excess of (HCO_3) due to reaction between (H_2O) and (CO_2).

4. Hydrogen Sulfide (H_2S)

The rotten-egg odor of hydrogen sulfide can be detected by most people in waters that have only a few tenths of a milligram per liter of this material in solution. (H_2S) is generated in natural waters by sulfate reduction, all plants, animals, and bacteria metabolize sulfur in order to synthesize amino acids such as cysteine and methionine. The bacteria involved are of the genus *Desulfovibrio desulfuricans* or genus *Desulfotomaculum* and are heterotrophs, that is ,they require organic matter for energy transfer (equation) (Langmuir,1997).

$$C + CaSO_4^{2-} \xrightarrow{Anaerobic\ Bacteria} CaS + 2CO_2 \text{ ....} \quad (5.4)$$

$$CaS + CO_2 + H_2O \longrightarrow CaCO_3 + H_2S \uparrow \text{ ....} \quad (5.4.1)$$

When the concentration of H_2S exceeds 0.05 mg/l in drinking water it irritates mucous and cause nausea, vomiting ,and epigastric pain following ingestion, and when inhaled, hydrogen sulfide is highly acutely toxic to human, it formed a complex with the (Fe^{3+})of the mitochondrial, herby blocking oxidative metabolism (WHO, 2006).

All water samples of wells were clear from H_2S as well as the springs with exception of the samples taken from Ganau spring which has a concentration of (7.5 mg/l) for the dry season and (7 mg/l) for the wet season.

5. Electrical conductivity (EC)

Electrical conductivity is the ability of ($1cm^3$) water to conduct an electric current at a standard temperature of 25°C and measures in micro-siemens per centimeter (µS/cm) and is depending on the total amount of soluble salts (Todd, 2005).

Electrical conductivity is an indirect measurement of salinity, and it is temperature dependent (Hem, 1991, APHA, 1998, Mazor, 1990). The response of the conductance value to temperature changes is somewhat different for different salts and different concentrations, but in dilute solutions for most ions an increase of 1°C increases conductance by about 2 percent. The variation of conductivity gives important information on the evolution of water quality.

The (EC) value of water samples were as the table below:

Dry Season (October)				**Wet Season (April)**			
Wells		**Springs**		**Wells**		**Springs**	
Range	**Med.**	**Range**	**Med.**	**Range**	**Med.**	**Range**	**Med.**
362.0-649.0	472.0	384-2050	548.0	354-632	462.0	371.0-2000.0	530.0
Units (µs/cm)							

The values of wet season are slightly lower than dry season due to dilution process by precipitation, the cations and anions like (EC) are slightly higher values in the dry season for the same reason.

In relation to conductivity, the mineralization of water may be represented as indicated in table (5.5). According to (Detay, 1997) water samples represent moderately mineralized water except for (Ganau) spring which is classified as excessively mineralized water.

Table (5.5) Relation between Water Conductivity and Mineralization (After Detay, 1997)

EC (µs/cm)	Mineralization
< 100	Very weakly mineralized water (granite terrains)
100 – 200	Weakly mineralized water
200 – 400	Slightly mineralized water (limestone terrains)
400 – 600	Moderately mineralized water
600 – 1000	Highly mineralized water
1000 <	Excessively mineralized water

In order to know whether there is intrusion of other water from other layer to the alluvium aquifer or not, during the pumping test of one well which selected, the (EC) of the pumped water was measured every (10) minutes. As shown in table (5.6), there are only slight differences in the reading, and it is therefore concluded that there is no leakage or intrusion of water from another aquifer or layer.

Table (5.6) EC & T^{o}C Values of Bosken Pumped Well for (10 minutes) Time Interval

Time	EC (µs/cm)	T^{o}C	Time	EC (µs/cm)	T^{o}C
10:10	710	19	11:00	632	19.3
10:20	685	19.2	11:10	619	19.5
10:30	659	19.3	11:20	621	19.6
10:40	641	19.5	11:30	625	19.1
10:50	639	19.2	above 11:30	fixed	fixed

6. Total Dissolved Solids (TDS)

Total dissolved solids (TDS) or salinity represents the total amount of solids remaining when a water sample evaporates to dryness (Drever, 1997). Total dissolved solids comprise inorganic salts and small amount of organic matter that are dissolved in water. The (TDS) determined by multiplying the (EC) by factor (0.64) .According to (Albu et al., 1997), the (TDS) values of water samples were as the table below:

Dry Season (October)				Wet Season (April)			
Wells		Springs		Wells		Springs	
Range	Med.	Range	Med.	Range	Med.	Range	Med.
232.0-415.0	302.1	246.0-1312.0	350.7	226.6-404.5	295.7	237.4-1280.0	339.0
Units (mg/l)							

According to (Drever, 1997, Altoviski, 1962, Gorrel ,1958) table(5.7) water samples are classified as fresh water except Ganau spring which is slightly brackish water (Altoviski, 1962) to brackish water (Gorrel,1958, Drever,1997).

Table (5.7) Classifications of Water According to (TDS) Content in (mg/l)

Water Class	Gorrel (1958)	Altoviski (1962)	Drever (1997)
Fresh water	0 – 1000	0 – 1000	< 1000
Slightly brackish water	--	1000 – 3000	--
Brackish water	1000 – 10,000	3000 – 10,000	1000 – 20,000
Salty water	10,000 – 100,000	10,000 – 100,000	--
Saline water	--	--	35,000
Brine water	100,000	> 100,000	> 35,000

7. Turbidity

Turbidity is the amount of suspended particulate matter in water which is caused by clay, silt, fine organic and inorganic matter and microorganisms. Turbidity measures the scattering of light on the suspended particles in the water using nephelometric turbidity unit (NTU) and (5 NTU) is usually acceptable for drinking (C .H., 2003,WHO, 2006).

The turbidity values of water samples were as the table below:

Dry Season (October)				Wet Season (April)			
Wells		Springs		Wells		Springs	
Range	Med.	Range	Med.	Range	Med.	Range	Med.
0.2-2.3	0.9	2.2-10.0	2.7	0.2-2.5	1.0	2.4-11.0	3.0
Units (NTU)							

5.5 Major Cations

1. Calcium (Ca^{2+})

Calcium is the most abundant of the alkaline-earth metals and is a major constituent of many common rock minerals. Calcium is an essential constituent of many igneous- rock minerals, like pyroxene and amphibole, and the feldspars. (Holand, 2003, Hem , 1991).

The source of calcium in the studied area is from the geological units such as Qamchuqa, Kometan, Sarmord, and the Jurassic Formations.

The (Ca^{2+}) concentration of water samples were as the table below:

Dry Season (October)				**Wet Season (April)**			
Wells		**Springs**		**Wells**		**Springs**	
Range	**Med.**	**Range**	**Med.**	**Range**	**Med.**	**Range**	**Med.**
41.6-96.0	60.8	48.0-248.0	73.6	40.0-90.0	58.0	47.0-238.4	69.0
Units (mg/l)							

2. Magnesium ($Mg^{2+)}$

Magnesium is an alkaline-earth metal. The geochemical behavior of magnesium, however, magnesium ions are smaller than sodium or calcium ions .In igneous rock, magnesium is typically a major constituent olivine, pyroxenes, amphiboles, and micas. Sedimentary forms of magnesium include carbonates such as magnesite and hydromagnesite, the hydroxide brucite, and mixtures of magnesium with calcium carbonate **(**Helstrup et al., 2007, Hem, 1991).The source of this ion is from Sarki, Sehkaniyan,and Qamchuqa Formations. The (Mg^{2+}) concentration of water samples were as the table below:

Dry Season (October)				**Wet Season (April)**			
Wells		**Springs**		**Wells**		**Springs**	
Range	**Med.**	**Range**	**Med.**	**Range**	**Med.**	**Range**	**Med.**
7.7-30.7	15.4	11.5-39.0	19.0	7.0-29.8	14.7	10.0-30.0	17.0
Units (mg/l)							

3. Sodium (Na^+)

Sodium is the most abundant member of the alkali- metal group of the periodic table. In igneous rocks, sodium is slightly more abundant than potassium, but in sediments, sodium is much less abundant (Faure, 1998).Human activities can have a significant influence on the concentration of sodium in surface water and ground water. The source of sodium ion in the studied area is from the clay minerals which exist in the soil of studied area. The (Na^+) concentration of water samples were as the table below:

Dry Season (October)				**Wet Season (April)**			
Wells		**Springs**		**Wells**		**Springs**	
Range	**Med.**	**Range**	**Med.**	**Range**	**Med.**	**Range**	**Med.**
1.4-49.3	11.5	1.41-52.0	24.0	1.3-44.0	11.0	1.3-50.0	22.5
Units (mg/l)							

4. Potassium (K^+)

Potassium is slightly less common than sodium in igneous rock but more abundant in all the sedimentary rocks .The principal potassium minerals of silicate rocks are the feldspars orthoclase and microcline, micas, and the feldspathoid leucite. In most natural water, the concentration of potassium is much lower than the concentration of sodium. According to (Daly, 1994) the (K:Na) ratio is a good indicator of pollution especially those caused by organic wastewater and soiled water . He suggested a ratio of (>0.3) as an indicator of such that pollution. The (K^+) concentrations of water samples were as the table below:

Dry Season (October)				**Wet Season (April)**			
Wells		**Springs**		**Wells**		**Springs**	
Range	**Med.**	**Range**	**Med.**	**Range**	**Med.**	**Range**	**Med.**
0.79-3.31	1.16	0.75-27.0	1.08	0.7-3.1	1.1	0.77-24.0	1.0
Units (mg/l)							

The source of potassium ion is from clay minerals.

5.6 Total Hardness (T.H)

Hardness caused by calcium and magnesium is usually indicated by precipitation of soap scum and the need for excess use of soap to achieve cleaning .Depending on the interaction of other factors, such as pH and alkalinity (Faure, 1998, Ljungberg, 2004). Hardness is expressed as the equivalent quantity of calcium carbonate (WHO, 2006), and it can be determined as follow:

$$Hardness_{equivalent CaCO_3} = \left(\frac{2(Ca^{2+})}{at.wt.Ca} + \frac{2(Mg^{2+})}{at.wt.Mg} \right) \times \frac{M.wt.CaCO_3}{2}$$

$$= 2.497(Ca^{2+}\ mg/l) + 4.115(Mg^{2+}\ mg/l) \text{ ...... (5.5) (Faure, 1998)}$$

The (T.H) values of water samples were as the table below:

Dry Season (October)				**Wet Season (April)**			
Wells		**Springs**		**Wells**		**Springs**	
Range	**Aver.**	**Range**	**Aver.**	**Range**	**Aver.**	**Range**	**Aver.**
167.0-319.0	214.0	183.0-780.0	256.0	158.0-299.0	202.3	179.0-719.0	241.4
Units (mg/l)							

According to Boyd (2000) the water samples are hard and fairly hard according to French degree except (Ganau) spring which is very hard water table (5.8).

Table (5.8) Different Classifications of Water Hardness

Boyd (2000)		**Detay (1997)**	
T.H(mg/l $CaCO_3$)	Type	T.H(French Degree)	Type
$T.H \leq 50$	Soft	0-7°	Very soft water
$50 < TH \leq 150$	Moderately hard	7-14°	Soft water
$150 < TH \leq 300$	Hard	14-20°	Moderately hard water
T.H > 300	Very hard	20-30°	Fairly hard water
		30-50°	Hard water
		>50°	Very hard water
1°=10 mg/l $CaCO_3$			

5.7 Major Anions

1. Bicarbonate (HCO_3^-) and Carbonate (CO_3^{2-})

Bicarbonate and carbonate are the producer of alkalinity which is the capacity for solutes it contains to react with and neutralize acid. The principal source of carbon dioxide species that produce alkalinity in surface or ground water is the CO_2 gas fraction of the atmosphere, or the atmospheric gases present in the soil or in the unsaturated zone lying between the surface of the land and the water table (Ljungberg, 2004).

The (HCO_3^-) concentrations of water samples were as the table below:

Dry Season (October)				Wet Season (April)			
Wells		Springs		Wells		Springs	
Range	Med.	Range	Med.	Range	Med.	Range	Med.
129.0-290.0	202.0	177.8-402.0	270.0	132.0-296.0	205.0	179.0-410.0	273.0
Units (mg/l)							

while the concentration of (CO_3^{2-}) is zero owing to pH value which was below (8.3) for all water samples .This means that below a pH value less than (8.3) all the (CO_3^{2-}) converted to (HCO_3^-) .The values of the second (wet) season are greater due to recharge occurrence which coincide with the values of (pH).

2. Sulfate (SO_4^{2-})

The natural sources are from (dissolution of evaporated rocks), or may be derived from chemical fertilizers, detergents, pesticides and tannin (WHO, 2006). The presence of sulfate in drinking-water can cause noticeable taste, and very high levels might cause a laxative effect in unaccustomed consumers.

The (SO_4^{2-}) concentration of water samples were as the table below:

Dry Season (October)				Wet Season (April)			
Wells		Springs		Wells		Springs	
Range	Med.	Range	Med.	Range	Med.	Range	Med.
5.9-84.0	42.0	14.0-257.0	44.0	5.3-77.0	38.0	13.0-248.0	38.0
Units (mg/l)							

The sources of sulfate are from the secondary gypsum which precipitates in the caverns and fissures of geological formations in the studied area, anthropogenic activities and sewage leaks are the other sources of sulfate.

3. Chloride (Cl^-)

The element chlorine is the most abundant of the halogens. Considerably more important sources are associated with sedimentary rocks, particularly evaporates like halite and sylvite. It is also abundant in minerals of igneous rocks like apatite and feldspathoid (Davis and Dewist, 1966). Chloride in drinking-water originates from natural sources, sewage and industrial effluents, urban runoff containing de-icing salt and saline intrusion. (Drever , 1997).

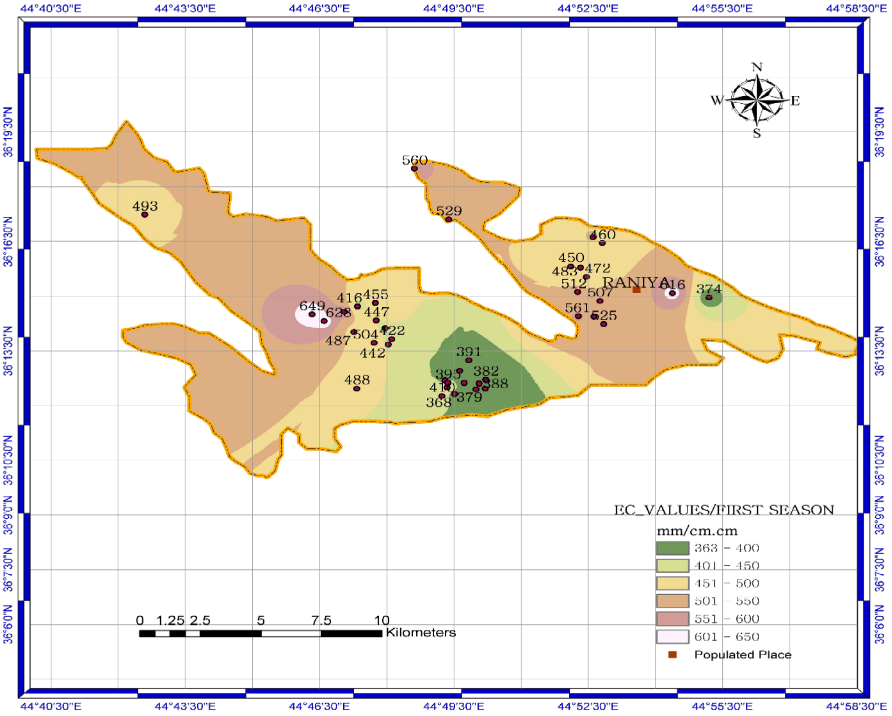
The (Cl^-) concentration of water samples were as the table below:

Dry Season (October)				**Wet Season (April)**			
Wells		**Springs**		**Wells**		**Springs**	
Range	**Med.**	**Range**	**Med.**	**Range**	**Med.**	**Range**	**Med.**
14.0-70.0	38.0	21.8-305.0	50.4	12.5-63.1	32.0	19.2-300	45.0
Units (mg/l)							

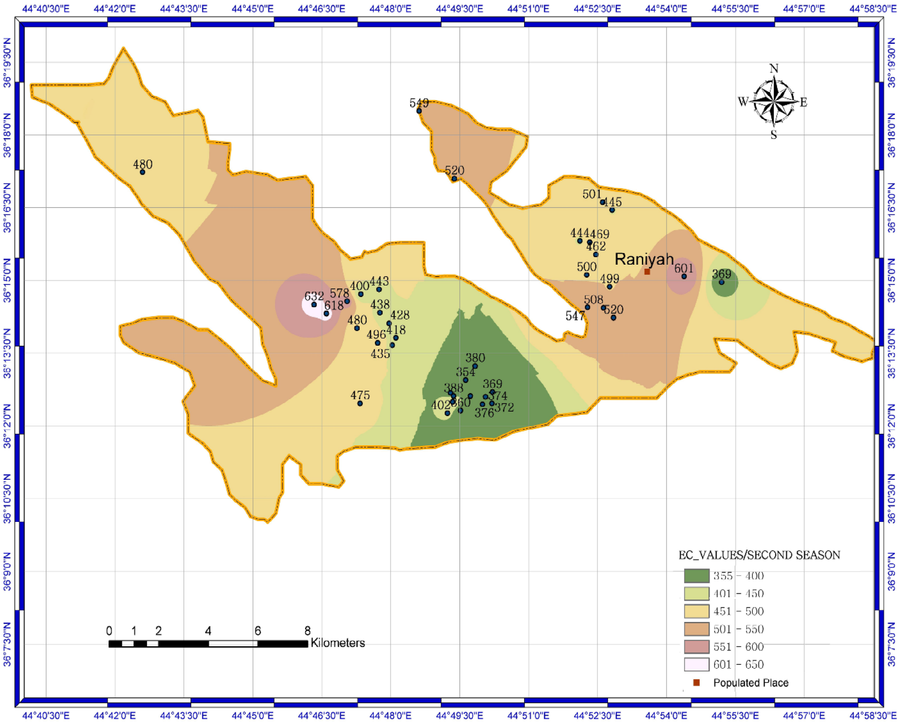
The sources of chloride are from the irrigation and anthropogenic activities.

5.8 Spatial distribution of water-quality parameters

The greatest values of (EC) and ion concentrations for two seasons were observed in the Hajiawa district and eastern parts of the Rania city Fig. (5.2), the reason behinds of this is these areas consist of much coarser deposits which allow more infiltration of runoff water .The spatial distributions of cations and anions are similar to (EC) ,therefore there was no need for individual maps. Regarding to springs another maps prepared by projecting the Stiff diagram on it instead of contour maps Fig. (5.3). These maps provide basis for making area-wide generalizations concerning the distributions of water-quality parameters, and they serve to isolate water quality problem areas and their related sources.

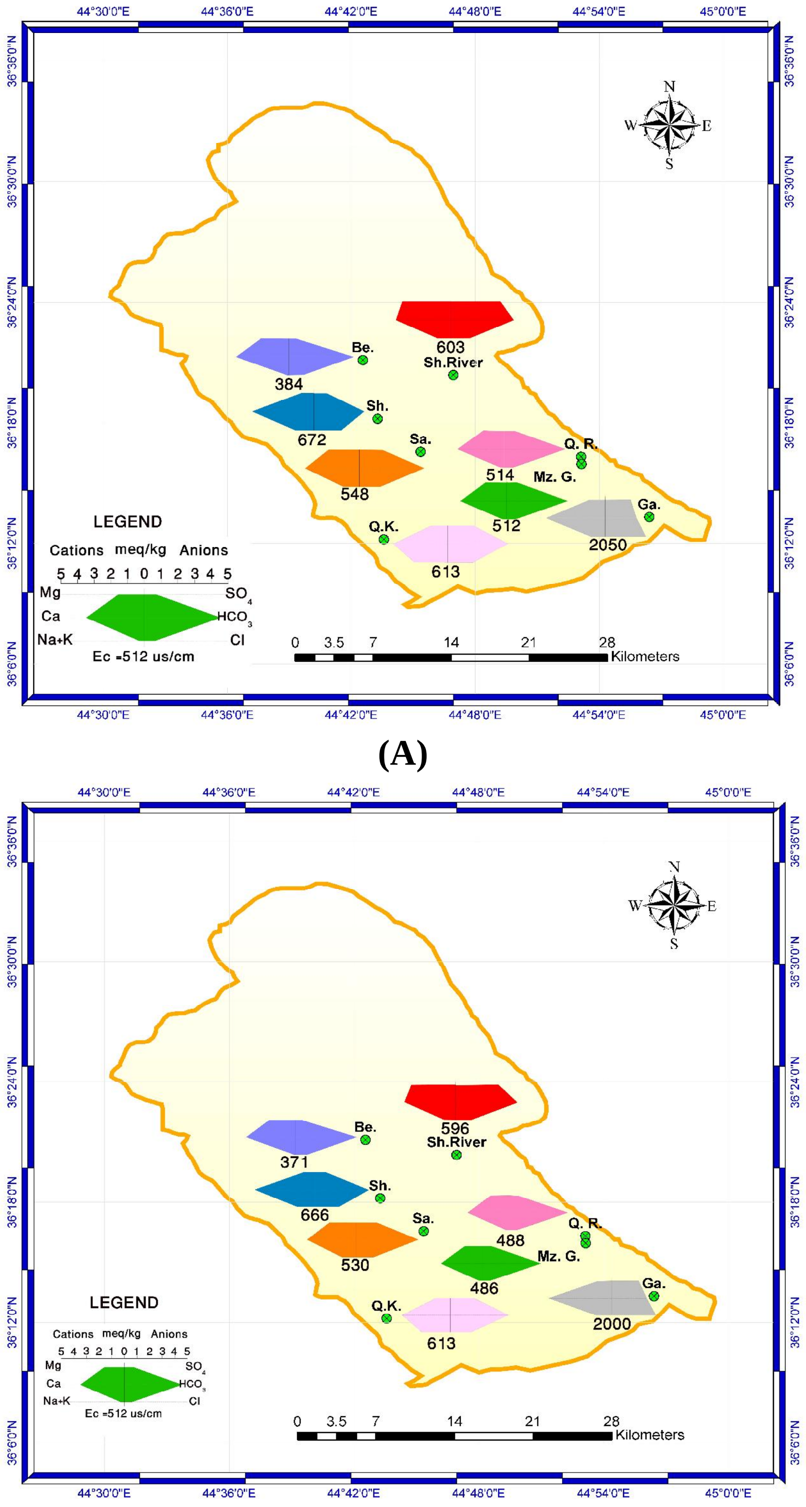


(A)



(B)

Fig. (5.2) Spatial Distribution of Electrical Conductivity:
(A) Dry Season (B) Wet Season



(A)

(B)

Fig. (5.3) Stiff Diagrams Represent the Chemical Compositions of Springs and Shaoor river in Rania Area
(A)Dry season (B) Wet Season

5.9 Minor Compounds

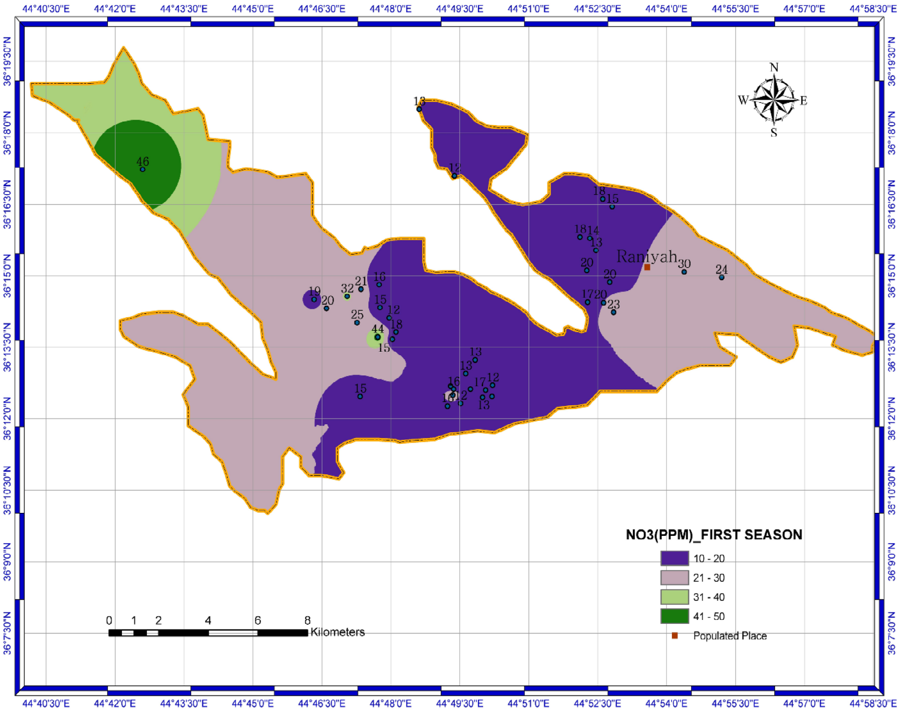
1. Nitrate (NO_3^-)

Nitrate is naturally occurring ion that is part of the nitrogen cycle. Nitrate is used mainly in inorganic fertilizers, and sodium nitrite is used as a food preservative, especially in cured meats (Hudak, 2000, Rodvang and Simpkins, 2001). The consumption of water with high nitrate concentration causes a number of health disorders, such as gastric cancer, goiter, birth malformations, hypertension and decreasing oxygen bearing capacity of the blood (methemoglobinemia), which is particularly important in the health of young infants (Majumdar and Gupta ,2000, McKenzie, 2001, Esteller ,2005) so-called "blue-baby syndrome" .

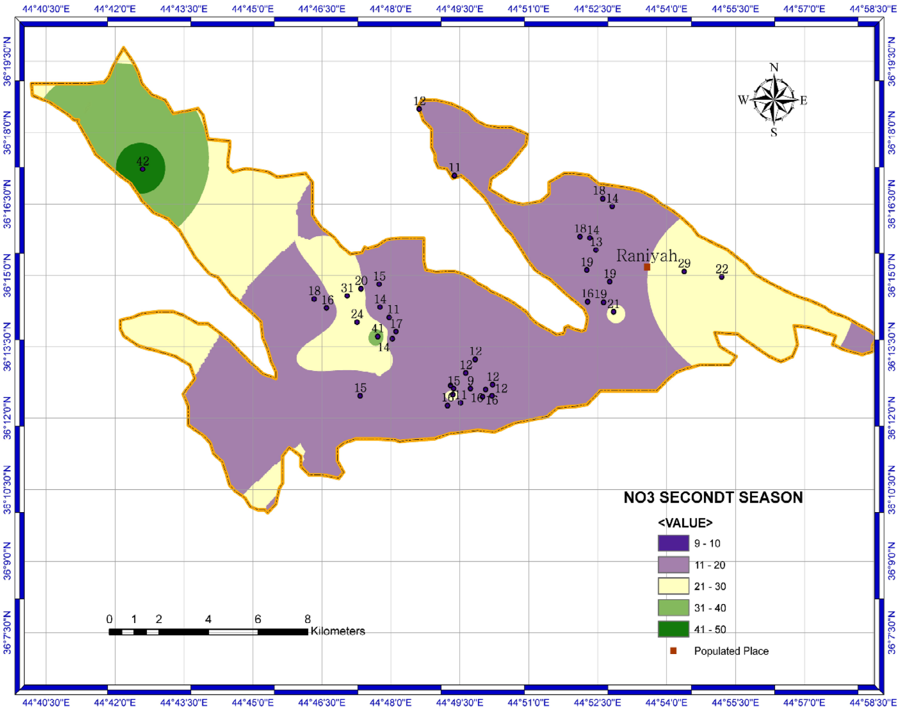
The (NO_3^-) concentrations of water samples were as the table below:

Dry Season (October)				**Wet Season (April)**			
Wells		**Springs**		**Wells**		**Springs**	
Range	**Med.**	**Range**	**Med.**	**Range**	**Med.**	**Range**	**Med.**
10.0-46.0	16.8	6.8-58.5	15.2	9.3-42.0	16.1	6.1-57.0	14.8
Units (mg/l)							

The wells No. (37 and 41) and Shkarta spring have high values of NO_3^-, the source is from animal waste and manure for well No. (37) and Shkarta spring, and from sewage for well No. (41) .Fig. (5.4) shows the spatial distribution of nitrate in the studied area.



(A)



(B)

Fig. (5.4) Spatial Distribution of Nitrate Ion:
(A) Dry Season (B) Wet Season

2. Phosphate (PO_4^{3-})

Phosphate is a rather common element in igneous rock, and it is also a fairly abundant in sediments (Hem, 1991). The most common mineral form is apatite, which is a calcium phosphate. Phosphorous compounds are present in many detergents, fertilizer and feed. Orthophosphate, poly phosphate and organic phosphate represent the usual forms of phosphorous found in aqueous solutions (McKenzie et al., 2001). Increasing concentration of (PO_4^{3-}) with increasing (NO_3^-) means that the source is from chemical fertilizer (Ali and Al-Manmi, 2005). Too much phosphate can cause health problems, such as kidney damage and osteoporosis; Phosphate shortages can also occur (Esteller, 2005).

The (PO_4^{-3}) concentrations of water samples were as the table below:

Dry Season (October)				**Wet Season (April)**			
Wells		**Springs**		**Wells**		**Springs**	
Range	**Med.**	**Range**	**Med.**	**Range**	**Med.**	**Range**	**Med.**
0.01-0.4	0.07	0.08-0.8	0. 1	n.d-0.3	0.06	0.04-0.6	0.09
Units (mg/l)							

The concentrations in some samples were not detected. The wells (37 and 41) and Shkarta spring have high values of PO_4^{3-}, the source is from animal waste and manure for well No. (37), and Shkarta spring, and from sewage for well No. (41). It is obvious that the pollution source is the same for NO_3^- and PO_4^{3-}.

5.10 Groundwater Quality Classification

To assess the geochemical evaluation and classification of groundwater, a graphical representation of expanded Durov diagram (1958), and Chadha diagram (1999) are used. As little attention is paid by Iraqi researchers and lack of articles in the Iraqi libraries on these two diagrams, it is necessary to discuss them in details, appendices (14 and 15). The chemical data of the groundwater samples collected from the studied area are plotted in the expanded Durov diagram Figs. (5.5 and 5.6). The chemical data of the sample points, appeared as a cluster, and fall in the subdivisions of (1) it means that HCO_3^- and Ca^{2+} dominant, frequently indicates recharging waters in lime-stone aquifer, while well (39) located in the field No. (2) for both seasons, and this means that HCO_3^- dominant and Mg^{2+} dominant or cations indiscriminant, with Mg^{2+} dominant or Ca^{2+} and Mg^{2+} important indicates waters often associated with dolomites, where Ca^{2+} and Na^+ with important partial ion exchange may be indicated. Wells No. (26 and 27) located in the field No. (4) for dry season, it means that SO_4^{2-} dominant or anions indiscriminant and Ca^{2+} dominant, $Ca^{2+}$and SO_4^{2-} dominant frequently indicates a recharge water in gypsiferous deposits, otherwise a mixed water or a water exhibiting simple dissolution may be indicated, but the gypsiferous deposits not exist in the aquifer, the SO_4^{2-} source may be derived from anthropogenic activity. Ganau spring also located in the field No. (4) for both seasons, the SO_4^{2-} source is from Kurrahina and Baluti Formations. When the data plotted in the Chadha diagram all samples fall in the field No. (5) (water type is Ca^{2+}-Mg^{2+}-HCO_3^-) except deep wells No. (26 and 27) which are located in the field No. (1) for dry season (Alkaline earths exceed alkali metals),and well No. (10) located in the field No. (6) for dry season (water type is Ca^{2+}-Mg^{2+}-Cl^-).Ganau spring also located in the field No.(6) Fig. (5.7).

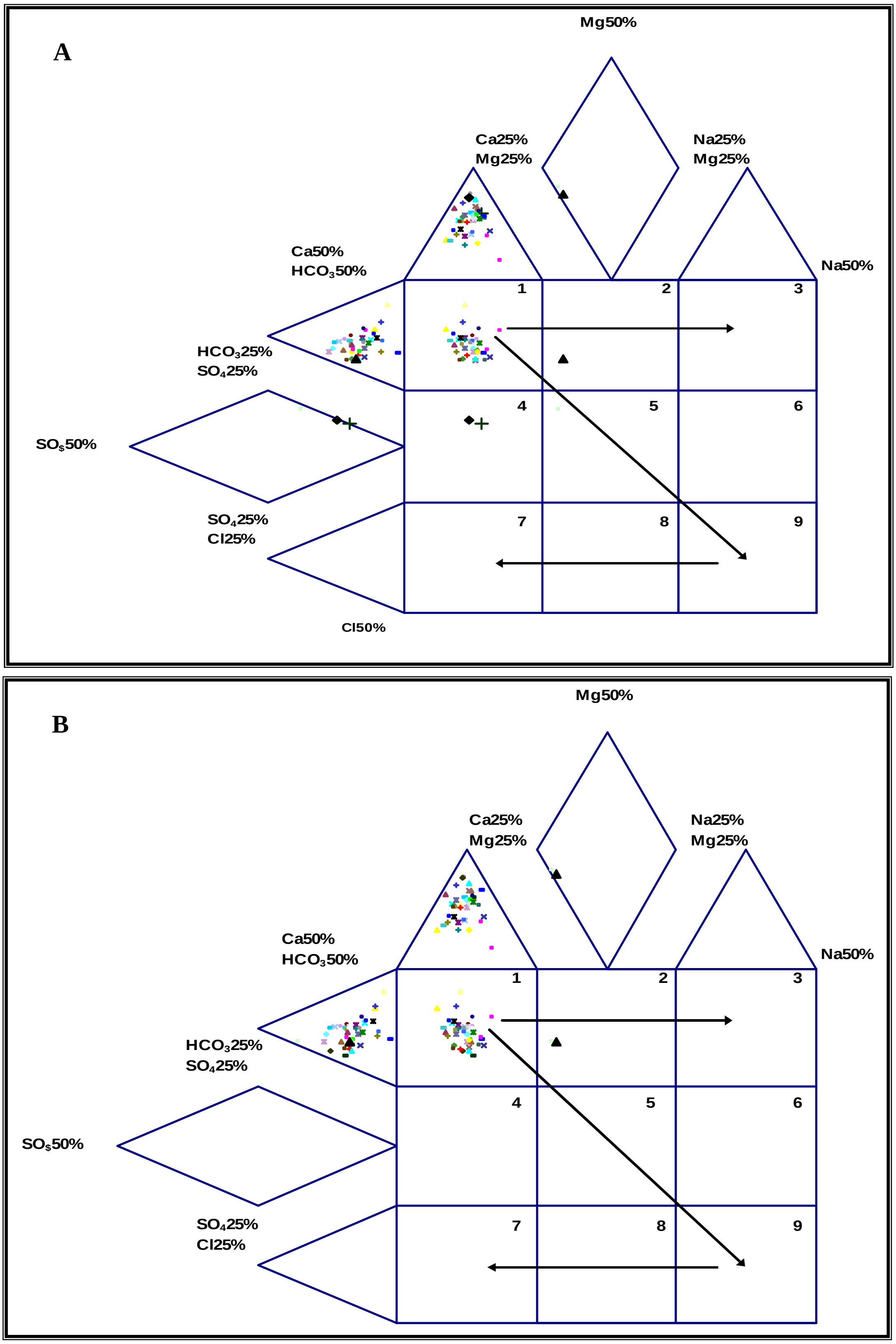


Fig. (5.5) Expanded Durov Diagram for Wells (A) Dry Season, (B) Wet Season

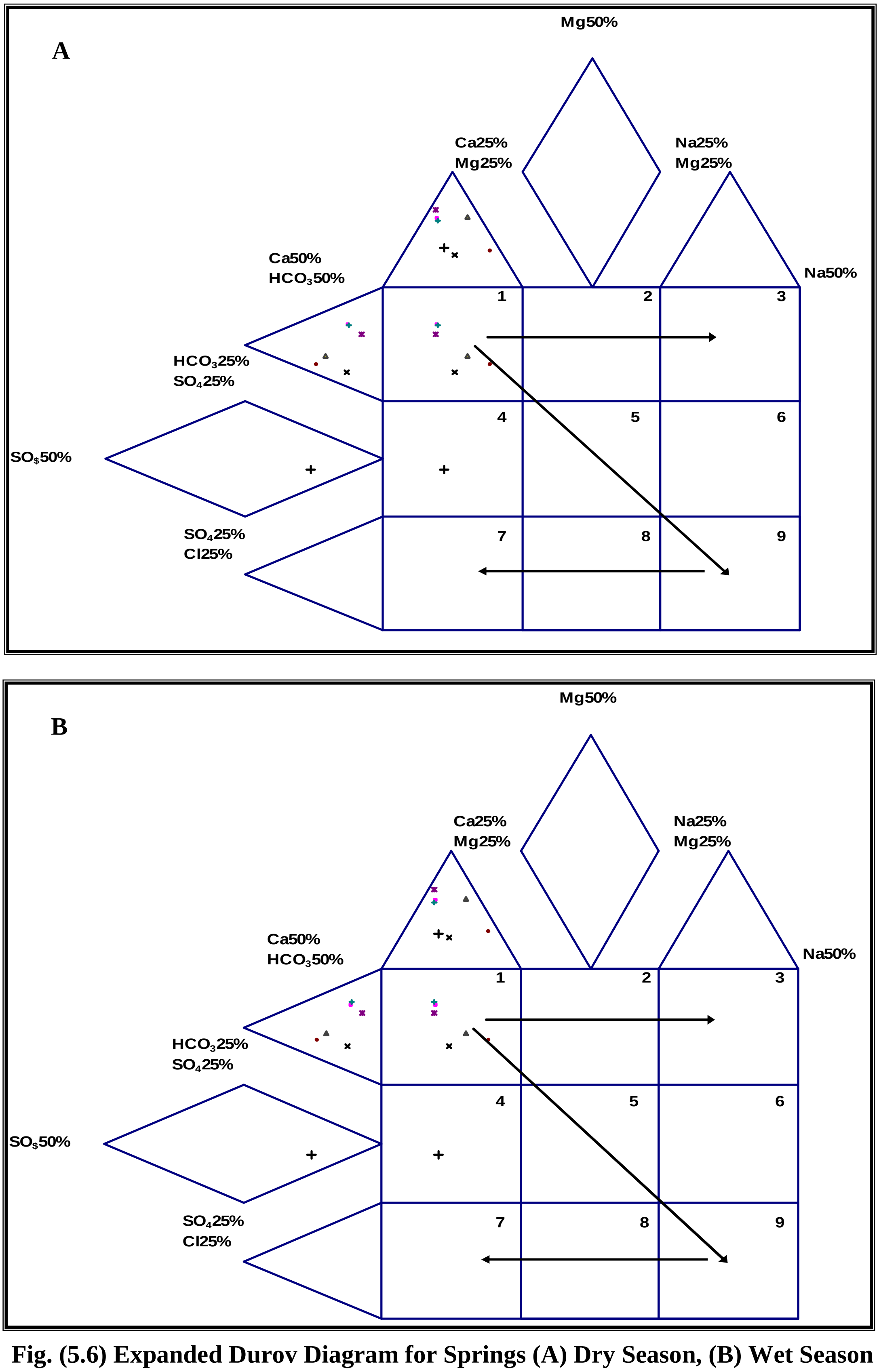


Fig. (5.6) Expanded Durov Diagram for Springs (A) Dry Season, (B) Wet Season

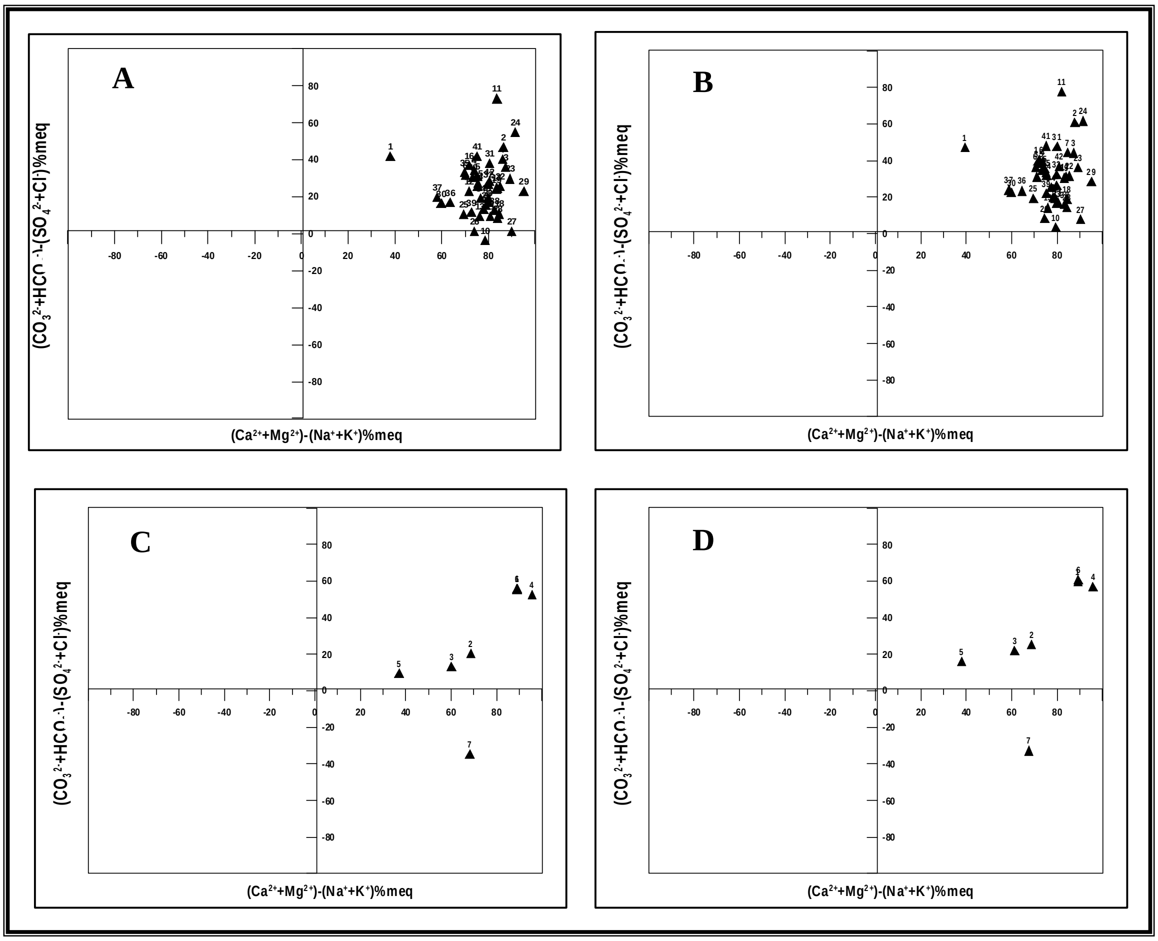


Fig. (5.7) Chadha Diagram for Water Samples

(A) Wells (Dry Season), (B) Wells (Wet Season)

(C)Springs (Dry Season), (D) Springs (Wet Season)

5.11 Mechanisms Controlling Groundwater Chemistry

Gibbs's diagrams, representing the ratios of Na^+: (Na^++ Ca^{2+}) and Cl^-: (Cl^-+ HCO_3^-) in (epm) units as a function of TDS are widely employed to assess the functional sources of dissolved chemical constituents, such as precipitation-dominance, rock-dominance and evaporation-crystallization-dominance or by combination of these influences (Gibbs, 1970 , Langmuir, 1997).The reason of using the ratios parameters above is the composition of world rainfall(unpolluted) which is chiefly determined by the (NaCl) of sea salt, also weathering of chemical rocks increases their (TDS), concentrations of (Ca^{2+}) and (HCO_3^-) relative to (Na^+) and (Cl^-). Evapotranspiration further and concomitant precipitation of $CaCO_3$ increases the (Na^+) and (TDS) content of water, and shifts the prevalent character (rock-dominance) of such water back toward zone of evaporation-dominance (Langmuir, 1997, Rao, 2006, Al-Manmi, 2007).

The chemical data of groundwater sample points of the area are plotted in Gibbs's diagrams Figs. (5.8 and 5.9). The distribution of sample points, as shown as a cluster, suggests that the chemical weathering of rock-forming minerals is influencing the groundwater quality except for Ganau spring where evaporation is the controlling factor. Semi-arid climate, gentle slope, lack of good drainage conditions and longer residence time of groundwater, and the depression of Ganau spring receive soil runoff water, further increase the (Na^+) and (TDS) content of it.

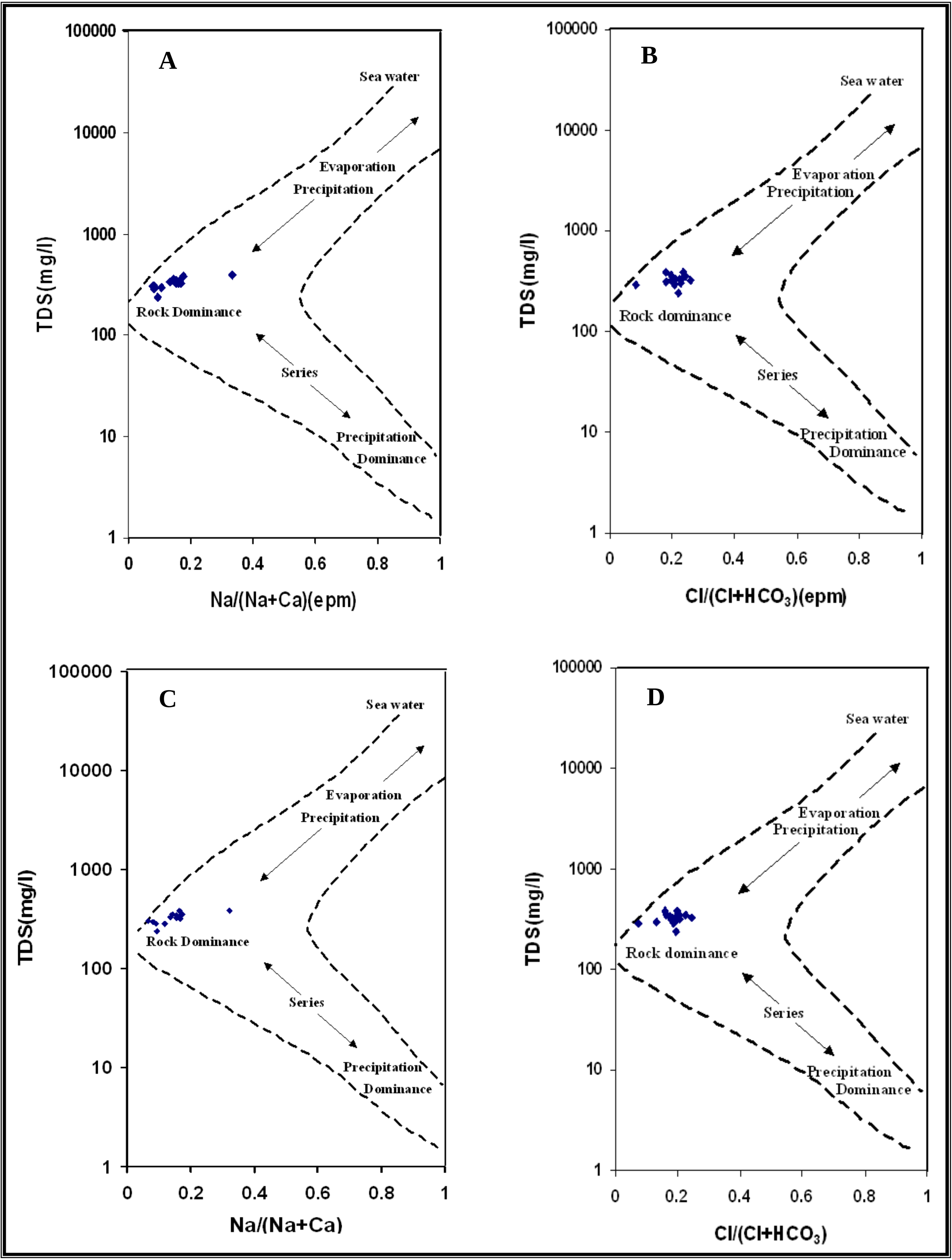


Fig. (5.8) Mechanisms Controlling Groundwater Quality (After Gibbs 1970)
(A, B) Wells (Dry Season) (C, D) Wells (Wet Season)

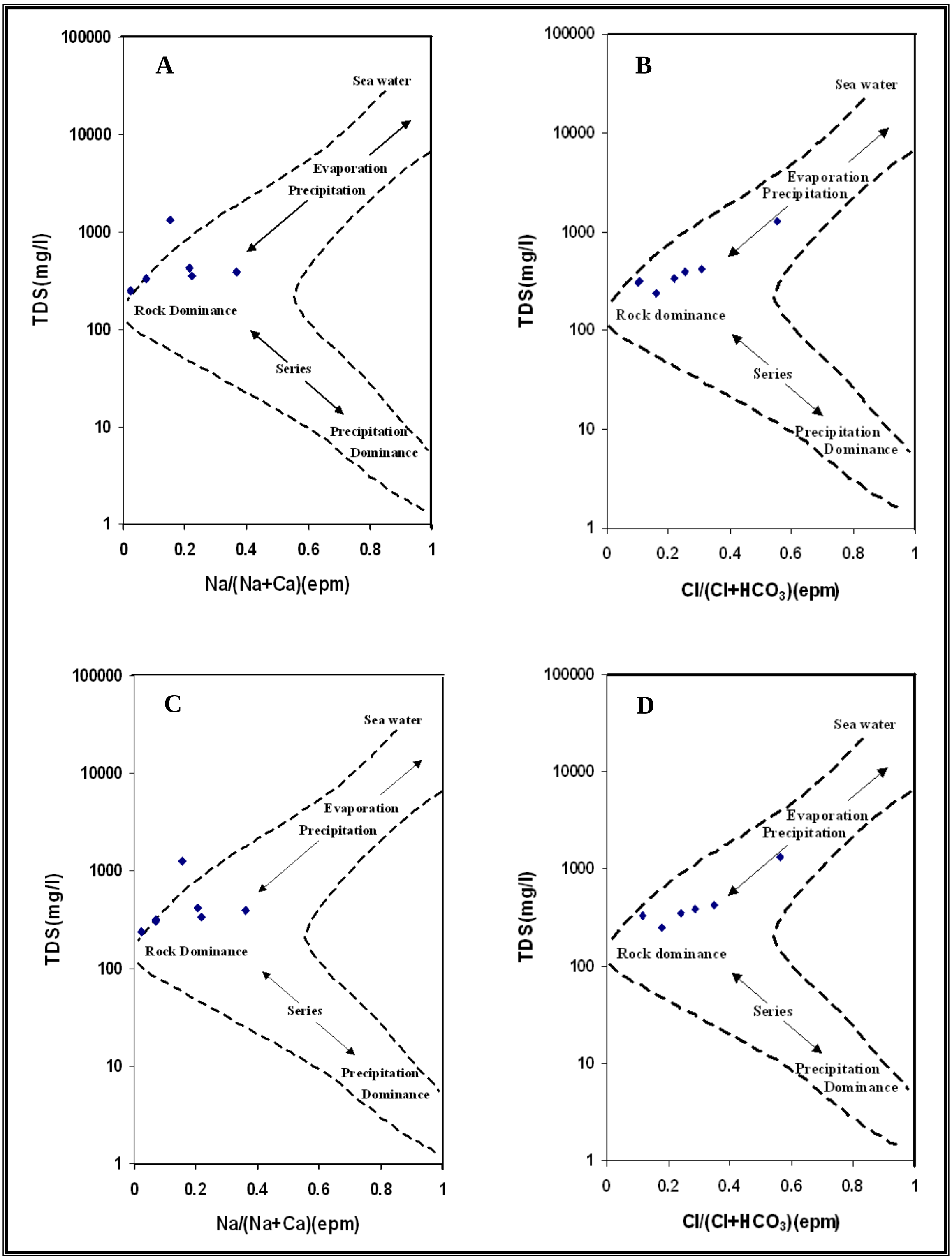


Fig. (5.9) Mechanisms Controlling Groundwater Quality (After Gibbs, 1970)
(A, B)Springs (Dry Season) (C, D) Springs (Wet Season)

5.12 Equilibrium Speciation Calculation

Hydrochemistry deals with the chemical and physical processes, which occurred during, water rock interactions. One of these processes is the mineral dissolution and precipitation (Al-Manmi and Saleh, 2006). Consequently, different parameters were calculated based on the chemical analysis of the water samples (Al-Zubi, 2000). These parameters are ionic strength, saturation indices, and P_{CO2}, for calcite, aragonite, dolomite, gypsum, anhydrite, magnesite and halite. These parameters for each site were input into ***WATEQ4F*** software (Ball and Nordstrom, 2003), a thermodynamic data-based computer program for calculating speciation of major, trace and redox elements in natural water. The program uses the Debye-Huckel-coefficient approach for activity-coefficient corrections.

The mass action law is one of the most useful relations in analyzing of the chemical processes in groundwater (Appelo, and Postma, 1999). It states that for a reaction:

$$\mathbf{aA + bB \longleftrightarrow cC + dD} \text{ .... (5.6)}$$

Where: a, b, c and d are the stochiometric fractions of the chemical constituents A, B, C and D respectively at equilibrium, the law can be stated as follows:

$$K_{eq} = \frac{[C]^c [D]^d}{[A]^a [B]^b} \text{ .... (5.7) (Drever, 1997)}$$

Where the quantities in brackets [ ] represent the thermodynamic effective concentration (activity) of the reactants and products, while K_{eq} is the equilibrium constant.

The activity of dissolved ions is referred the effective concentration, therefore, the activity of a given solution could be related to the activity coefficient by the fallowing reaction:

$$a_i = \gamma_i m_i \text{ .... (5.8) (Drever, 1997)}$$

Where: a_i: is the activity of certain ion,

m_i: is the molar concentration of the same ion in(mol/kg)

γ_i: is the activity coefficient of the same ion and can be calculated as follow:

$$\log \gamma_i = \frac{-Az_i^2\sqrt{I}}{1+Ba_i\sqrt{I}}$$ .... (5.9) (Drever, 1997)

Where:

A, B: constants that depend on pressure and temperature

ai: effective size of the hydrated ion in angstroms. Z: valance

In nearly pure water, where all solute ions or molecules contact only water molecules, ($a_i = m_i$) and the activity coefficients of all solutes equal unity. As salt concentrations increase, however, individual aqueous species must move closer together and are, therefore, more and more likely to come in contact. Because the interaction between adjacent ions is largely Columbic, it is also proportional to the charge of the ions involved (Langmuir, 1997). These effects are embodied in the definition of ionic strength (I) which is given by:

$$I = \frac{1}{2}\sum\left(m_i z_i^2\right)$$ .... (5.10) (Drever, 1997)

In this study the chemistry of the groundwater is often necessary to express the extent of water chemical equilibrium with the minerals of the aquifer matrix. The common minerals such as calcite, dolomite, halite, gypsum, etc. involved in the reactions between water and rock matrix, some of these mineral reactions are listed in table (5.9).

Table (5.9) Equilibrium Constants at 25°C and Enthalpies of Reaction for Selected Reactions (Drever, 1997)

Minerals	**Dissolution reaction**	**Enthalpy ΔH°r (Kcal/mol)**	**Log K T=25°C**
Anhydrite	$CaSO_4 = Ca^{2+} + SO_4^{2-}$	-7.15	-4.36
Aragonite	$CaCO_3 = Ca^{2+} + CO_3^{2-}$	-10.83	-8.336
Calcite	$CaCO_3 = Ca^{2+} + CO_3^{2-}$	-9.61	-8.480
Dolomite	$CaMg(CO_3)_2 = Ca^{2+}+Mg^{2+}+2CO_3^{2-}$	-9.436	-17.09
Gypsum	$CaSO_4.2H_2O = Ca^{2+}+SO_4^{2-}+2H_2O$	-0.46	-4.58
Halite	$NaCl=Na^{+}Cl^{-}$	3.82	1.58
Magnisite	$MgCO_3 = Mg^{2+}+CO_3^{2-}$	-25.81	-8.03

5.13 Calculations of Saturation Indices

Saturation indices express the extent of chemical equilibrium between water and mineral phases in the matrix of the aquifers and could be regarded as a measure of dissolution and /or precipitation processes relating to the water rock interaction (Drever 1997, Domenico, and Schwartz, 1998).The calculation of water saturation degree with respect to solid mineral phases can be reached as in the following equation (Drever, 1997):

$$SI_x = \log \frac{IAP(T)}{Ksp(T)} \text{ .... } (5.11)$$

Where

SI_x :is the saturation index of mineral x,

IAP (T): is the ion activity products at specified temperature (^{o}C),

and *Ksp*: is the equilibrium solubility product costant of mineral x.

The resulting values indicate whether the solution is under saturated (-SIx), supersaturated (+SIx), or at equilibrium (SIx = 0) with respect to the mineral in question.

5.14 Theoretical CO_2 Partial Pressures

The P_{CO2} is considered the most important factor controlling the precipitation and dissolution of carbonate minerals; groundwater contains more (CO_2) than surface water due to the decomposition of organic mater in the topsoil layer.

P_{CO2} can be calculated by the below equation (Langmuir, 1997):

$$LogP_{CO_2} = -pH + Log \frac{(\gamma HCO_3 \ mHCO^-{}_3)}{K_{CO_2} K_1} \text{ .... } (5.12)$$

Where

K_{CO2} is the equilibrium (Henry's law) constant for CO_2

and K_1 is the first dissociation constant of H_2CO_3

5.15 Results

Using the computer software ***WATEQ4F***, saturation indices, ionic strength, and Log P_{CO2} for different mineral phases were calculated, and the summary of equilibrium speciation calculation for the two seasons tabulated in table (5.10) and the detail results are tabulated in the appendices (16 to 21).

Table (5.10) Range and Median Values of Ionic Strength, Log P_{CO2}, and Minerals Saturation Indices for Rania Area

Parameters& mineral phases	**Dry season (October)**				**Wet season (April)**			
	Wells		**Springs**		**Wells**		**Springs**	
	Range	**Med.**	**Range**	**Med.**	**Range**	**Med.**	**Range**	**Med.**
Ionic Strength	0.0057-0.0113	0.0074	0.0056-0.0264	0.01	0.0055-0.011	0.0069	0.0055-0.0252	0.0094
Log P_{CO2}	-12.78-(-1.59)	-2.11	-2.97-(-1.16)	-1.87	-2.79-(-1.73)	-2.15	-3.04-(-1.26)	-1.97
$SI_{Anhydrite}$	-3.14-(-1.86)	-2.29	-2.78-(-1.16)	-2.09	-3.22-(-1.89)	-2.34	-2.82-(-1.18)	-2.17
$SI_{Aragonite}$	-1.27-0.54	-0.19	-0.25-0.33	-0.18	-1.14-0.52	-0.16	-0.26-0.37	-0.1
$SI_{Calcite}$	-1.13-0.66	-0.04	-0.102-0.48	-0.03	-0.99-0.67	-0.01	-0.12-0.52	0.05
$SI_{Dolomite}$	-2.46-1.13	-0.46	-0.65-0.68	-0.44	-2.2-1.12	-0.44	-0.69-0.72	-0.35
SI_{Gypsum}	-2.9-(-1.63)	-2.05	-2.53-(-0.93)	-1.86	-2.97-(-1.65)	-2.1	-2.56-(-0.94)	-1.94
SI_{Halite}	-8.94-(-7.2)	-7.91	-9.03-(-6.42)	-7.48	-9.01—7.27	-7.97	-9.12-(-6.44)	-7.55
$SI_{Magnisite}$	-1.89-(-0.4)	-1.05	-1.12-(-0.35)	-0.96	-1.76-(-0.12)	-0.99	-1.14-(-0.34)	-0.95
P_{CO2} (Bar) Ionic Strength (mol/Kg)								

From table (5.10) the following points can be concluded:

1-Wells:

- 38 % of the samples for dry season and % 47 for wet season have positive values of SI $_{calcite}$ which means that the water is oversaturated with respect to Calcite. The increasing percent in the wet season is due to increasing values of (pH and HCO_3), which caused further precipitation and make the aqueous environment more alkaline. Another conclusion is that Calcite is the abundant mineral of the aquifer and the recharge area, but also indicate that more than 50 % of the samples are under saturated

-12 % of the samples for dry season and % 14 for wet season have positive SI $_{Dolomite}$ values, which mean that water is oversaturated with respect to

Dolomite -5 % of the samples for dry season and % 14 for wet season have positive SI $_{\text{Aragonite}}$. It concluded that the Dolomite is less abundant than Calcite.

–All samples have negative values of (SI $_{\text{Anhydrite}}$, SI $_{\text{Gypsum}}$, SI $_{\text{Halite}}$, and SI $_{\text{Magnisite}}$)which means that the water is under saturated with respect to (Anhydrite , Gypsum , Halite , and Magnisite). It is concluded that the sources of these minerals are secondary minerals or from anthropogenic activity.

2-Springs:

–All springs have negative values of (SI $_{\text{Anhydrite}}$, SI $_{\text{Gypsum}}$, SI $_{\text{Halite}}$, and SI $_{\text{Magnisite}}$)which means that the water is under saturated with respect to (Anhydrite , Gypsum , Halite , and Magnisite).

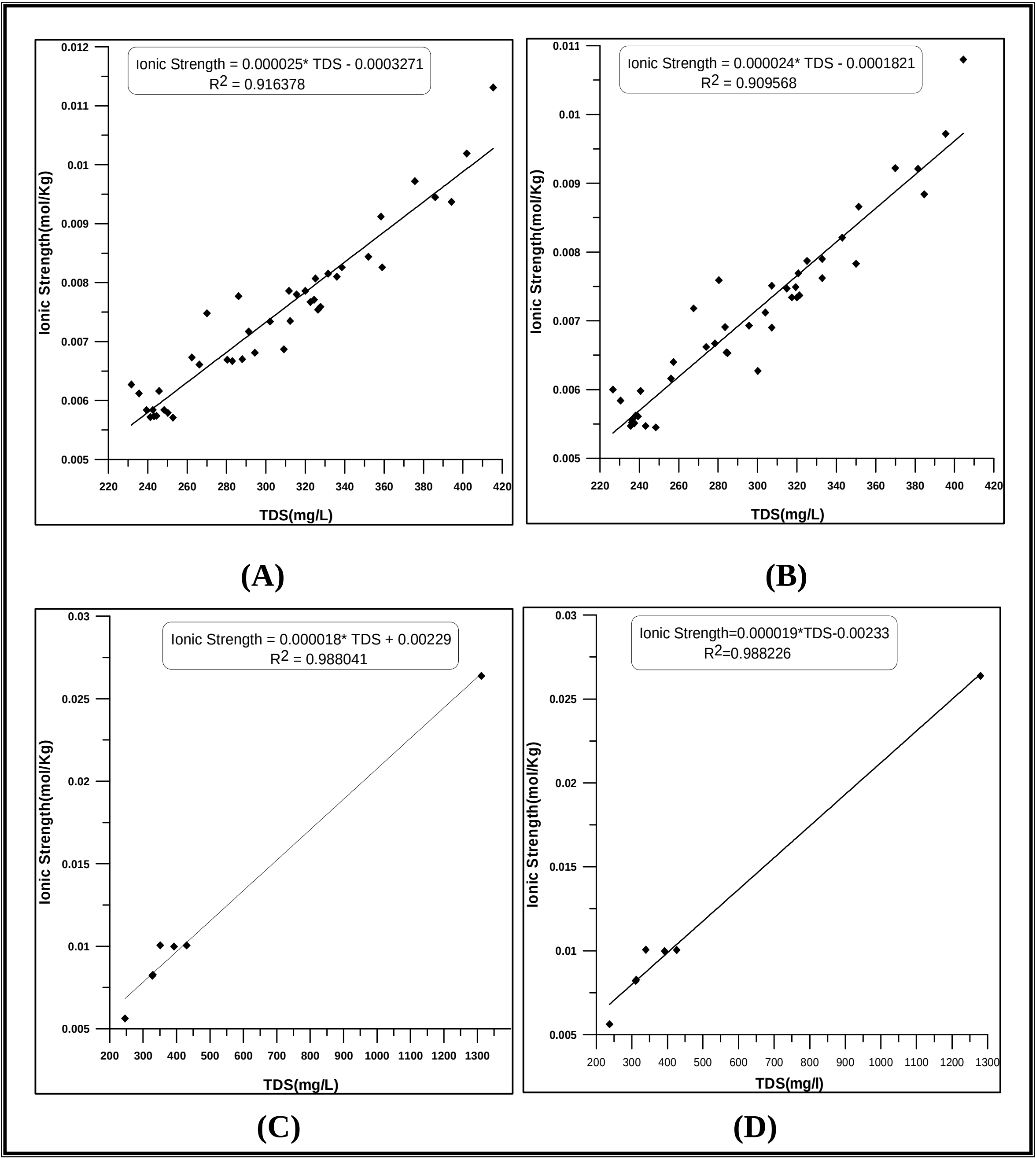
-Betwata spring is oversaturated with respect to (Calcite ,Aragonite, Dolomite),it means that the aquifer contains high amount of Calcite and Dolomite ,also over saturation state in springs suggests a mechanism of diffuse flow, not conduit flow and there is a more residence time between the water and the aquifer materials, also the diffuse flow suggested as a close system whereas in a closed system, once the available carbon dioxide is used up, the dissolution of limestone terminates (Raeisi and Karami, 1997).

-Saruchawa, Quali Rania, and Kwera Kani springs are under saturated with respect to Calcite ,Aragonite, and Dolomite ,it suggested that a mechanism of conduit flow for spring as mentioned in the chapter(3).

Ganau spring is under saturated with respect to (Aragonite and Dolomite) but oversaturated with respect to (Calcite).On first inspection it seems surprising that. In fact, according to the previous section, this can not be explained by a prolonged water-rock contact time (Diffuse flow), but to a loss of CO_2 from the groundwater due to a high degree of karstification (Chicano,et al., 2001).

5.16 Relationship between Ionic Strength and TDS

Fig. (5.10) represents a high significant relationship between ionic strength (mol/Kg) and TDS (mg/l).



(A) **(B)**

(C) **(D)**

Fig. (5.10) Relationship between Ionic Strength and TDS
(A, B)Wells (Dry & Wet Season) (C, D) springs (Dry &Wet Season)

5.17 Groundwater Suitability

Whether a groundwater of a given quality is suitable for a particular purpose depends on the criteria or standards of acceptable, quality for that use. Quality limits of water supplies for drinking water, industrial purposes, and irrigation apply to groundwater because of its extensive development for these purposes (Todd, 2005). The groundwater of Rania area is utilized for different purposes, therefore it is necessary to verify its suitability for these purposes.

5.17.1 Quality Criteria for Drinking Purpose

Drinking water may be defined as sanitarily non-defective water when it does not cause any health trouble or diseases, (Hassan, 1998). Suitability of groundwater as a drinking water depends upon several parameters such as its major and minor inorganic chemicals, organic chemicals, biological characters and radioactivity characters (Al-Manmi, 2007). There are several standards to determine the suitability of a groundwater as a drinking water such as WHO standards, U.S.A standards and Iraqi standards. The water analyses were classified with regard to the hardness using Detay (1997) and Todd (2005) classification. Ganau spring is considered to be very hard. According to Iraqi Drinking Water Standards (IDWS, 1998) in which the recommended limit for hardness is 500 mg/l. Hard water leads to incidence of urolithiosis (WHO, 2006), anencephaly, parental mortality, some types of cancer. Such waters can also develop scales in water heaters, distribution pipes and well pumps, boilers and cooking utensils, and require more soap for washing clothes. The pH (7.1–7.7) of groundwater samples in dry and wet season during 2006 is within the safe limits (6.5–8.5) prescribed for drinking water by Iraqi drinking water standards (IDWS, 1998) and (WHO, 2006) table (5.11). The content of TDS (mg/l) is also safe with respect to the recommended limit of 1000 mg/l allowed in all groundwater samples in both seasons except for the Ganau spring. According to (WHO, 2006) all samples of both seasons are suitable for drinking with respect to cations and anions except the samples of Ganau spring table (5.11). However, all samples exceed the recommended limit for calcium ion according to (IDWS, 1998) which is 50 mg/l. Furthermore, Shkarta spring has high value of (NO_3^-, PO_4^{3-}) that exceed both the (WHO, 2006) and the (IDWS, 1998) limits. Their waters are therefore not suitable for human drinking.

Table (5.11) Comparison of Water Samples with (WHO, 2006 and IDWS, 1998) Standard for Drinking Water

Variables	**WHO (2006) mg/l**	**IDWS (1998) mg/l**	**Dry season (October)**		**Wet season (April)**	
			Wells	**Springs**	**Wells**	**Springs**
Ca^{2+}	75	50	41.6-96.0	48.0-248.0	40-90	47-238.4
Mg^{2+}	125	50	7.7-30.7	11.5-39.0	7-29.8	10-30.0
Na^+	200	200	1.4-49.3	1.41-52.0	1.3-44	1.3-50.0
K^+	12	-	0.79-3.31	0.75-27.0	0.7-3.1	0.77-24.0
Cl^-	250	250	14.0-70.0	21.8-305.0	12.5-63.1	19.2-300.0
SO_4^{2-}	250	250	5.9-84.0	14.0-257.0	5.3-77.0	13.0-248.0
NO_3^-	50	50	5.48-46.0	5.4-42.0	6.8-58.5	6.1-57
PO_4^{3-}	0.4	-	0.01-0.4	0.08-0.8	n.d-0.3	0.04-0.6
T.H	-	500	167.0-319.0	183.0-780.0	158.0-299.0	179.0-719.0
TDS	1000	1000	232.0-415.0	245.8-1312.0	226.6-404.5	237.4-1280.0
pH	6.5-8.5	6.5-8.5	6.65-8	6.7-8.14	6.8-8.12	6.8-8.21
H_2S	0.05	-	-	7.5	-	7.0
Turbidity	5NTU	-	0.2-2.3	0.2-2.5	2.2-10	2.4-11.0

5.17.2 Groundwater Uses for Livestock

According to (Altoviski, 1962) table (5.12) all water samples are very good for livestock and poultry, and according to (Ayers and Westcot , 1994) table (5.13) they are excellent except Ganau spring which is very satisfactory for livestock and poultry.

Table (5.12) Water Quality Guide for Livestock and Poultry Uses (Altoviski, 1962)

Parameters (mg/l)	**Very Good**	**Good**	**Permissible**	**Can be used**	**Maximum limit**
Na^+	800	1500	2000	2500	4000
Ca^{2+}	350	700	800	900	1000
Mg^{2+}	150	350	500	600	700
Cl^-	900	2000	3000	4000	6000
SO_4^{2-}	1000	2500	3000	4000	6000
T.D.S	3000	5000	7000	10000	15000
T.H	1500	3200	4000	4700	54000

Table (5.13) Water Quality Guide for Livestock and Poultry Uses (Ayers and Westcot 1994)

Water Salinity (EC) (dS/m)	Rating	Remarks
<1.5	Excellent	Usable for all classes of livestock and poultry.
1.5 – 5.0	Very Satisfactory	Usable for all classes of livestock and poultry. May cause temporary diarrhoea in livestock not accustomed to such water; watery droppings in poultry.
5.0 – 8.0	Satisfactory for Livestock	May cause temporary diarrhoea or be refused at first by animals not accustomed to such water.
	Unfit for Poultry	Often causes watery faeces, increased mortality and decreased growth, especially in turkeys.
8.0 – 11.0	Limited Use for Livestock	Usable with reasonable safety for dairy and beef cattle, sheep, swine and horses. Avoid use for pregnant or lactating animals.
	Unfit for Poultry	Not acceptable for poultry.
11.0 – 16.0	Very Limited Use	Unfit for poultry and probably unfit for swine. Considerable risk in using for pregnant or lactating cows, horses or sheep, or for the young of these species. In general, use should be avoided although older ruminants, horses, poultry and swine may subsist on waters such as these under certain conditions.
>16.0	Not Recommended	Risks with such highly saline water are so great that it cannot be recommended for use under any conditions.

5.17.3 Groundwater Uses for Building Purposes

Altoviski (1962) classifications were used to evaluate the suitability of water samples for building purposes, table (5.14), and according to his classification all water samples are suitable for building purposes.

Table (5.14) Water Quality Guide for Building Uses (Altoviski, 1962)

Parameters(mg/l)	Na^+	Ca^{2+}	Mg^{2+}	Cl^-	SO_4^{2-}	HCO_3^-
Permissible limit	1160	437	271	2187	1460	350

5.17.4 Quality Criteria for Industrial purpose

According to (Hem, 1991) water samples of Rania area are suitable for all industries except textile, Chemical pulp and paper, because (Ca^{2+} and Mg^{2+}) concentrations exceed maximum permitted values (20 and 12 mg/l) respectively table (5.15).

Table (5.15)Water Quality Standards for Industrial Uses (after Hem, 1991)

Parameters	Textile	Chemical pulp and paper		Wood chemicals	Synthetic rubber	Petroleum products	Canned, dried, frozen fruits and vegetables	Soft-drinks bottling	leather tanning	Hydraulic cement manufacture
		Unbleached	Bleached							
Ca		20	20	100	80	75	--	100	--	--
Mg	0	12	12	50	36	30	--	--	--	--
Cl	0	200	200	500	--	300	250	500	250	250
HCO_3^-	0	--	--	250	--	--	--	--	--	--
SO_4^{2-}	0	--	--	100	--	--	250	500	250	250
NO_3^-	0	--	--	5	--	--	10	--	--	--
Cu	0.01	--	--	--	--	--	--	500	--	--
Zn	--	--	--	--	--	--	--	--	--	--
TH	25	100	100	900	350*	350	250	--	Soft	--
TDS	100	--	--	1000	--	1000	500	--	--	600
pH	2.5 – 10.5	6 – 10	6 – 10	6.5 – 8	6.5 – 8.3	6 – 9	6.5 - 8.5	--	6 - 8	6.5 - 8.5
T (°F)	--	--	95	--	--	--	--	--	--	--
TSS	5	10	10	30	5	10	10	--	--	500
Suitable samples	Un suitable	Un suitable	Un suitable	All samples suitable except Ganau spring	All samples suitable except Ganau spring	All samples suitable except Ganau spring	All samples suitable except Ganau spring	All samples suitable except Ganau spring	All samples suitable except Ganau spring	All samples suitable except Ganau spring
Units(mg/l) except T										

5.17.5 Quality Criteria for Irrigation Purpose

The EC and Na^+ play a decisive role in verifying water suitability for irrigation. Higher salt content in irrigation water causes an increase in soil solution osmotic pressure (Ayers and Westcot, 1994). The salts, besides affecting the growth of plants directly, also affect the soil structure, permeability, and aeration, which indirectly affect the plant growth. Another important chemical parameter for judging the degree of suitability of water for irrigation is sodium content or alkali hazard, which is expressed in adjusted sodium adsorption ratio (SAR_{adj}). The SAR_{adj} is computed, where the ion concentrations are expressed in meq/l, as shown below:

$$SAR_{adj} = \frac{Na}{\sqrt{\frac{(Ca^{2+} + Mg^{2+})}{2}}}[1 + (8.4 - pH_c)] \ldots\ldots\ldots\ldots\ldots \quad (5.13)$$ (Ayers and Westcot, 1994)

There is a close relationship between *SAR* values in irrigation water and the extent to which Na^+ is absorbed by soils. If water used for irrigation is high in Na^+ and low in Ca^{2+}, the ion-exchange complex may become saturated with Na^+, which destroys soil structure, because of dispersion of clay particles. As a result, the soils tend to become deflocculated and relatively impermeable. Such soils can be very difficult to cultivate. The values of SAR_{adj} are as follows and the details are listed in the appendices (11 to 13):

Dry season (October)				**Wet season (April)**			
Wells		**Springs**		**Wells**		**Springs**	
Range	**Med.**	**Range**	**Med.**	**Range**	**Med.**	**Range**	**Med.**
0.09-3.03	0.68	0.09-3.02	1.4	0.08-2.79	0.67	0.08-2.83	1.34
Units (mg/l)							

This evaluation is necessary owing to the fact that private personal and public lands and gardens are presently irrigated using groundwater of the city Rania. There are several methods for ground water classification for irrigation purposes, such as Richards (1954) classification, is one which classify irrigation water according to its SAR_{adj} values and its electrical conductivity. The most recent evaluation of water suitability for irrigation is that proposed by (Ayers and Westcot ,1994) which considers the (EC) values, permeability of the soil, toxic effect of the ions, the SAR of the water, and the side effects of some ions as described in table (5.16).According to this classification all water sample are good (none restriction) for agriculture except Ganau spring which is slightly to moderately suitable for irrigation. A computer program prepared by the researcher to calculate SAR_{adj} and to plot the data on the US Salinity

Laboratory diagram. According to US Salinity Laboratory Diagram all water samples fall as cluster points, in class (C_2S_1) as shown in Fig. (5.11). These waters are relatively good for irrigation purposes, except for the Ganau spring which falls in class (C_3S_1) Fig. (5.11), which means that it is suitable for irrigation. These rates indicate low salinity and low sodium hazards. The good waters can be used for irrigation with little danger of harmful levels of exchangeable Na^+.

Table (5.16) Guidelines for Interpretations of Water Quality for Irrigation (Ayers and Westcot ,1994)

Potential Irrigation Problem				Units	Degree of Restriction on Use		
					None	Slight to Moderate	Severe
Salinity(affects crop water availability)							
	ECw			**µmohs/cm**	< 700	700-3000	> 3000
	(or)						
	TDS			**mg/l**	< 450	450 – 2000	> 2000
Infiltration (affects infiltration rate of water into the soil. Evaluate using ECw and SAR together)							
SAR	= 0 – 3	**and ECw**	=		> 700	700 – 200	< 200
	= 3 – 6		=		> 1200	1200 – 300	< 300
	= 6 – 12		=		> 1.9	1900 – 500	< 500
	= 12 – 20		=		> 2900	2900 – 1300	< 1300
	= 20 – 40		=		> 5000	5000 – 2900	< 2900
Specific Ion Toxicity *(affects sensitive crops)*							
	Sodium (Na)						
	surface irrigation			**SAR**	< 3	3 – 9	> 9
	sprinkler irrigation			**meq/l**	< 3	> 3	
	Chloride (Cl)						
	surface irrigation			**meq/l**	< 4	4 – 10	> 10
	sprinkler irrigation			**meq/l**	< 3	> 3	
	Boron (B)			**mg/l**	< 0.7	0.7 – 3.0	> 3.0
Miscellaneous Effects (affects susceptible crops)							
Nitrogen (NO_3 - N)				**mg/l**	< 5	5 – 30	> 30
Bicarbonate (HCO_3^-)							
(overhead sprinkling only)				**meq/l**	< 1.5	1.5 – 8.5	> 8.5
pH					**Normal Range 6.5 – 8.4**		

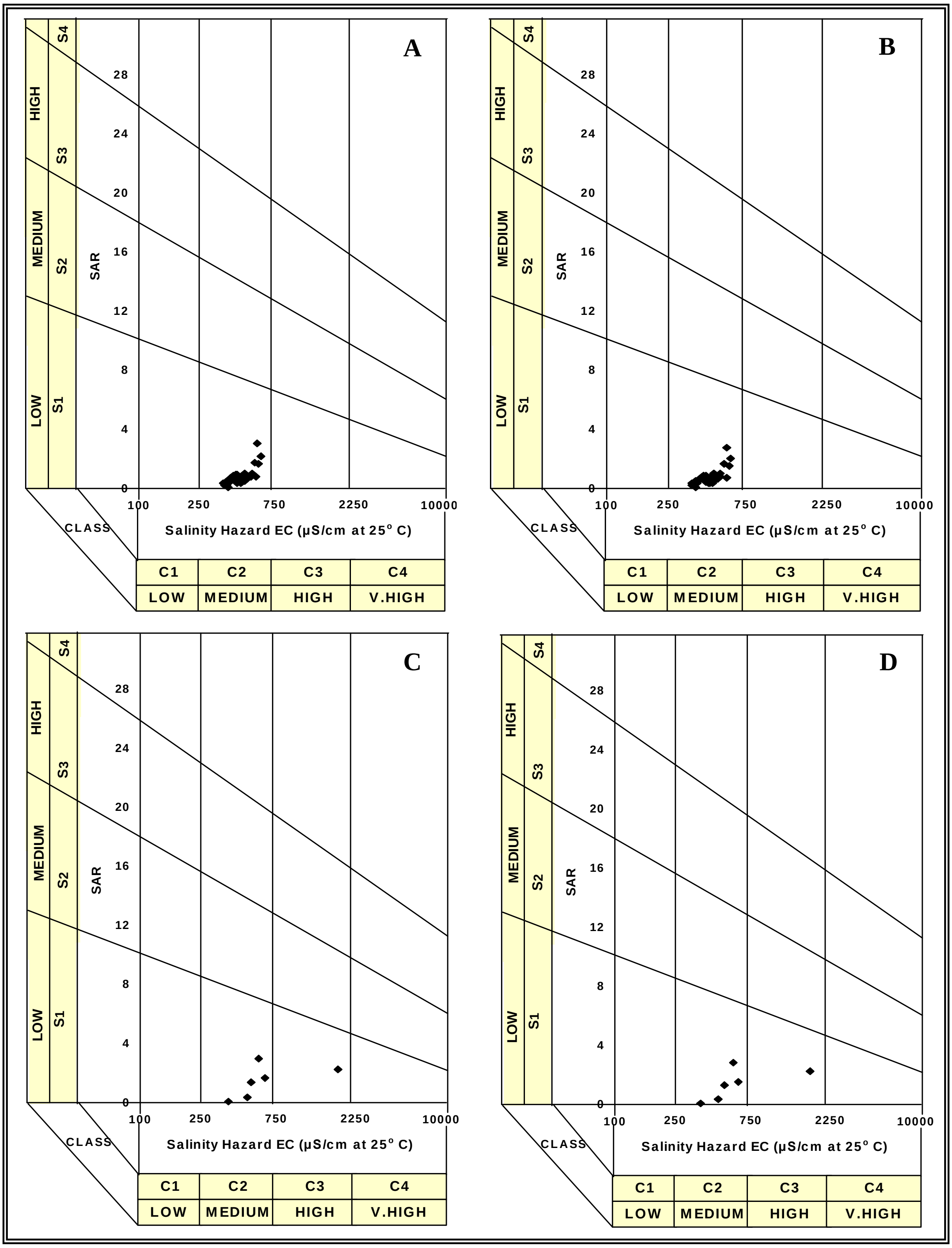


Fig. (5.11) Classification of Irrigation Waters
(After U.S. Salinity Laboratory Staff 1954):
(A) Deep wells (Dry Season) (B) Deep wells (Wet Season)
(C)Springs (Dry Season) (D) Springs (Wet Season)

Chapter SIX

GROUNDWATER FLOW MODELING

Groundwater Flow Modeling

6.1 Evaluation of Groundwater Resources

One of ways to evaluate the ground water resources is mathematical modeling. A model can be used to predict the impact of man’s interference in the hydrological equilibrium of a groundwater basin. It can simulate the effects of new irrigation schemes, new patterns and rate of groundwater abstraction, and artificial recharge of the basin, and can do so for any desired length of time (Ahlfeld et al., 2005, Todd, 2005,Grabert , 2006, Sarwar and Eggers, 2007).

6.2 Purpose

The purpose of this model is to simulate aquifer behavior at normal conditions as well under various stress schemes whereby it could predict the impact of hypothetical future water withdrawals. The model will be used as a management tool to simulate future hydraulic heads given various projected water-use demands. In addition, the model will be used in future cooperative studies to develop a conjunctive-use optimization model for determining sustainable yield of Quaternary aquifer. This chapter briefly describes the hydrogeology of the model area, specifically in relation to the application of model's boundary conditions and hydraulic parameters. It is limited to ground-water flow in the Quaternary aquifer .Various scenarios of projected ground-water withdrawals for years 2005 to 2010 are simulated.

6.3 Principles of Groundwater Modeling

Groundwater modeling can be used to simulate the flow and transport processes in an aquifer. A groundwater model can be used in an interpretative sense to gain insight into the head distribution and the flow pattern within a watershed. It can also be used to assess different scenarios that may occur in the future or to assess and better understand processes that have already occurred. A model is an abstraction of the reality in order to aid the understanding of and/or predict the outcomes of the real system (Sarwar and Eggers, 2007). It is however, practically impossible to perfectly represent all natural processes included, and consequently all groundwater models are simplifications of real situations (Anderson and Woessner, 1992). Groundwater models simulate the hydraulic head and flows, and can be either physical or mathematical (McKee, et al., 2003, Asim, 2005). The model can be steady state, representing conditions where the inflows and outflows to the model are constant with time. For time variant or transient models, initial conditions must also be specified. Fig. (6.1) shows a simplified description of a groundwater model with its inputs and outputs.

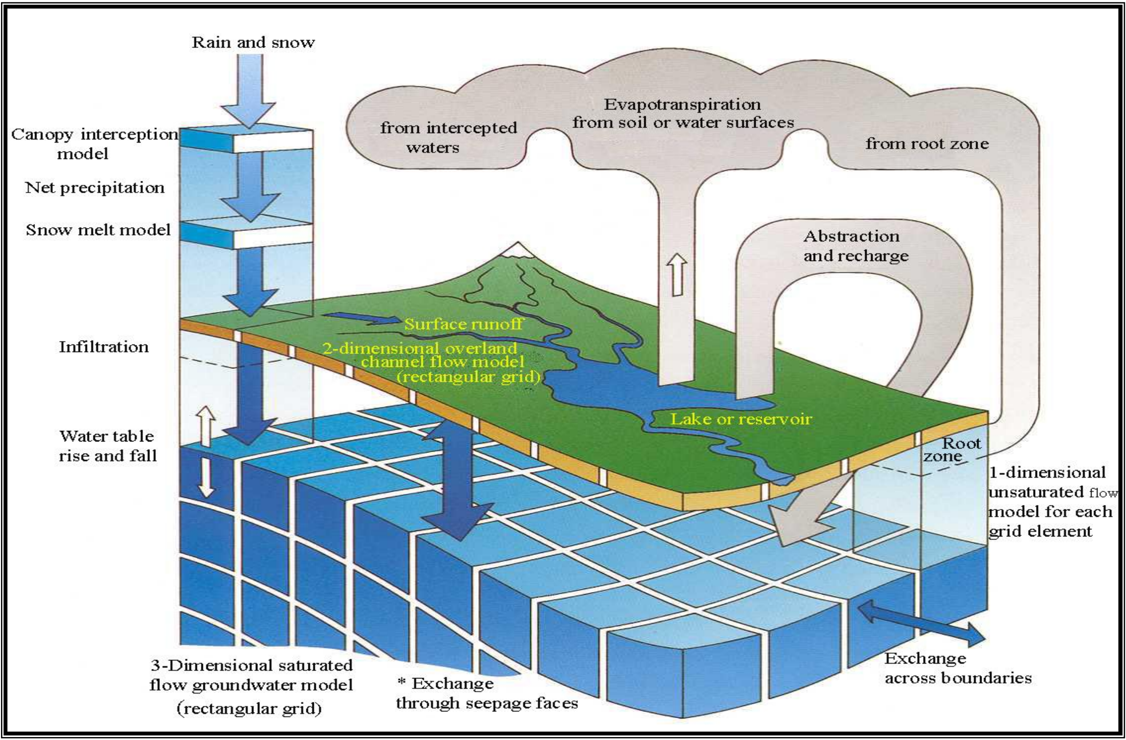


Fig (6.1) Simplified Description of a Groundwater Model with its Inputs and Outputs (After Anderson and Woessner, 1992)

6.3.1 Data Required Developing a Groundwater Model

The first phase of groundwater model study consists of collecting all existing geological and hydrological data on the groundwater basin in question. This will include information on surface and subsurface geology, water table, precipitation, evapotranspirtation, pumped abstraction, stream flows, soil land use, vegetation, irrigation aquifer characteristics, stream boundaries, and ground water quality (Kresic, 1997, Asim, 2005, Szucs**,** et al.2006). Developing and testing the numerical model requires a set of quantitative hydrogeological data that fall into two categories:

- Data that define the physical framework of the groundwater basin
- Data that describe its hydrological stress

These two sets of data are then used to estimate groundwater balance of the basin. The separate items of each set are listed in table (6.1).

Table (6.1) Data Required Developing a Groundwater Models

Physical frame work	**Hydrological stress**
1. Topography 2. Geology 3. Types of aquifers 4. Aquifer thickness and lateral extent 5. Aquifer boundaries 6. Lithological variation within the aquifer 7. Aquifer characteristics	1. Water table elevation 2. Type and extent of recharge area 3. Rate of recharge
Groundwater balance	

It is common practices to present the results of hydrogeological investigation in the form of maps, geological sections, and tables. This procedure is also followed when developing the numerical model. The only difference is that for the model specific set of maps must be prepared, these specific maps are:

- Contour maps for the upper and lower aquifers boundaries
- Maps for the aquifer characteristics
- Water table contour maps
- Maps for the net recharge of the aquifer system.

6.3.2 Conceptual model

The purpose of a conceptual model is to organize field data and to consider how these data can be translated into a physical or mathematical model. It is hence one of the first steps in the modeling process (Schwartz, 1990, Rojas and Dassargues, 2007). A conceptual model is a simplified representation of reality with a focus on the geology and hydrogeology. Construction of a conceptual model includes the definition of the basin boundaries, aquifers and non-aquifers recharge and discharge sources (Anderson and Woessner, 1992, WMO, 1994).

6.3.3 Grid design

In order for a numerical model to be able to solve the differential equation, a grid is superimposed over the study area. The model sets up a water balance equation for each discrete cell in the grid, thus creating a system of equations that is solved numerically cell by cell. All inflows and outflows for the specific cell are represented, and the solution is a value for the hydraulic head. There are two different types of grid designs; finite difference grids and finite element grids. ***MODFLOW*** uses the finite difference grid in which the cells are rectangular. In finite element models, the spatial domain is divided into a mesh of elements that could be of irregular shape. The advantage of the finite difference grid used in ***MODFLOW*** is that it is easier to use than the finite element grid, but on the other hand some irregular features can be better represented by the finite element grid (Anderson and Woessner, 1992, Stanton , 2003). In the block-centered finite difference method, an aquifer system is replaced by a discretized domain consisting of an array of nodes and associated finite difference blocks (cells), Fig. (6.2) shows the spatial discretization scheme of an aquifer system with a mesh of cells and nodes (5 rows, 9 columns, and 5 layers) at which hydraulic heads are calculated, the location of each cell in the grid is described with an *i,j,k* indexing system (Kresic,1997) where:

- *i* is the row index: *i*=I,2,... "n row"
- *j* is the column index: *j*=I,2... "n column"
- *k* is the layer index: *k*= 1,2,... "n layer"

The nodal grid forms the framework of the numerical model. Hydrostratigraphic units can be represented by one or more model layers. The thickness of each model cell and the width of each column and row can be specified. The locations of cells are described in terms of layers, rows, and columns (Chiang, 2005).

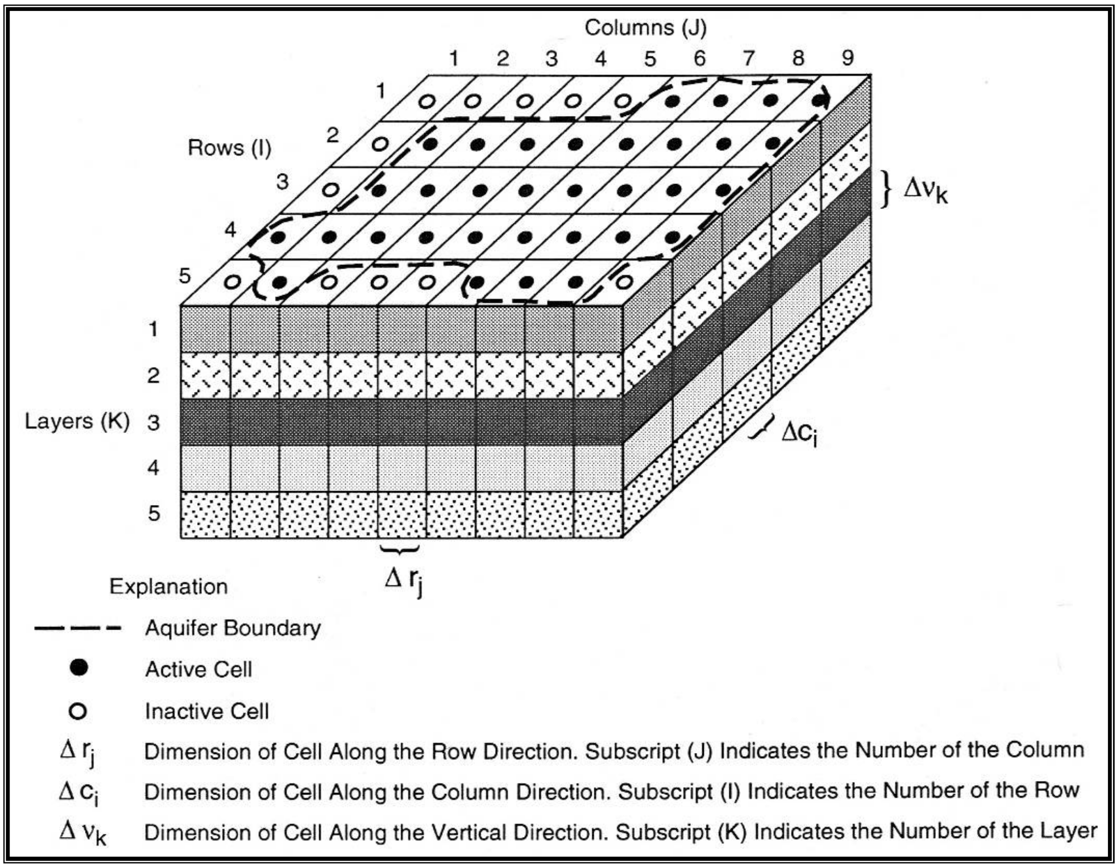


Fig. (6.2) A Discretized Hypothetical Aquifer System

(After Kresic, 1997)

6.3.4 Boundary conditions

The boundary conditions of the differential equation represent either a dependent variable (head) or the derivative of the dependent variable (flux) at the model boundaries. There are three types of boundary conditions for groundwater flow models:

- Specified head boundaries where the head is given.
- Specified flow boundaries where the flow across the boundary is given.
- Head dependent boundaries where the flow across the boundary is calculated.

From a given value of the head, this type is usually referred to as mixed type of boundary condition the boundaries can be physical or hydraulic. Physical boundaries can be for example impermeable rock, lakes or waterways. Examples of hydraulic boundaries are water divides or flow lines (Anderson and Woessner, 1992, WMO, 1994).

6.3.5 Calibration and Sensitivity Analysis

Although often explained separately in modeling reports, calibration and sensitivity analysis are inseparable and are part of the same process.

Calibration is the process of finding a set of boundary conditions, stresses, and hydrogeologic parameters which produces the result that most closely matches field measurements of hydraulic heads and flows (Kresik, 1997, Hill, 1998, Attia and Sadoon, 2007).

Model calibration can be performed for steady state conditions, transient conditions, or both.

6.3.6 Verification

A model is verified "if its accuracy and predictive capability have been proven to lie within acceptable limits of error by tests independent of the calibration data" (Anderson and Woessner, 1992, Todd, 2005). A typical verification is performed for an additional field data set in either steady state or transient simulation. If the calibrated model parameters such as boundary conditions, stresses and distribution of hydrogeologic characteristics (conductivity/ transmissivity, effective porosity) are correct , this additional independent field data set should be closely matched by the model for the new boundary conditions and stresses.

6.3.7 Prediction

Once the model is calibrated, preferably for both steady state and transient conditions, it can be used for prediction which is the purpose of most modeling efforts. Prediction is the reward for the effort put into the all preceding modeling phases and the stage which model designers, more or less patiently, wait for. It is not uncommon, and it is even recommended, that the user performs a "mock prediction" during early stage of model development (Stanton, 2003, Todd, 2005).

6.3.8 Flow and Transport Programmes

1. MODFLOW

MODFLOW is one of the world’s most used programs for groundwater modeling. ***MODFLOW*** can be used for unconfined, confined and combination aquifers and for both two and three dimensional flow. As it focuses on the saturated zone, processes taking place at the surface and in the unsaturated zone are not represented. The partial differential equation (6.1) describing the groundwater flow is solved numerically for each discrete cell in the defined grid. Equation (1) solved in ***MODFLOW*** is a combination of the three-dimensional Darcy’s law and the mass balance equation (Ahlfeld, et al., 2005):

$$\frac{\partial}{\partial x}(K_{xx}\frac{\partial h}{\partial x})+\frac{\partial}{\partial y}(K_{yy}\frac{\partial h}{\partial y})+\frac{\partial}{\partial z}(K_{zz}\frac{\partial h}{\partial z})-w=S_c\frac{\partial h}{\partial t}\text{........}\quad\textbf{(6.1)}$$

Where hydraulic head, *h* (m), is the dependent variable. The hydraulic conductivity is represented here in the three coordinate directions (x, y and z) by *Kxx, Kyy* and *Kzz* (m/day), *Ss* is the specific storage (dimensionless) and *W* (1/day) represents the general source/sink term per volume of aquifer. If *W* is positive, water is leaving the system and if it is negative water is entering the system, *t* (days) stands for time. If the problem is steady-state, there is no time-variant parameter and the right side of the equation vanishes. The result of a ***MODFLOW*** simulation is typically illustrated as contours or isolines representing the groundwater surface. (Anderson, and Woessner, 1992)

6.4 Model Purpose of Rania Quaternary Aquifer

Ground-water flow through the Rania area (Quaternary aquifer) was simulated using a three-dimensional finite-difference ground-water flow model. The purposes of the ground-water flow model were to quantify sustainable yield for the ground-water flow system, create sensitivity analyses of the Quaternary aquifers' properties, and produce predictive modeling results based on safe yield and sustainable yield water use scenarios, and predictive results to the current pumping condition.

6.5 Model Objectives

The objectives for this ground-water flow model included calibrating the model to a steady-state condition using the geological and hydrogeological characterization to establish an interpretive model. Additionally, the model was calibrated to the transient condition using the established steady-state calibration and hydrographs. The model results document a method to quantify the sustainable yield of a ground-water flow system using a numerical ground-water flow model. The transient calibration was used to simulate potential future water use scenarios. A final objective was to document the effects that current water usage is having on the hydrological system of the Rania area.

6.6 Conceptual Model

The Quaternary aquifer is the most extensive hydrostratigraphic unit in the Rania area, and therefore has the greatest storage of the active model area. Cross sections show that the Quaternary aquifer is approximately more than 140 m thick. The northern part of the studied area is predominantly carbonate rocks. The layer of the model was established based on the Quaternary.

Recharge is distributed throughout the model domain based on lithological facies of the Quaternary aquifer .

6.7 Spatial Descritization

The region was divided into a grid with one layer of cells. The layer has (107) columns and (59) rows of cells. Each cell represents (416) meters in the x-direction, (416) meters in the y-direction. The model contains (6313) total cells with (2062) active cells, the total model surface area is (357) km^2. Inactive areas were established where no water level data could be collected due to lack of wells.

6.8 Boundaries

Boundary conditions have great influence on the computation of flow velocities and heads within the modeled area. The boundaries which are specified for the numerical model are similar to those of the Quaternary conceptual model and are shown in Fig. (6.4).Three types of boundary conditions are used in the Rania groundwater flow model, specified head positive values (+1) in the I bound array defines an active cells when expressing the domain inside. A (0) value defines inactive cells (no flow) taken place within the cells I bound defines any outer flow boundary cells which represented by at the northeast and set at the foothills of the Rania and Pelewan anticline, while Dokan Lake is represented as a constant head (-1) at the south and southeast. Carbonate aquifers were excluded from the model area due to the lack of wells and water-level data. The two rivers Dimana and Shaoor excluded from the boundary due to lack of leakage factor and the amount of recharge from them.

6.9 Initial Hydraulic Head

MODFLOW requires initial hydraulic heads at the beginning of a flow simulation .Initial hydraulic heads at constant head cells are used as specified head values of these cells, for steady state simulation the initial heads are used as starting values, the water-level data for (27) wells were collected for the period of 2005.Actual head values derived from the water wells which obtained from the Sulaimani drilling directorate were loaded to the model as initial heads.

6.10 Water Budget

Inputs of water to the Quaternary aquifer include direct recharge from water surplus, subsurface flow from the surrounding carbonate aquifers, and possible exchange with Shaoor and Dimana streams. The outputs include pumping for irrigation and residential use, discharge through streams baseflow, subsurface flow to Dokan lake and direct evapotranspiration. The total value for discharge due to pumping was evenly distributed through the specified flow cells by taking the calculated pumping value and distributing it evenly to each cell assigned to represent pumping well .Recharge was distributed throughout the study area to account for the recharge value reported in the water budget.

6.11 Software Selection

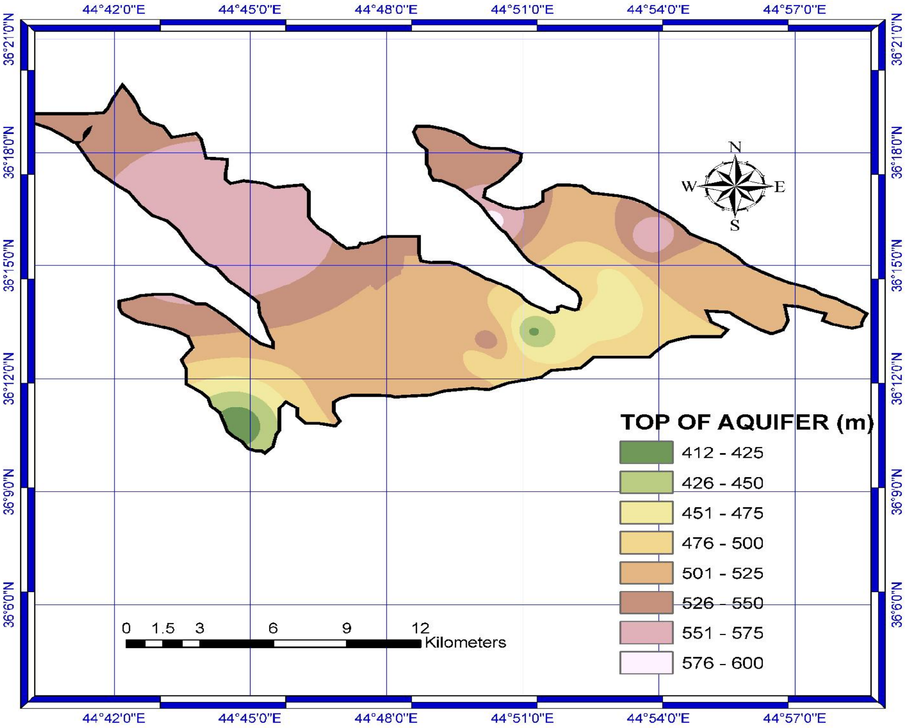
The processor software chosen for this model is ***PROCESSING MODFLOW***, a three-dimensional finite-difference ground-water flow model (Chiang and Kinzelbach, 2003). Though the geology and topography of the study area, a finely spaced finite-difference grid was used to simulate the system. Hydraulic head is calculated at the node in the center of each cell, and is the average value calculated from the adjacent cells. All of the hydraulic properties are constant throughout the cell.

6.12 Parameter Values - Hydraulic Conductivity

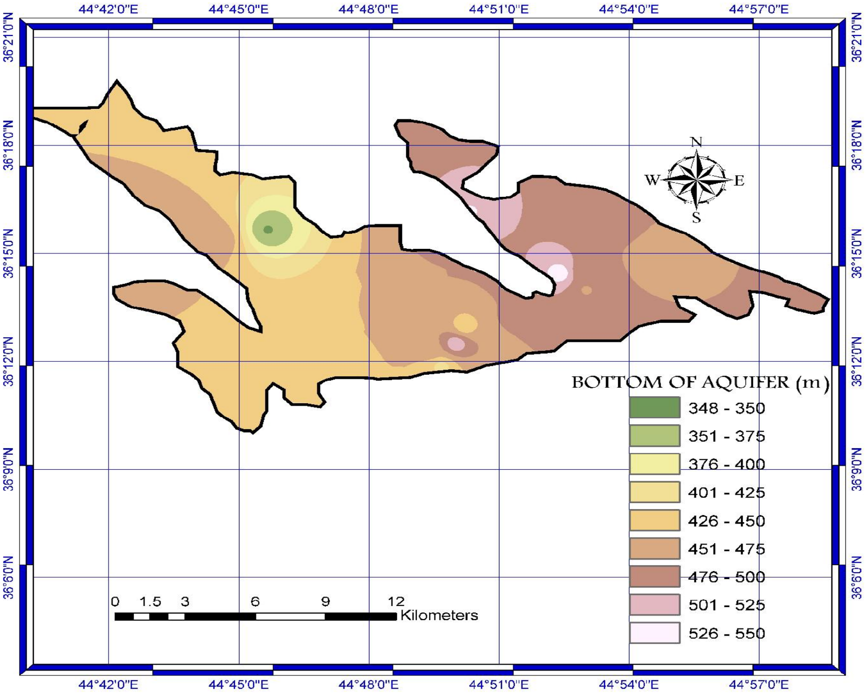
Initial values of hydraulic conductivity, transmissivity, and specific yield for the Quaternary aquifer were evaluated from well tests and aquifer test of (11) wells. These values were used as initial parameter values for the model. The values were altered later through trial and error during calibration. Initial estimate of recharge was calculated using the precipitation data from the Dokan meteorological station located close to the studied area. The method of soil water balance was used for estimating recharge from precipitation data. The calculated values were used to provide initial values to the recharge zones.

6.13 Aquifer Material Properties

The top elevation and the bottom elevation of the layer were also provided; the values for the top and bottom of the aquifer were derived from data sheet of the wells obtained from the data bank of water resources management directorate in Baghdad (Fig. 6.3 A, B) .Transmissivity is one of the input readings required in the model; the distribution of aquifer transmissivity was also prepared and the values were loaded to the model. Flow packages representing recharge (L/T) with positive values and wells (L^3/T) with negative values will be introduced to the transient model .Recharge is defined by assigning the data to each vertical column of cells.



(A)



(B)

Fig.(6.3)A) Top of the Aquifer, B) Bottom of the Aquifer

The input parameters are assumed to be constant during a given stress period, negative values indicate pumping wells; ***MODFLOW*** assumes that a well penetrates the full thickness of the cell (Chiang, 2005) .To calculate heads in each cell in finite difference grid ***PROCESSING MODFLOW*** (***PMWIN pro)*** prepares one finite difference equation for each cell, expressing the relationship between the head at a node and the heads at each of the six adjacent nodes at the end of time step. Strongly implicit procedure (SIP) package is used to solve the system of finite difference equation.

6.14 Time Stepping

Time stepping is desicretizing of flow equation through time and is used in transient simulation while in steady state simulation time variation is not included.

6.15 Dokan Lake Stage

Three scenarios of lake stage were simulated, the first was when the stage is set at (489 m) which was the predominance lake level in 2005, the second was set as the minimum stage of the lake which is at (486 m), and the third was set as (511 m) which is the maximum stage of the lake. The Lake stage data were obtained from the Dokan Dam directorate.

6.16 Results

6.16.1 Model Calibration

Calibration is the process of adjusting model inputs to achieve a desired degree of correspondence between the model simulations and the natural groundwater flow system (Harbaugh, 2005, Navarro, 2002). In other words, the model was calibrated through trial and error until the solution matches the known (usually hydraulic heads) .For this model calibration is made for hydraulic heads inputs (manual calibration) to reach the matching between inputs and model simulation. After all of these hydraulic heads are the primary results of ***MODFLOW*** simulation Fig. (6.4).The shape and distributions of observed (Fig. 3.5 in chapter three), and calculated hydraulic heads are similar and same flow direction.

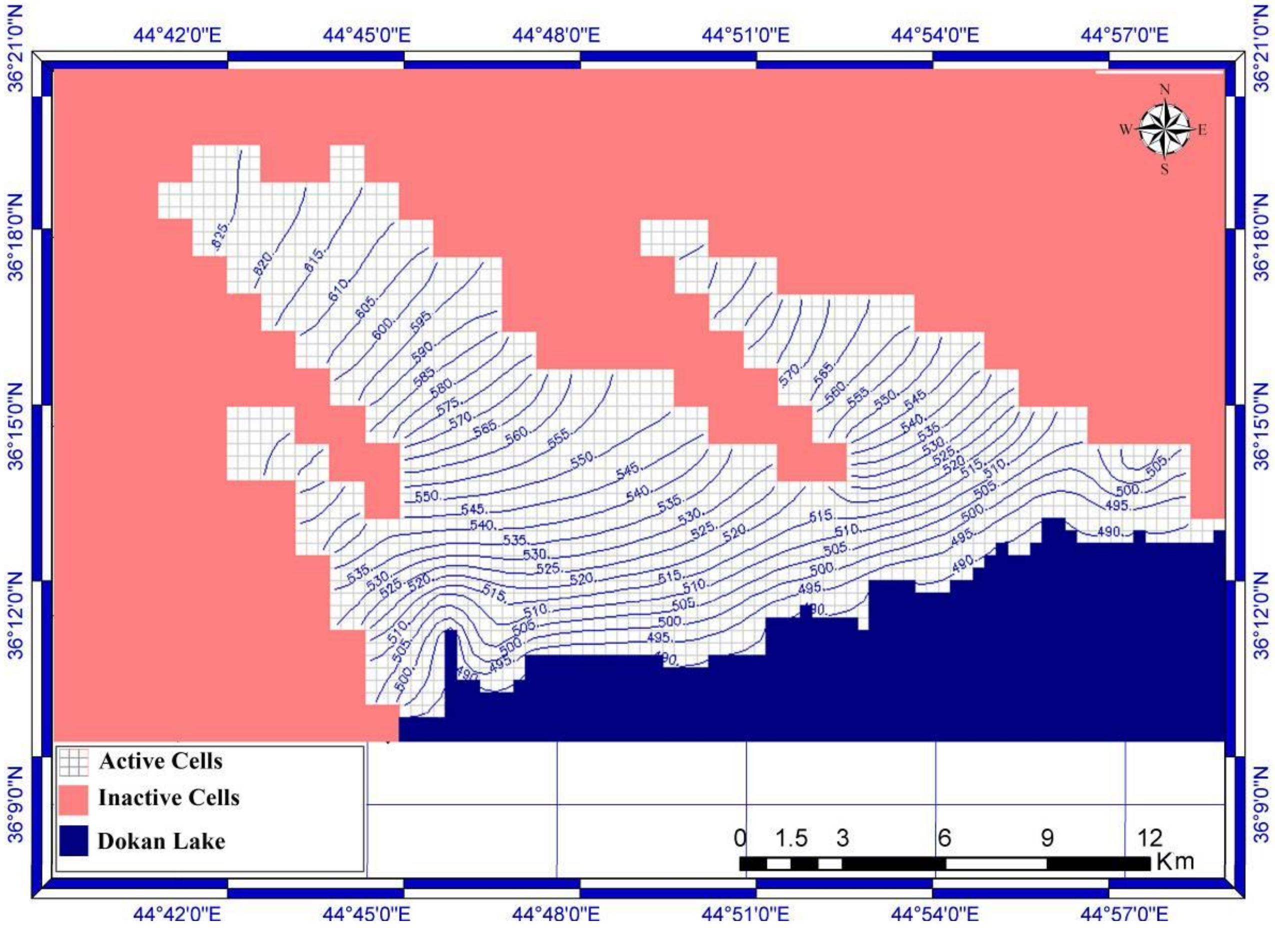


Fig. (6.4) Calculated Heads in Steady State Simulation

PMWIN pro calculates water budget for each sub region in each time step, the percent of discrepancy:

$$Discrepancy\ \% = \frac{100 \times (INPUT - OUTPUT)}{(INPUT + OUTPUT)/2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (6.2)$$

In this step (steady state simulation) the percent discrepancy was (-0.05 %) this means that the model equation has been correctly solved, this is agrees with what is mentioned in the literature requiring that the mass balance for any time step in a model should have less than a 1% discrepancy (Harbaugh, 2005).The calibration criteria for the steady-state model were established using the criteria outlined in Harbaugh (2005).

After the steady-state model was calibrated, the transient model was possible to calibrate. The transient calibration involved altering several model parameters, including parameters that had been established through the steady-state calibration. Upon the calibration of the transient condition, the steady-state condition was re-calibrated with the transient parameter values to assure that the model satisfied the calibration criteria for both the steady-state and transient conditions.

The calibration criteria included maintaining the mass balance requirements for each time step (less than 1% discrepancy). The qualitative criteria for the transient calibration were to create simulated hydraulic heads which had the same trends and the same magnitude of change as the observed hydraulic heads. The transient calibration had two objectives. The first was that the transient calibration would serve as a validation of the steady-state calibration. The transient calibration would also establish the framework for the creation of predictive scenarios. The predictive scenarios had different pumping scenarios to simulate potential water use in the area.

6.16.2 Transient Simulation & Model Development

The application of groundwater model to a real situation depends on the accuracy of the input data, the availability of these data requires considerable analysis, like the evaluation of hydrological data (rainfall, evapotranspiration, surface runoff, soil moisture) .Groundwater recharge was evaluated based on these calculations.

For transient calculations of groundwater flow simulation, an initial condition created from the steady state model was used .Sinks (wells) and sources (recharge) were also introduced for this simulation. The initial base line condition is simulated with no pumping wells, while recharge is modeled as a source.

The aquifer receives (117) mm/year as aerial recharge; the mentioned value is a groundwater recharge during four months Dec. (17.8 mm), Jan. (44.73 mm), Feb.(32.62 mm), and (21.87) mm in April.

Since the model uses (L/T) as units for recharge, the values changed to 0.00057, 0.00144, 0.001165 and 0.000705 m/day respectively for the four months.

6.16.3 Time Stepping in Transient Simulation

1. Simulation without Pumping

The time for one year simulation without sinks (wells) is divided into 12 stress periods, each stress period represents a month ,while the period length of each stress period are divided into days so the total time steps is equal to 12 months, while the total simulation time equals to 365 days. The model output as a monthly flow map depends on the variation of the above package (groundwater recharge).

The calculated head values for each step are noticed to show slight differences in head contours. Fig. (6.5) shows the calculated heads for the last step in this simulation (September), also the heads were calculated for minimum and maximum lake stage Figs. (6.6 and 6.7).

From the results it is obvious that the Dokan lake stage has significant influence on the head fluctuations within the area close to the lake.

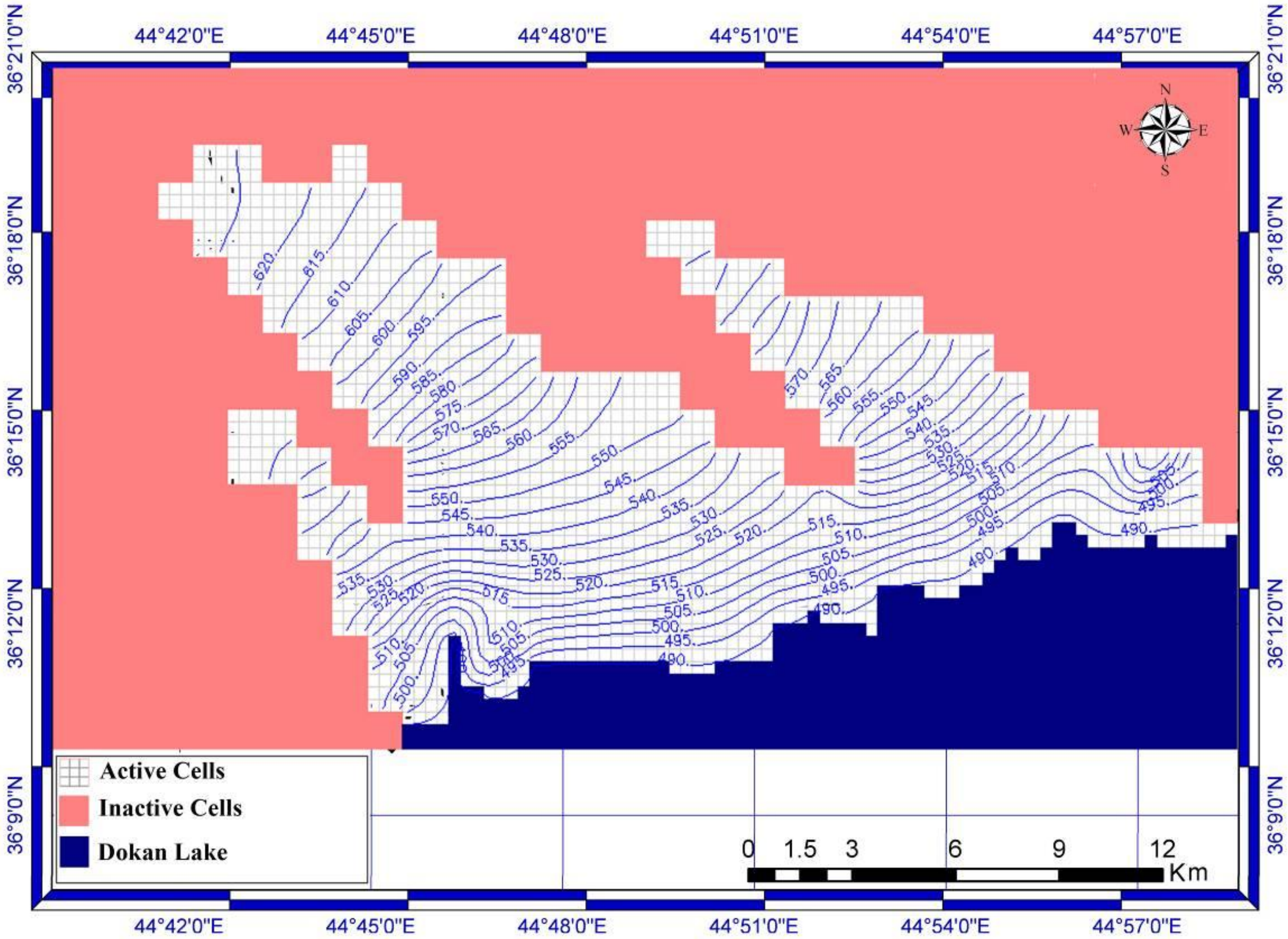


Fig. (6.5) Calculated Hydraulic Heads at the end of 1 Year Transient Simulation (Lake State 489 m)

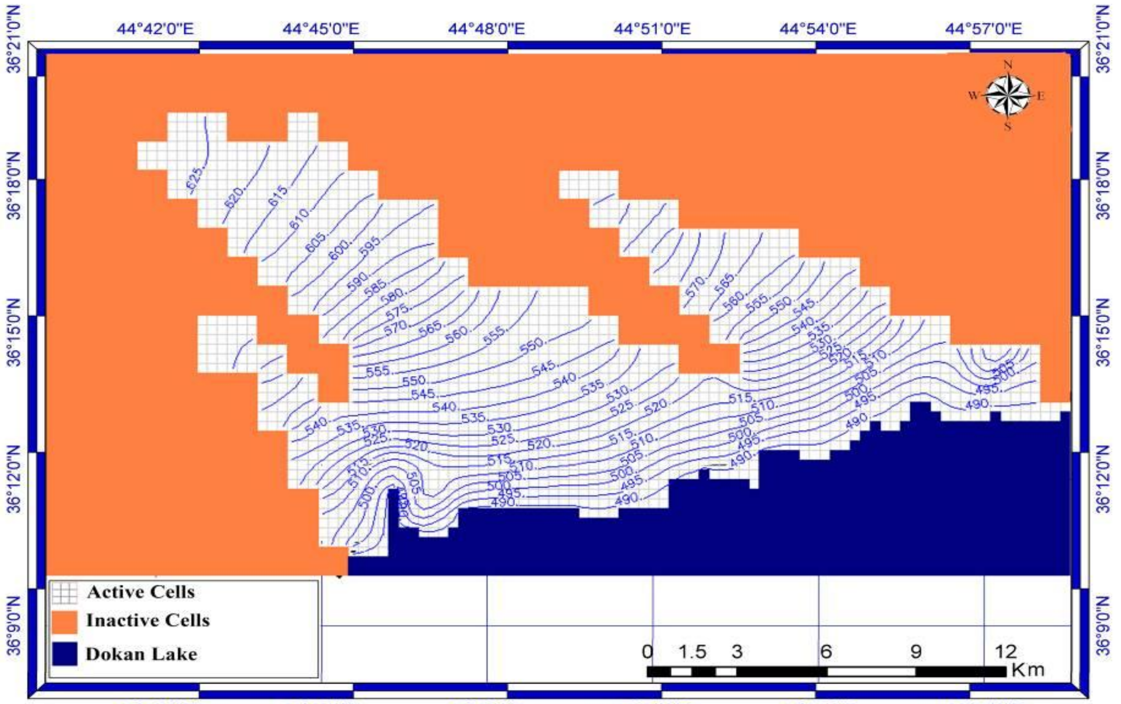


Fig. (6.6) Calculated Hydraulic Head at the end of 1 year Transient Simulation (Dokan Lake State at 486 m)

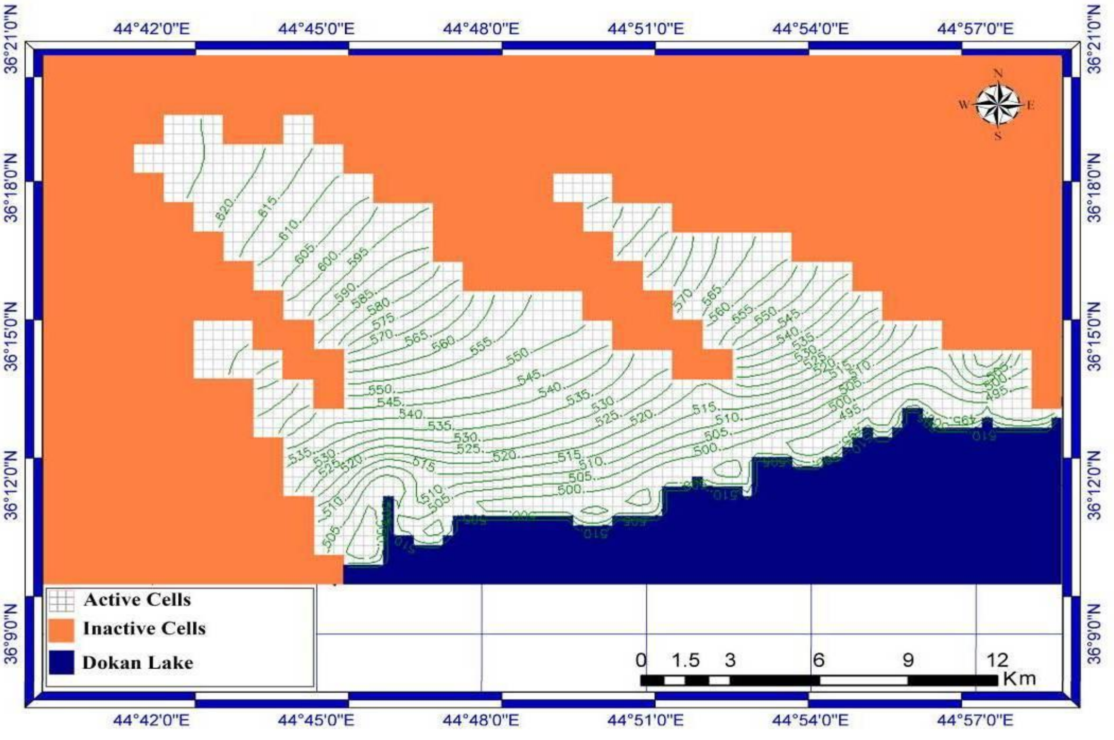


Fig. (6.7) Calculated Aquifer Hydraulic Head at the end of 1 Year Transient Simulation when Dokan Lake Stage is Set at 511 m

6.17 Predictive Simulation

A model may be used to predict future groundwater flow conditions, such simulation estimates the hydraulic response of an aquifer, and also it can predict the pumping rate needed to monitor the hydraulic heads.

A pumping (groundwater management) strategy is a set of spatially and possibly temporary distributed rates of extracting water from aquifer (Parelta, R.C., 2004) .

To predict the simulation for 1 and 5 years, the stress period were divided into 10 stress periods, one year simulation is divided into 2 period lengths ,one for wet period represented by 120 days while the another one for dry period represented by 240 days. A number of discharged wells were added to the model and distributed in the areas of population like Rania with 49 wells ,Chuar Qurna 36 wells ,Hajiawa 30 wells ,and Shkarta camp 12 wells with mean daily discharge of (600 m^3/day) .Some cells were selected for head cross check shown as cross section Fig. (6.8).Table (6.2) shows the hydraulic heads for the selected cells during different simulation periods. Figs. (6.9 and 6.10) show the calculated head values after 1 and 5 years with pumping.

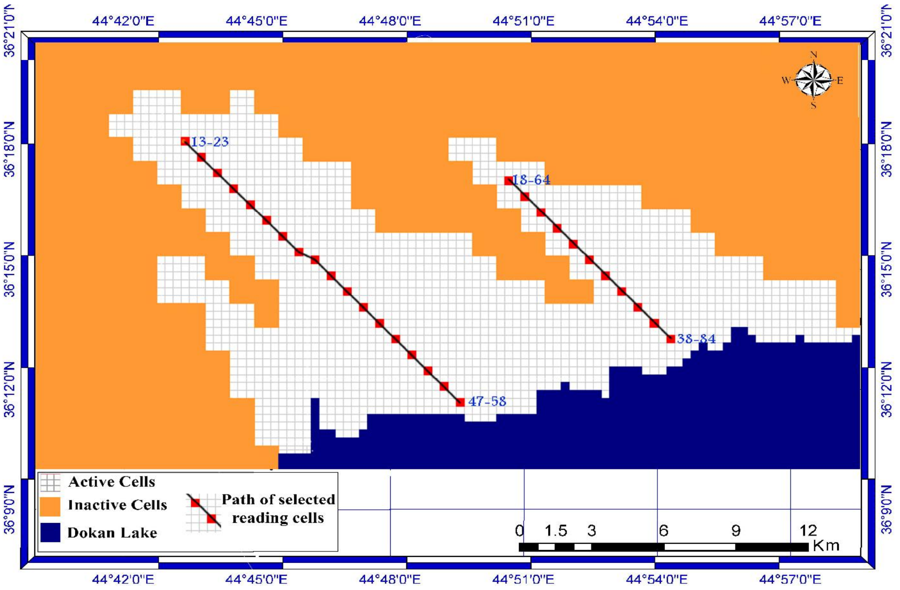


Fig. (6.8) Paths of Selected Cells for Reading Hydraulic Head Checking for Transient Simulation

Table (6.2) Aquifer Hydraulic Head for Selected Cells during Different Simulation Periods

cell No.	Hydraulic Heads (m. a.s.l)			Hydraulic Heads (m a.s.l) with Pumping	
	INPUT	**Steady State**	**1 Year Later**	**1 Year Later**	**5 Years Later**
13-23	622.00	622.31	622.57	622.73	622.34
15-25	618.00	618.66	618.72	618.71	618.75
17-27	614.00	614.56	614.62	614.63	614.62
19-29	610.00	610.03	610.23	610.35	609.99
21-31	604.00	604.67	604.88	604.94	604.74
23-33	598.00	598.00	598.21	598.26	598.10
25-35	590.00	589.98	590.25	590.45	590.04
27-37	580.00	580.57	580.49	580.35	580.71
28-40	574.00	574.38	574.57	574.73	574.43
30-42	565.00	565.46	565.50	565.47	565.53
32-44	558.00	557.28	557.35	557.35	557.37
34-46	550.00	550.02	550.17	550.25	550.11
36-48	543.00	543.16	543.32	543.34	543.23
38-50	536.00	535.77	536.08	536.14	535.92
40-52	528.00	527.31	527.91	528.20	527.42
42-54	516.00	516.84	516.94	516.87	516.96
45-56	506.00	506.13	506.19	506.29	506.14
47-58	496.00	496.63	496.20	496.07	496.05
18-64	592.00	592.03	592.35	592.44	592.18
20-66	586.00	585.89	586.12	586.21	585.99
22-68	578.00	578.44	578.53	578.50	578.57
24-70	572.00	571.83	572.09	572.17	571.97
26-72	565.00	565.10	565.43	565.56	565.23
28-74	556.00	556.37	556.64	556.71	556.52
30-76	545.00	544.99	545.32	545.35	545.18
32-78	534.00	533.60	534.15	534.35	533.60
34-80	522.00	521.76	522.12	522.23	521.72
36-82	509.00	509.00	508.99	508.93	508.95
38-84	497.00	497.29	496.72	496.58	497.08

The maximum draw down for transit simulation with pumping was (0.94 m) for one year simulation and (0.96 m) for five years simulation (table 6.2).

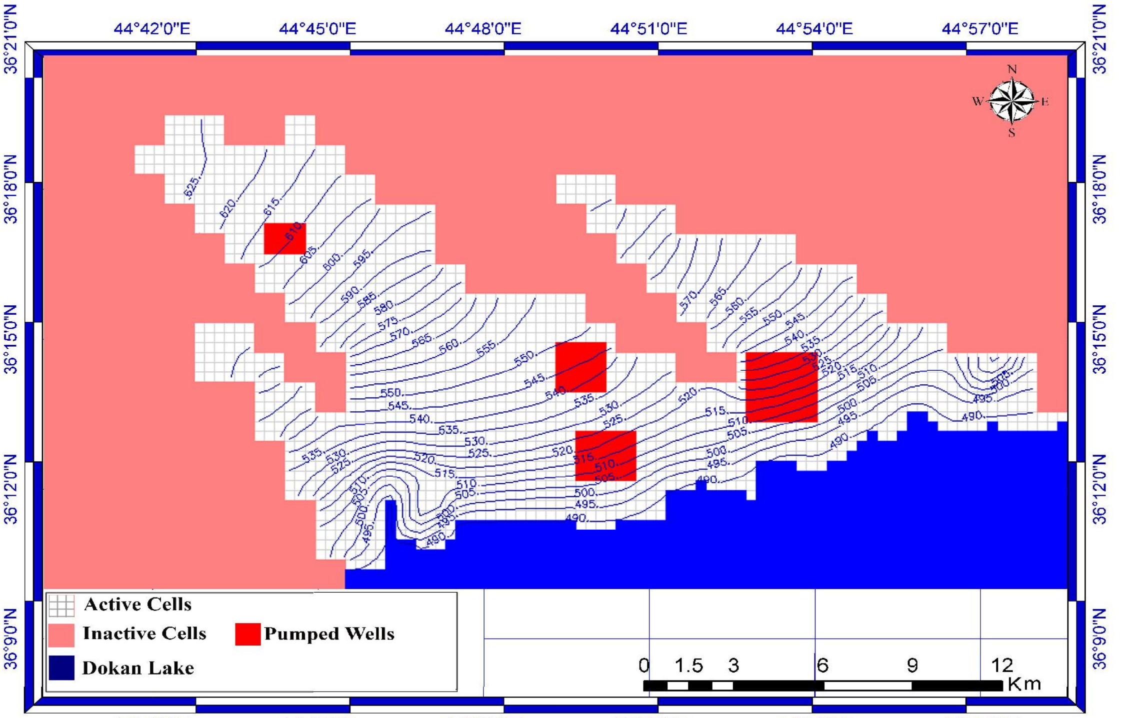


Fig. (6.9) Calculated Hydraulic Head at the end of 1 Year Transient Simulation (with Pumping)

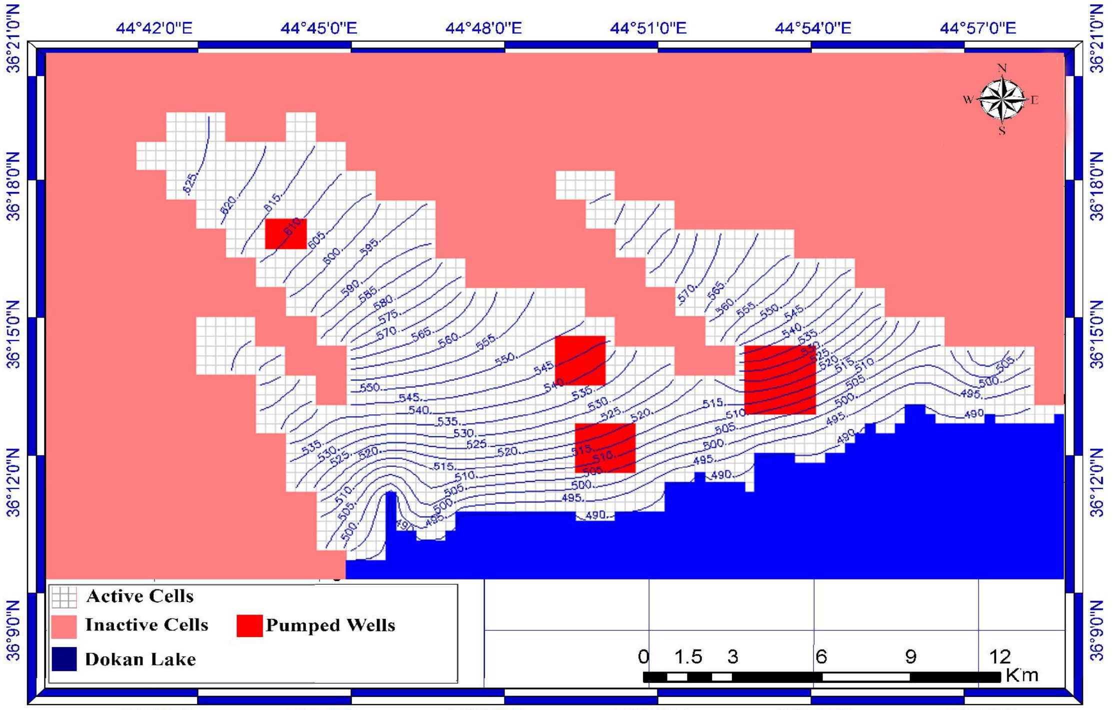


Fig. (6.9) Calculated Hydraulic Head at the end of 5 year Transient Simulation (with Pumping)

CHAPTER SEVEN

SUMMERY, CONCLUSIONS AND RECOMENDATIONS

Summary, Conclusions and Recommendations

7.1 Summery and Conclusions

The analysis of the data in the previous chapters leads to the following conclusions:

1. Location and Geological Characterization

The studied area is located northeastern of Iraq to the northwestern part of Sulaimaniyah Governorate between latitude ($36^{\circ}\ 09^{-}\ 42^{=}$, $36^{\circ}\ 32^{-}\ 00^{=}$) and longitude ($44^{\circ}\ 30^{-}\ 00^{=}$, $44^{\circ}\ 59^{-}\ 41^{=}$), with an approximately area of (981) km^2. The municipal center of Rania is located approximately 10 km north of Dokan Lake. It is approximately 131 km, from the Sulaimaniyah city. The topography of the district is mountainous in the north, with elevations exceeding 2400 m a.s.l, while in the southern plains near Dokan Lake the elevations reduce to about 500 m.a.s.l.

Rania district composed of different geological rock units belonging to different age range from early Jurassic (Sarki Formation) to Quaternary deposits.

2. Meteorology and Water Balance

-Regarding the climate in the area is characterized by rainy cold winter and hot-dry summer. The average annual rainfall for the period (1980-2005) is 743 mm/year, relative humidity is 56.5 % the average temperature is 33.3 °C, average wind speed is 2.36 m/sec, average sunshine duration 10.97 hours and annual pan evaporation is 2408.3 mm/year.

-By applying (CROPWAT 4.0) program the annual reference evapotranspiration on the bases of Penman equation was 1709.5 mm, annual actual crop evapotranspiration was 1230.8 mm, and effective precipitation was (620.6 mm).

-According to (Al-Kubaisi, 2004) classification the climate of Rania district classify as (*humid-moist*) for both mode (1 and 2).

- The crop groups which are exist in the studied area include Wheat 44 %, Barley 31 % Sunflower 13.5 %, Chickpea 7 %, Maize 0.6 %, Tobacco 0.3 %, and Sweet Melon 0.12 %.The crop water requirement, ETo, ETc, Effective Rainfall, FWS, NIWRi (mm/period), and NIWRi (m^3/ha) for the mentioned crops were calculated based on (CROPWAT 4.0) program and the results are as table below:

Out put / **Crop type**	**Barley**	**Wheat**	**Sunflower1**	**Sunflower2**	**Tobaco**	**Cheakpea**	**Sweet melon**	**Maize**
Eto(mm/period)	754	897	724	906.1	783	551	849	842
CWR (Etm)(mm/period)	540	605	535	641.9	605	405	608	568
Actual crop Evapotranspiration(Etc)	707	711	629	755.2	697	477	715	669
Total Rainfall(mm/period)	621	621	145	10.6	3.7	57	57	50.38
Effective Rainfall (mm/period)	496	496	126	9.95	3.6	52	52	47
Field water supply(FWS) (l/s/ha)	0.24	0.24	0.57	0.8	0.9	0.65	0.71	0.64
Net irrigation requirement NIWRi (mm/period)	241	241	516	700	650	401	658	564
Net irrigation requirement NIWRi (m^3/ha)	2410	2410	5160	7000	6500	4010	6580	5640

-According to Mehta's simple water balance model the total runoff is 143 mm which is 19.2 % of the total rainfall and the groundwater recharge is 117.2 mm which is 15.75 % of the total rainfall.

-The amount of runoff based on (SCS) method was 166.6 mm.

-Based on spring hydrograph analysis the recharge amount to springs was (205.9905, 16.22349, 3.19302, and 25.97129) million cubic meter per year for (Saruchawa, Qulai Kanimaran, Ganau, and Qulai Rania) springs respectively.

3. Hydrogeological Characterization

-The ground-water system of the Rania area was delineated into four distinct aquifers which are Lower Jurassic (karstic fissured), Upper Jurassic (complex karstic fissured), Early-late Cretaceous Limestone (Karstic), and Quaternary (intergranular).

- A (1-year) programme including measurements of water tables was performed during the year 2002 by the FAO, while another was effectuated by the researcher in year 2006. The Variations in hydraulic head were monitored using a network of the two piezometers. The variations in the water table for two piezometers over the period 2002 and 2006 indicates the extent to which the water table responds to precipitation magnitude and its distribution. There were some differences in the response of individual piezometers to rainfall events, partly due to variations in the specific yield of alluvial deposits.

-ground water flows from Quaternary toward the southeast where it is assumed to discharge into the Dokan Lake.

- Aquifer properties of the Quaternary Aquifer which is the main aquifer in the area were calculated using well tests. The hydraulic conductivity was range between 0.51 to 58.78 m/day with median value of 2.09 m/day, the transmissivity range between 44.6 to 4260 m^2/day with median value of 169.6 m^2/day, and specific yield range between 0.0031 to 0.15 with median value of 0.079.

- The aquifer is assumed to be high yield relative to the other aquifers due to the aquifer property values and a larger saturated thickness due to the shallow water table.

-Stratigraphy and structure are the main factors controlling the existence of springs in the studied area.

-There are four main karst spring systems in the area which are Saruchawa – Mackok, Qulai Rania, Qulai Kanimaran, and Ganau systems.

-According to (Springer et al. 2004) classification the flow rate of the main springs is sixth order for Qulai Rania,Qulai Kanimaran, and Ganau while is fifth order for Mezgauti Gaura ,Betwata ,and Shkarta and seventh order for Saruchawa spring.

-According to Ashjari (2006) conceptual model the springs output Sarchwa is discharge from the plunge of the fold (NP), Betwata and Shkarta discharge from limbs (NL), Qulai Kanimaran discharges only from one limb of the anticline (CL), and Qulai Rania and Kwera Kani discharges from a combination of limb, plunge apex and river (CN).

- From the time series analysis of main springs discharges the following conclusions were obtained:

-The autocorrelogram exceeds the confidence limits for approximately (85, 60, 35, and 82) days for (Saruchawa, Qulai Kanimaran, Ganau, and Qulai Rania) respectively indicating that the autocorrelation coefficients for this period are significantly different from zero and that the process of springs discharge is not independent. In other words, the system has a long memory except for Ganau spring, with dominant large channels and relatively poorly developed matrix porosity, and has a low storage. A physical explanation is that the aquifer storage is significant and that it releases water gradually.

-Cross-Correlograms for springs flow and precipitation are statistically insignificant for the(Saruchawa, Qulai Kanimaran, and Qulai Rania) springs which indicates the antecedent precipitation beyond this period has no direct influence on stream discharge. For the Ganau spring, cross-correlation shows a very minor level of significance from 3 to 9 days which is due to direct precipitation on the area of spring lake, but after that changes are insignificant. Low cross-correlation values for both of these springs show that the influence of infiltration is significantly attenuated by the porous medium

- The spectral density function of the springs discharge exhibits its highest peak at low frequencies (0.0028, 0.0028, 0.0055, and 0.0028) cycles per day, equivalent to (364, 364, 182, and 364) day periodicity for (Saruchawa, Qulai Kanimaran, Ganau, and Qulai Rania) respectively. This confirms the presence of a seasonal recharge and discharge cyclicity for all springs. Considerable peak at the middle frequencies (about 17 days) for Ganau spring show relatively low densities.

-The cross-amplitude function (CAP) relating precipitation and discharge .The system notably filters the input signal (precipitation) at higher frequencies (above 0.1, 0.1, 0.17, and 0.13 or periods of less than 10, 10, 6, and 7.5 days) for(Saruchawa, Qulai Rania, and Qulai Kanimaran) respectively and there is a significant increase in the signal at low frequencies. This phenomenon indicates that there is a quickflow component inside the aquifer system, although there is also a noticeable base flow component.

-from the Gain function The observed attenuation is another indication of the aquifer's small to moderate storage capacity, for (Ganau and Qulai Kanimaran).The low storage of the system could be explained by the presence of many large tunnels which directly contribute to the aquifer discharge and low effective porosity. In contrast the results for (Saruchawa, and Qulai Rania) is showed that there is a quick flow and there is no attenuation, therefore it’s a good indication for large storage capacity.

- The highest coherence function observed between precipitation and discharge is (0.95, 0.93, 0.91, and 0.83) (Saruchawa, Qulai Kanimaran, Ganau,and Qulai Rania)respectively. On the basis of statistical parameters and physical properties of springs the flow regime of Ganau and Qulai Kanimaran is diffuse flow(low portion)and conduit flow (high portion),and Saruchawa,Qulai Rania is diffuse flow(high portion)and conduit flow (low portion).

4. Environmental Isotopes

-All water samples fall between the global meteoric line (GMWL) and Eastern meteoric water line (which is the meteoric line of Mediterranean precipitation) (EMWL). The regression line for the δ^2H ‰ and δ^{18}O ‰ was calculated to be:

$$\boldsymbol{\delta^2 H= (5.1329)\ \mathrm{x}\ \delta^{18}O-0.373} \text{........ (4.20) (n=21)}$$

The correlation coefficient was found to be high (0.93).

-Wells (Bn zery, Rapareen 4, Rapareen 1, and Shilanay), Betwata and Saruchawa springs and Shaoor stream are located above the local meteoric water line (LMWL) obtained by (Maulood, 2003),which may be attributed to the following:

1-There are three sources of recharge, first is direct (focused) from coarse texture ephemeral stream beds (transmission losses) like (Shaoor) stream, the second is diffuse recharge areally distributed through soil matrix from direct precipitation, and the third is from macro-scale openings such as fractures, solution holes. Saruchawa is thought to be recharged by source one from the Shaoor stream and the source two.

-The case is different for Betwata spring; the depletion here is an indication of recharge from the distant mountainous areas located higher in altitude than the studied area.

-The values of (D-excess) indicate the same assumptions above. There are two groups of it one is greater than (20 ‰) and the other is less than (20 ‰). The

(D-excess) values of wells (Bn zery , Rapareen 4, Rapareen 1 ,and Shilanay), Betwata and Saruchawa are all greater than (20 ‰).

-Groundwater recharge in the basin originates only from heavy downpours that are depleted in the heavy isotopes (δ^2H and δ^{18}O), as has been suggested for other arid and semi-arid regions.

-Wells with lower temperature values contain more depleted stable isotopes; this means that the water table is shallow and it is affects by ambient temperature and direct recharge from precipitation.

-The relationship between δ^{18}O contents of the samples against the elevation indicate two lines:

1- *Elevation* = $-8.8755X\ \delta^{18}O + 506.93$ $R^2 = 0.01378$(n=17)........ (4.21)

2- *Elevation* = $-201.69X\ \delta^{18}O + 623.94$ $R^2 = 0.5423$ (n=17)........... (4.22)

This means that there is depletion in δ^{18}O content of the water samples with the increase in elevation for the second line ,but the relation of the first group is very weak because the elevation variations is small.

5. Hydrochemistry and Water Suitability

-The hydrochemical study of wells, and spring for two seasons, dry and wet, showed that the water is colorless, odourless characterized by low value of total dissolved salts, predominant ions are calcium and bicarbonate and the chemical type of water is calcium bicarbonate.

-The spatial distribution of electrical conductivity (EC) showed that the center of Rania has high value of ions.

-According to Gibbs's diagrams the mechanisms controlling groundwater chemistry is the chemical weathering of rock-forming minerals except for Ganau spring where evaporation is the controlling factor.

From the speciation calculation based on (WATEQE4F) computer program it can be seen that:

- 38 % of the well samples for dry season and % 47 for wet season have positive values of SI $_{calcite}$ which means that the water is oversaturated with respect to Calcite. The increasing percent in the wet season is due to increasing values of (pH and HCO_3), which caused further precipitation and make the aqueous environment more alkaline. Another conclusion is that Calcite is the abundant mineral of the aquifer and the recharge area. But also indicate that more than 50 % of the samples are under saturated.

-12 % of the well samples for dry season and % 14 for wet season have positive SI $_{Dolomite}$ values, which mean that water is oversaturated with respect to Dolomite -5 % of the samples for dry season and % 14 for wet season have positive SI $_{Aragonite}$. It concluded that the Dolomite is less abundant than Calcite.

–All well samples have negative values of (SI $_{Anhydrite}$, SI $_{Gypsum}$, SI $_{Halite}$, and SI $_{Magnisite}$)which means that the water is under saturated with respect to (Anhydrite , Gypsum , Halite , and Magnisite). It is concluded that the sources of these minerals are secondary minerals or from anthropogenic activity

All springs have negative values of (SI $_{Anhydrite}$, SI $_{Gypsum}$, SI $_{Halite}$, and SI $_{Magnisite}$)which means that the water is under saturated with respect to (Anhydrite , Gypsum , Halite , and Magnisite).

-Betwata spring is oversaturated with respect to (calcite, aragonite, dolomite), it means that the aquifer contains high amount of calcite and dolomite, also over saturation state in springs suggests a mechanism of diffuse flow, not conduit flow and there is a more residence time between the water and the aquifer materials, also the diffuse flow suggested as a close system whereas in a closed system, once the available carbon dioxide is used up, the dissolution of limestone terminates.

-Saruchawa,Quali Rania, and Kwera Kani springs are under saturated with respect to Calcite ,Aragonite, and Dolomite ,it suggested that a mechanism of conduit flow for spring .

-Ganau spring is under saturated with respect to (aragonite and dolomite) but oversaturated with respect to (calcite).On first inspection it seems surprising that. In fact, according to the previous section, this can not be explained by a prolonged water-rock contact time (Diffuse flow), but to a loss of CO_2 from the groundwater due to a high degree of karstification .

-All samples exceed the recommended limit for calcium ion according to (IDWS, 1998) which is 50 mg/l

-Shakarta spring is not suitable for drinking because it exceeds permissible limit for NO_3^- ion, proposed by (IDWS) and (WHO).

-According to US Salinity Laboratory diagram, the water samples are relatively good for irrigation.

- Water samples are suitable for all industrials except for textile, chemical pulp and paper industry.

-All water samples are suitable for building purposes and livestock except Ganau spring.

-The chemical data of the groundwater samples collected from the studied area are plotted in the expanded Durov diagram. The chemical data of the sample points, appeared as a cluster, and fall in the subdivisions of (1) it means that HCO_3^- and Ca^{2+} dominant, frequently indicates recharging waters in limestone aquifer, while well No. (39) located in the field No.(2) for both seasons and this means that HCO_3^- dominant and Mg^{2+} dominant or cations indiscriminant, with Mg^{2+} dominant or Ca^{2+} and Mg^{2+} important, indicates waters often associated with dolomites, where Ca^{2+} and Na^+ with important partial ion exchange may be indicated. Wells No. (26, 27) located in the field No. (4) for dry season ,it means that SO_4^{2-} dominant or anions indiscriminant and Ca^{2+} dominant, $Ca^{2+}$and SO_4^{2-} dominant frequently indicates a recharge water in gypsiferous deposits, otherwise a mixed water or a water exhibiting simple dissolution may be indicated but the gypsiferous deposits not exist in the aquifer, the SO_4^{2-} source may be derived from anthropogenic activity. Ganau spring also located in the field No. (4) for both seasons, the SO_4^{2-} source is from Kurrahina and Baluti Formations. When the data plotted in the Chadha diagram all samples fall in the field No. (5) (water type is Ca^{2+}-Mg^{2+}-HCO_3^-) except deep wells No. (26, 27) which is located in the field No.(1) for dry season(Alkaline earths exceed alkali metals),and well No.(10),located in the field No.(6) for dry season(water type is (Ca^{2+}-Mg^{2+}-Cl^-).Ganau spring also located in the field No.(6).

6. Ground-Water Flow Modeling

-A ground-water flow modeling constructed upon Quaternary aquifer to predict the effects of pumping on the head drawdown after(1, and 5) years, also two scenario introduced to the model one when the Dokan Lake reach minimum level (486 m),while the other when it reaches maximum level (511 m).

-The steady-state model was calibrated to less than the allowable discrepancy under the definition of a “good model”. The calibrated steady-state model results showed that recharge appears slightly more sensitive than hydraulic conductivity, and that model sensitivity is more zone-dependent than parameter-dependent.

- The shape and distributions of calculated, and observed hydraulic heads are similar and same flow direction.

-The results showed that there is a significance effect of Dokan lake elevation on the groundwater head elevation near the lake.

- The maximum draw down for transit simulation with pumping was 0.94 m for one year simulation and 0.96 m for five years simulation.

7.2 Recommendations

On the basis of the conclusions drawn above, a number of recommendations are put forward:

1-The model developed in this study should be used as a framework for future modeling efforts, and needs to be revisited and updated in the future. The most powerful step in the use of a model of a natural system is apost-audit to quantify the accuracy of the model, and make improvements as more data become available for future work. An example of data that could aid making a better attempt is geophysical surveys which can possibly help determining the bottom surface for the Quaternary Aquifer. Another example is the data that allow the simulation of Dokan Lake level as a time variant boundary.

2-More aquifer tests will enrich the present the aquifer parameter estimation. The aquifer tests should be conducted with an observation well allowing for the determination of storage coefficients. Several aquifer tests within each aquifer will allow a statistical validation of the aquifer parameter values used in the ground-water flow model. Variograms could be created using the results from several aquifer tests to set error limits to parameter values. The error limits would provide insight into the “goodness” of the calibrated parameter values

3-The predictive scenarios are under the constrain of lack of long-term hydrologic monitoring data. There are not enough data available to represent the climatic fluctuations of the region, nor are there exact data on the amount of water use. The predictive scenarios are more properly titled extended interpretive scenarios.

4-Scenarios that simulate potential water use assuming that all of the remaining variables including climate are constant. Additional calibration is necessary to use this model for predictive purposes because of the influence of constant-head and general-head boundaries on the solution.

5- In order to conclude that water is suitable for human drinking, further analyses such as trace elements and bacteriological analyses for water taken from springs and wells will be necessary.

6- Periodic analyses of complete chemical and physical water quality parameters are recommended in order to assure that no serious problems may arise in the studied springs and wells.

7- Proper treatment of groundwater , such as water softening ,ion exchange , and demineralization to reduce concentration of (Ca^{2+})ion and reduce NO_3^- in Shkarta spring because this spring is the unique source of drinking in Shkarta village

8-Contineous monitoring of the springs is highly recommended in order to fully understand the spring regimes thus allowing proper management.

9-Analyzing precipitation and springs water periodically for stable isotopes in order to construct a stable isotope regional equation in order to predict groundwater residence time and type of aquifer porosity .Samples for $\delta^{18}O$ and δ D isotope should be taken during snow melt and summer to determine the difference of $\delta^{18}O$ and δ D for snow melt waters recharging the groundwater.

10-Installation of more observation wells in order to achieve long-term monitoring that could indicate aquifer storage changes.

11-Continuous daily discharge measurement for Qashan and Shaoor streams in order to account it in precise water balance and manage them.

12- Using of ^{3}H isotope analysis to determine the age of groundwater.

13- Springs are a natural fortune of this region, it is recommended that:

A. Protection of Saruchawa spring (one of the largest spring in the area) by constructing a bailey around it to prevent incoming runoff water from a wadi located above it that has caused its water quality deterioration.

B. Ganau spring should be protected as a natural protectorate and tourist area benefiting from its mineral water for skin health problems.

14. Artificial recharge to Quaternary aquifer is possible if small dams could be constructed on the Shaoor and Qashan steams. Harvested rainwater could be recharged to the aquifer to be reused in drought seasons.

15- The Bekhme aquifer is regarded as a good aquifer elsewhere in the northern of Iraq, it is therefore recommended to drill some deep wells to exploit its water and to determine its hydraulic properties.

16-Installing a meteorological station in Rania basin in order to collect data that is more representative to the area.

17. Exploiting the water of Kwera Kani spring and allocating it to some parts of Rania city which have shortage in water supply, because its water is flowing to the sewage system. .

REFERENCES

References

- **Adams, S., Titus, R., Pietersen, K., Tredoux, G. and Harris, C., 2001.** *Hydrochemical Characteristics of Aquifers near Sutherland in the Western Karoo, South Africa***.** Journal of Hydrology 24: pp 91-103.
- **Adar E. M. , Dody, A. Geyh ,M. A. Yair, A., Yakirevich A., and Issar ,A. S. ,1998**. *Distribution of Stable Isotopes in Arid Storms.* Hydrogeology journal, Vol. 6, No.1. pp 50-65.
- **Aggarwal ,P.K., Gat, J.R., and Froehlich, F.O.(edts.), 2005.** *Isotopes in the Water Cycle, Past Present and Future of a Developing Science***.** Springer Publisher, the Netherland. 377 P.
- **Ahlfeld, D. P., Barlow, P.l. M., and Mulligan, A. E., 2005.** *GWM—A Ground-Water Management Process for the U.S. Geological Survey Modular Ground-Water Model (MODFLOW-2000)***,** U.S. Geological Survey Ground-Water Resources Program Open-File Report 2005-1072**,** 130P.
- **Alfaro, C. and M. Wallace. , 1994**. *Origin and Classification of Springs and Historical Review with Current Applications,* Environmental Geology, Vol. 24, pp. 112-124.
- **Ali, S.S., Stevanovic, Z., and Jemcov, I., 2007**. *The Mechanism and influence on Karstic Spring Flow-Sarchinar Spring Case Example (NE Iraq).* 4th Conference on Hydrogeology, Management, and Ecology in karst terrain ,Florida.
- **Ali, S.S., and Al-Manmi, D.A.M., 2005.** *Geological and Hydrochemical Study of Zalim Spring , Shahrazoor, Sulamania, Iraq***.** Iraqi Journal of Earth Science, Vol.5, No.1 pp.15-28.
- **Al-Jabari, M.H.A., Muhammad, K.I.,and Hasson, N.A**.,**2000**. *Hydrology*, Ministry of Higher Education and Scientific Research, University of Baghdad, 1063 P, (in Arabic).

References

- **Al-Janabi, Y.A., Al-Saadi, N.A., Zainal, Y.M., Al-Bassam, K.S. and Delaimy, M.R. , 1992.** *Work procedure, part 21, Chemical laboratories***,** S.E. Geol. Survey and Mining, Baghdad, 88p.
- **Al-Kubaisi, Q.Y. , 2004.** *Annual Aridity Index of TYPE.1 and TYPE.2 Mode Options for Climate Classification***.** Iraqi journal of Science. Vol. 45 C, No.1. pp. 32-41.
- **Allen R. G., Pereira L. S., Raes D., and Smith M.M , 2006.** *Crop Evapotranspiration, (guidelines for computing crop water requirements).* FAO Irrigation and Drainage Paper No. 56, 307 P.
- **Allison, G.B., Barnes ,C.J., Hughes ,M.W. and Leaney , F.W.J., 1984.** *Effect of Climate and Vegitation on Oxygen-18 and Deuterium Profiles in Soils*. In: Isotope Hydrology, IAEA symposium 270, September 1983, Vienna: 105-123.
- **Al-Manharawi, S. and Hafiz, A., 1997.** *Fresh Water, Resources and Quality.* Arabic Press. Cairo, 181 P. (In Arabic).
- **Al-Manmi, D.A.M., 2002.** *Chemical and Environmental Study of Groundwater in Sulaimaniya City and its Outskirts***,** Unpublished M.Sc. Thesis, College of Science, University of Baghdad, 200 P.
- **Al-Manmi, D.A.M, and Saleh, H., 2006.** *Groundwater Quality Problems of a Gypsyferous and Urbanized area Kifry City , NE of Iraq***,** Iraqi Journal of Earth Science, Vol.6, No.1 pp.12-28.
- **Al-Manmi, D.A.M., 2007.** *Groundwater quality evaluation of Kalar town, Sulamani/ NE-Iraq***,** Iraqi Journal of Earth Science, Vol.7, No.2 pp.31-52.
- **Al-Nsour, I.A.Al., 2000**. *Hydrology and Hydrochemistry of mujib basin-Jordan*, Ph.D. Thesis, unpublished, University of Baghdad, College of Science, 234 P.

References

- **Alsaaran, N. A., 2006.** *Using Environmental Isotopes for Estimating the Relative Contributions of Groundwater Recharge Mechanisms in an Arid Basin, Centralsaudi Arabia***.** The Arabian Journal for Science and Engineering, Volume 31, Number 1A.
- **Al-Shami, Alaee, 1993.** Irrigation Projects in Iraq. Ministry of Irrigation, directorate of proceeding and plan, water resources department, Baghdad.
- **Al-Surdashi, A, M.A., 1999.** *Sequence Stratigraphic Analysis of the Early Jurassic, Central and Northern Iraq*, Unpublished Ph.D. Thesis, College of Science, University of Baghdad, 162 P.
- **Altoviski , M.E. , 1962.** *Handbook of Hydrogeology*. Gosgoelitzdat, Moscow, USSR (in Russian), 614 P.
- **Al-Zubi , H.A. , 2000.** *Environmental and Geochemical Aspects of Soil and Groundwater Resources in North –East Mafraq-Jordan*. Unpublished Ph.D. Thesis, College of Science, University. of Baghdad, 201 P.
- **Ameen, B.M., 2008**. *Sedimentology and Lithostratigraphy of Qamchuqa Formation from Kurdistan Region, NE-Iraq*. Unpublished Ph.D. Thesis, College of Science, University of Sulaimani, 143 P.
- **Amin, A.N.M., 2003.** *Principles of Crop Productivity under Dry Farming*, University of Sulaimani ,College of Agricultural ,department of Crop Science, 200 P (in Arabic).
- **Anderson, M.P. and Woessner ,W.W., 1992**. *Applied Groundwater Modeling: Simulation of Flow and Advective Transport*. Academic Press, San Diego.381 P.
- **APHA, 1998**. *Standard Methods of the Examination of Water and Wastewater* .20th ed., Washington D.C., American Public Health Association.
- **Appelo, C.A.J. and Postma, D. , 1999.** *Geochemistry, Groundwater and Pollution***.** Rotterdam: A.A. Balkama, 536 P.

References

- **Ashjari, J. , 2006 .** *Influences of Anticlinal Structure on Regional Flow, Zagros, Iran.* Journal of Cave and Karst Studies, Vol. 68, No. 3, pp 118–129.
- **Asim , M., 2005.** *Hydrochemical Characterization and Numerical Modeling of Groundwater Flow in A Part of the Himalayan Foreland Basin* Ph.D. Thesis unpublished, Kent State University 243p.
- **Attia, A. M. , and Sadoon ,M. N. ,2007.** *The Effect of Hypothetical Artificial Recharge on Water Table Altitudes of Shallow Dibdiba Sandy Aquifer in Safwan-Zubair Area ,South of Iraq* Iraqi Journal of Earth Science, Vol.7, No.2 pp.53-72.
- **Ayers, R.S. and Westcot, D.W. ,1994.** *Water Quality for Agriculture***.** Irrigation and Drainage Paper 29, Rev. 1, FAO, Rome, Italy, 174 P.
- **Aziz , B.Q. ,2002 .***Vertical Electric Sounding of Chwarqurna area*, FAO representation for Northern Iraq, Sulaimani sub-office, Report No.35. 18 P.
- **Baban , E .N . and Ali ,P.M .,2002** .*Vertical Electric Sounding of Sofian Village*, FAO representation for Northern Iraq, Sulaimani sub-office, Report No.25,16 P.
- **Bajjili , W. , and Al-Hadidi , K. ,2005 .***Hydrochemical Evaluation in Azraq Basin, Jordan, using Environmental Isotopes and GIS Techniques.* http://events.esri.com/uc/2005/papers/index.cfm
- **Ball , J. W., and Nordstrom , D. K., 2003.** *User's Manual for WATEQ4F, with Revised Thermodynamic Data Base and Test Cases for Calculating Speciation of Major, Trace, and Redox Elements in Natural Waters:* U.S. Geological Survey Open-File Report 91-183, 189 pp.
- **Ball, J.W. and Nordstrom, D.K. ,2003.** *WATEQ4F – A Computer Program for Calculating Speciation of Major, Trace and Redox Elements in Natural Water.* USGS, Open file Report, pp. 91-189.
- **Bautrus , K.A.,1988.** *Hydrological Study of the Lesser Zab River.* M.Sc. Thesis Unpublished, College of Science, University of Baghdad, 125 P.

References

- **Behmanesh, O. , 2003**. *The Aspects of Water Balance in the Irrigateed Area (Southwest Part of Urumieh Lake)*, M.Sc. Thesis, International Institute for Geo-information Science and Earth Observation, Netherlands, 75 P.
- **Bellen, R.C., Van Dunnington, H.V., Wezel, R. and Morton, D.M. ,1959.** *Lexique Stratigraphique International***.** Vol. III, Asie, Fasc. 10a, Iraq, Paris, 336 P.
- **Bolton, 1956**.*The Geology and Economic Prospects of the Rania area*, Manuscript report No.269, GEOSURV, Baghdad.
- **Bolton, 1958d .***The Geology of the Ranya area***,** Manuscript report No.271, GEOSURV, Baghdad.
- **Boonstra, J, and de Ridder, N.A. ,1981**. *Numerical Modeling of Groundwater Basins*, ILRI publication 29, ILRI, Netherlands, 226 P.
- **Box, G.E.P. and Jenkines, G.M., 1976.** *Time Series Analysis: Forcasting and Control*, Holdn Day ,San Francisco, 575 P.
- **Boyd, C.E., 2000.** *Water Quality. An Introduction*. Kluwer Acad. Publisher, USA, 330 P.
- **Bradley, C., 2002** *Simulation of the Annual Water Table Dynamics of a Floodplain Wetland, Narborough Bog, UK*. Journal of Hydrology, Vol.261: pp 150-172.
- **Bryan ,K. ,1919**. *Classification of Springs*, Journal of Geology, Vol.27, pp. 522-561.
- **Buday, T., 1980.** *The Regional Geology of Iraq, Vol. I. Stratigraphy and Paleogeography***.** I.I.M. Kassab and S.Z.Jassim (Eds). SOM, Baghdad, Dar El Kutib Publ. House, Univ. of Mosul., 445P.
- **Buday, T. and Jassim, S.Z. , 1987**. *The Regional Geology of Iraq, Vol. II:Tectonism, Magmatism, and Metamorphism***.** 352 P.
- **Burdon, D.J and Mazlounr, S., 1958.** *Some Chemical Types Of Groundwater From Syria,* UNESCO Symp.Tehran, pp.73-90.UNESCO, Paris.

- **Buringh, P., 1960**. *Soils and Soil Conditions of Iraq*, Ministry of agriculture, Baghdad, Iraq, 322 P.
- **C.H., 2003.** *Guidelines for Canadian Drinking Water Quality***.** Supporting Documentation, Federal-Provincial-Territorial Committee on Drinking Water, Ottawa, Ontario, Canada. 36 P.
- **Chadha**, **D.K., 1999.** *A Proposed New Diagram for Geochemical Classification of Natural Waters and Interpretation of Chemical Data*. Hydrogeology Journal, Vol.7, pp. 431-439.
- **Chen , J. Tang, Ch., and yu, J . , 2006.** *Use of ^{18}O , ^{2}H and ^{15}N to Identify Nitrate Contamination of Groundwater in Waste Water Irrigated Field Near the City of Shijiazhuang, China* **,** Journal of Hydrology , Vol. 326, pp. 367-378.
- **Chen, Z., Nie, Z., Zhang, G., and Wan, L., 2006 .***Environmental isotopic study on the recharge and residence time of groundwater in the Heihe River Basin, northwestern China***,** Hydrogeology Journal Vol.14: pp. 1635–1651.
- **Chiang, W.H. and Kinzelbach, W., 2003 .** *Modflow a Computer Program for Groundwater Flow and Pollution***.**
- **Chiang, W.H., 2005 .** *3D-Groundwater Modeling with PMWIN, A Simulation System for Modeling Groundwater Flow and Transport Processes,2nd edition***,** Springer Berlin Heidelberg, 414 P.
- **Chicano, M. L, Bouamama, M. Vallejos ,A., and Bosch, A. P., 2001.** *Factors, Which Determine the Hydrogeochemical Behaviour of Karstic Springs. A Case Study from the Betic Cordilleras, Spain.* Applied Geochemistry Vol.16: pp . 1179-1192.
- **Chnaray , M. A. H. S, 2003** .*Hydrogeology and Hydrochemistry of Kepran Basin Erbil-N Iraq*. Unpublished Ph.D. Thesis, College of Science, University of Baghdad, 161 P.
- **Clark , D. , Smith, M., and El-Askari , K. , 1998.** *CROPWAT 4 Windows version 4.2: user guide*. University of Southampton, 43 P.

References

- **Clark , I , and Fritz , P. , 1997.** *Environmental Isotopes in Hydrology***.** Lewis Publishers, New York, 328P.
- **Clarke, F.W., 1924.** *Mineral Wells and Springs*. pp. 181-217 in U.S. Geological Survey. editor. The data of geochemistry. U.S. Government Printing Office, Washington.
- **Cooper, H.H. and C.E. Jacob, 1946**. *A Generalized Graphical Method for Evaluating Formation Constants and Summarizing Well Field History,* American. Geophysical Union Trans., Vol. 27, pp. 526-534.
- **Coplen, T. B., 1994.** *Reporting of Stable Hydrogen, Carbon, and Oxygen Isotopic Abundances***,** Pure and Applied Chemistry, Vol. 66, pp. 273-276.
- **Coplen, T. B., Wildman, J. D. and Chen, J., 1991.** *Improvements in the Gaseous Hydrogen-Water Equilibration Technique for Hydrogen Isotope Ratio Analysis,* Analytical Chemistry, Vol. 63, pp. 910-912.
- **Craig, H., 1961a.** *Standards for Reporting Concentrations of Deuterium and Oxygen-18 in Natural Waters***.** Science Vol.133: pp. 1833-1834.
- **Craig, H., 1961b.** *Isotopic Variations in Meteoric Waters***.** Science Vol.133: pp 1702-1703.
- **Daly, D. ,1994.** *Chemical Pollutant in Groundwater: a Review of the Situation in Ireland***.** Conf. "Chemicals a cause for Concern?", Cork, 3-4/11/1994.
- **Dansgaard ,W. ,1964 .***Stable Isotopes in Precipitation*.Tellus,Vol.19: pp. 436-468.
- **Dastane, N.G., 1978**. *Effective Rainfall in Irrigated Agriculture* .FAO Irrigation and Drainage Paper No.25, 76 P.
- **Davis, S.N. and Dewiest, R.J.M., 1966.** *Hydrogeology***.** John Wiley and Sons Inc., New York, 463 P.
- **Dellur, J.W., 1999.** *The Hand Book of Groundwater Engineering.* Purdue University, West Lafayette, Indian, 940 P .

References

- **Deming, D., 2002.** *Introduction to Hydrogeology*. McGraw-Hill Higher Education, USA, 468 P.
- **Detay, M., 1997.** *Water Wells – Implementation, Maintenance and Restoration***.** John Wiley and Sons, London, 379 P.
- **Doctor, D. H. and Alexander, E. C., 2006.** *Interpretation of Water Chemistry and Stable Isotope Data from a Karst Aquifer According to Flow Regimes Identified through Hydrograph Recession Analysis.* Hydrological Processes, Vol. 25, pp. 82-92.
- **Domenico, P.A. and Schwartz, F.W.**, **1998**. *Physical and Chemical Hydrogeology.* John Wiley and Sons Inc., New York, 506 P.
- **Drever, J.I., 1997.** *The Geochemistry of Natural Water, Surface and Groundwater Environments,* 3rd ed., Prentice Hall, USA, 436 P.
- **Durov, S.A, 1948.** *Natural Waters and Graphic Representation of their Composition*. Dokl.Akad.Nauk SSSR vol. 59, pp. 87-90.
- **Einsiedl, F., 2005.** *Flow System Dynamics and Water Storage of a Fissured-Porous Karst Aquifer Characterized by Artificial and Environmental Tracers,* Journal of Hydrology,Vol. 312 . pp. 312–321.
- **Epstein, S. and Mayeda, T., 1953.** *Variation of* ^{18}O *Content of Water from Natural Sources*. Geochim. Cosmochim. Acta, Vol. 4, pp. 213-224.
- **Esteller, M.V. and Andreu,J.M. , 2005.** *Anthropic Effects on Hydrochemical Characteristics of the Valle de Toluca Aquifer (central Mexico)***.**Hydrogeology Journal.Vol.13: pp. 378-390.
- **Fatah, M.A., 2004.** *Some Practical tests to Reduce Seepage from Earthen Ponds for Different Texture Soils* M.Sc. Thesis unpublished College of Agriculture, University of Sulaimani, 145 P.
- **Faure , G. ,1998.** *Principles and Application of Geochemistry (2nd ed.).* Prentice Hall Inc, USA, 600 P.
- **Faure, G.,1986.** *Principles of Isotope Geology***,** John Willy & Sons, New York, 587 P.

- **Fennessey, N. M. a., and Vogel, R. M., 1996.** *Regional Models of Potential Evaporation ,and Reference Evapotranspiration For The Northeast USA.* Journal of Hydrology, Vol.184. pp. 337-354.
- **Fetter, C.W. ,1994.** *Applied Hydrogeology*: Prentice Hall Inc., Englewood Cliffs, N.J.691 P
- **Flora ,S .P ., 2004 .** *Hydrogeological Characterization and Discharge Variability of Springs in the Middle Verde River Watershed, Central Arizona,* Unpublished M.Sc Thesis. Northern Arizona University. 237 P.
- **Gammons .Ch .H .,Poulson .S .R ., Pellicori .D .A ., Reed. P.J., Roesler .A .J. and Petrescu .E .M ., 2005 .***The Hydrogen and Oxygen Isotopic Composition of Precipitation ,Evaporated Mine Water, and River Water In Montana ,USA* ,Journal of Hydrology,Vol.328, pp. 319-330.
- **Gardi, L., 2002.** *Isotope Hydrology of the Cordevole Catchment, Province of Belluno, North Italy,* Unpublished M.Sc. Thesis. Paper No.2. Free University of Amsterdam, Faculty of Earth and Life Science.28 P.
- **Gebreegziabher, Y., 2004.** *Assessment of the Water Balance of Lake Awassa Catchment, Ethiopia***.** Nternational Institute for Geo-Information Science and Earth Observation Enschede, the Netherlands 103 P.
- **Gibbs, R.J., 1970.** *Mechanisms Controlling World Water Chemistry***,** Science, Vol. 170: pp. 1088-90.
- **Gill, R. (ed.), 1997.** *Modern Analytical Geochemistry, an Introduction to Quantitative Chemical Analysis for Earth, Environmental and Materials Scientists***.** Longman, London, 329 P.
- **Grabert ,V .K ., and Narasimhan ,T. N ., 2006 .***California's Evolution Toward Integrated Regional Water Management: A Long-Term View,* Hydrogeology Journal,Vol.14, pp. 407-423 .
- **Guay , B. Eastoe , C. and Austin, L. B., 2006.** *Identifying Sources of Groundwater in the Lower Colorado River Valley, USA, with* $\delta^{18}O$, δD *and* ^{3}H*: Implications for River Water Accounting***,** Hydrogeology journal , Vol. 14: pp 146-158.

- **Gupta , S .K . Deshpande ,R .D . Bhattacharya ,S .K ,and Jani ,R .A. 2005 .** *Groundwater $\delta^{18}O$ and δD from Central Indian Peninsula: Influence of the Arabian Sea and the Bay of Bengal Brunches of the Summer Monsoon***,** Journal of Hydrology, Vol. 303. pp. 38-55.
- **Haji , L. , Karim, H.K., Ahmad, and Q. Baban , A.R., 2001.** *Agro-Ecological Zoning of ChuarQurna, Bngrd, Sangasar, Qaladza, and Khalakan*, FAO, Sulaimani office, report No.24, 33 p.
- **Haji, L., Karim, H.K., Ahmad, and Q.Baban , A.R. , 2002.** *Agro-Ecological Zoning of Sulaimani Region- Kurdistan- Iraq*, FAO, Sulaimani office, report No.25, 49 P.
- **Harbaugh, Arlen W., 2005.** *MODFLOW-2005, the U.S. Geological Survey Modular Ground-Water Model the Ground-Water Flow Process***,** Techniques and Methods 6–A16. U.S. Geological Survey**,** 206 P**.**
- **Hasan, M.A., Ahmed, K.M., and Sracek, O. ,2007.** *Arsenic in Shallow Groundwater of Bangladesh: Investigations from three Different Physiographic Setting*. Hydrogeology Journal Vol.15: pp. 1507-1522.
- **Hassan, I. O., 1998 .***Urban Hydrology of Erbil City Region*. Unpublished Ph.D. Thesis, College of Science, University of Baghdad, 119 P.
- **Hawkins, R. H., 2004.** *National Engineering Handbook*, United States Department of Agriculture Natural Resources Conservation Service, 791 P.
- **Healy R.W. and Cook, P.G., 2002.** *Using Groundwater Levels to Estimate Recharge*.Journal of Hydrogeology, Vol.10, No.1, pp.91-109.
- **Helstrup, T., Jorgensen, N. O. and Yakubo, B. B.,2007.** *Investigation of Hydrochemical Characteristics of Groundwater from the Cretaceous-Eocene Limestone Aquifer in Southern Ghana and Southern Togo using Hierarchical Cluster Analysis***.** Hydrogeology Journal Vol. 15: pp. 977–989.

- **Hem, J.D. ,1991.** *Study and Interpretation of the Chemical Characteristics of Natural Water***.** USGS Water Supp. Paper no. 2254, 263 P.
- **Hill M. C., 1998.** *Methods and Guidelines for Effective Model Calibration* U.S. Geological Survey Water-Resources Investigations Report 98-4005. 98 P.
- **Hoefs, J., 1997.** *Stable Isotope Geochemistry***,** 4th ed., Springer-Verlag, Berlin.450 P.
- **Holland, H.D. ,2003**. *Treatise on Geochemistry,* Elsevier Science, Netherlands, 5500 P.
- **Horita, J., Wesolowski, D., and Cole, D., 1993.** *The Activity-Composition Relationship of Oxygen and Hydrogen Isotopes in Aqueous Salt Solutions:I. Vapor-liquid Water Equilibration of Single salt solutions from 50 to 100 °C***,** Geochim. Cosmochim. Acta, Vol. 57, pp. 2797-2817.
- **Hudak, P.F. ,2000.** *Regional Trends in Nitrate Content of Texas Groundwater***.** Journal of Hydrology, Vol.228: pp. 37-47.
- **Hunt ,R .Coplen ,T .Haas ,N . Saad ,D. and Borchardt ,M. , 2005 .***Investigating Surface Water -Well Interaction Using Stable Isotope Ratios Of Water***,** Journal of Hydrology ,Vol. 302, pp. 154-172.
- **IGS, 1998** .*Iraqi Guidelines Standard for Drinking water,* (in Arabic).
- **International Atomic Energy Agency (IAEA), 1993.** *Manual on Mathematical Models in Isotope Hydrogeology,* Vienna, TECDOC-910, 207 P.
- **International Atomic Energy Agency (IAEA), 1993.** *Mathematical Models and their Applications to Isotope Studies in Groundwater Hydrology,* Proceedings of a final Research Co-ordination Meeting held in Vienna, 1-4 June 1993, TECDOC-777.279 P.
- **Jacobson, R.L. and Langmuir, D., 1974.** *Controls on the Quality Variations of Some Carbonate Spring Waters.* Journal of Hydrology. Vol. 23, pp. 247-265.

- **Jassim , S.Z. and Goff .J .C (eds.), 2006** . *Geology of Iraq*. Dolin , Prague and Moravian Museum , Brno . 341P.
- **Jawad, S.B., 2008.** *Toward a National Groundwater Monitoring Network*. Proceeding from the first conference on Environmental Challenges in Iraq, Iraq- Sulaimani, 11-12/1/2008.
- **Jemcov, I., 2006.** *Water Supply Potential and Optimal Exploitation Capacity of Karst Aquifer Systems*. Environmental Geology, Vol.51, pp.767-773.
- **Jenkines,G.M. and D.G..1967.** *Spectral Analysis and its Applications*, Holdn Day, San Francisco, 525 P.
- **Johnson, E.E., 1955.** *Groundwater and Wells* .Inc.Saint Paul, Minn., 440 P.
- **Karim, K.H., 2004.** *Basin Analysis of Tanjero Formation in Sulaimani Area, NE-Iraq***.** Unpublished Ph.D. Thesis, College of Science, University of Sulaimani, 133 P.
- **Kassam, A. and Smith, M., 2001.** *FAO Methodologies on Crop Water Use and Crop Water Productivity*. Expert meeting on crop water productivity, Rome. Italy, paper No Cwp-M07.
- **Kebede, S.,Travi, Y., Asrat, A., 2008.** *Groundwater Origin and Flow Along Selected Transects in Ethiopian Rift Volcanic Aquifers*. Hydrogeology Journal, Vol.16, pp.55-73.
- **Kendall, C. and Coplen, T.B., 1985.** *Multisample Conversion of Water to Hydrogen by Zinc for Stable Isotope Determination***.** Anal. Chem. Vol. 57, pp. 1437-1440.
- **Komac, B., 2001.** *The Karst Springs of the Kanin Massif***,** Anton Melik Geographical institute, Report, COBISS: 1.01., 37p.
- **Korkmaz, N., 1990.** *The Estimation of Groundwater Recharge from Spring Hydrographs*. Hydrological Sciences- Journal - des Sciences Hydrologiques, 35, 2, 4. pp. 209-217.

- **Kortelainena, N. M., and Karhub, J. A., 2004.** *Regional and Seasonal Trends in the Oxygen and Hydrogen Isotope Ratios of Finnish Groundwaters: a Key for Mean Annual Precipitation*. Journal of Hydrology Vol.285: pp 143–157.
- **Kresic, N., 1997.** *Quantitative Solutions in Hydrogeology and Groundwater Modeling*. Lewis Publisher, pp. 287-302.
- **Kruseman ,G .P. and de Ridder ,N.A.,1994 .** *Analysis and Evaluation of Pumping Test* Data. International Institute for Land Reclamation and Imporovement, Wageningen, the Netherlands, 377P.
- **Langmuir, D., 1997.** *Aqueous Environmental Geochemistry***.** Prentice Hall, USA, 600P.
- **Lioyd , J.W. ,1965**.*The Hydrochemistry of the Aquifers of North-Eastern Jordan*. Journal of Hydrology, Vol.3, pp.319-330.
- **Ljungberg, V. ,2004.** *Assesment of Groundwater flow and Pollutant Transport through Modeling***.** M.Sc Thesis, Unpublished, College of Science, Stokholm.Sweeden.110 P.
- **Maillet, E.,1905.** *Essais D,hydraulique Souterraine et luviale*. Librairie Sci., A. Hermann ,Paris ,218 P.
- **Majumdar D, and Gupta, N., 2000**. *Nitrate Pollution of Groundwater and Associated Human Health Disorders***.** Indian Journal Environmental Health Vol.42No.1: pp. 28–39.
- **Martin, D .L., and Gilley, J .R., 1993.** *Irrigation Water Requirements* **,** national engineering hand book, part 623,chapter two, United State Department of Agriculture, Soil Conservation Service.284 P.
- **Mawlood, D., 2003.** *Application of Isotope Hydrology Studies Considering the Specific Climate, Hydrogeological and Geological Conditions in order to Research Underground Water Resources in a Specific Area in the Near East***.** Unpublished Ph.D. Thesis. Vienna University of Technology.306 P (in German).

- **Mazor, M. ,1990.** *Applied Chemical and Isotopic Groundwater Hydrology*. Open Univ. Press, New York, 274 P.
- **McKee, P. W. and Clark, B. R., 2003.** *Development and Calibration of a Ground-Water Flow Model for the Sparta Aquifer of Southeastern Arkansas and North-Central Louisiana and Simulated Response to Withdrawals; 1998-2027***.**U.S. Geological Survey Water-Resources Investigations Report 03-4132.80P.
- **McKenzie, J.M., Sigel, D.I., Patterson, W. and McKenzie, D.J., 2001.** *A Geochemical Survey of Spring Water from the Main Ethiopian Rift Valley, Southern Ethiopia: Implications for Well-head Protection***.** Hydrogeology Journal Vol.9: pp. 256-272.
- **Mehta, V. K., walter, M.T., and DeGloria, D. S. 2006.** *A Simple Water Balance Model* **.**Cornell University, Technical report No.5, 9 p.
- **Meinzer, O. ,1923.** *Outline of Ground-Water Hydrology,* USGS Water Supply Paper 494.
- **Mekonnen, S. C., 2005.** *Assessment of Catchment Water Balance Using GIS and Remote Sensing; Roxo, Portugal***,** M.Sc. Thesis, International Institute for Geo-information Science and Earth Observation, Netherlands,118 P.
- **Modi , P.N., 2000.** *Irrigation Water Resources and Water Power Enginerring.4th ed.* Standard Book House , Nai Sarak,Delhi,750P.
- **Mohyaldin, I. M.J., 2007.** *Stratigraphy and Sedimentology of Organic-rich Limestones of the Chia Gara Formation, Rania Area, Sulaimani, Kurdistan Region, NE Iraq***.** Journal of Zankoy Sulaimani,Vol.10,No.1, pp.91-102
- **Mook, W.G., and Vries, J.J.De.V., 2001.** *Environmental Isotopes in the Hydrological Cycle Principles and Applications***.** Centre for Isotope Research, Groningen, Netherlands, 916 P.

- **Mustafa,O. M. ,2007.** *Impact of Sewage Wastewater on the Environment of Tanjero River and its Basin within Sulaimani City/NE-Iraq* .Unpublished M.Sc. Thesis, College of Science, University of Baghdad, 128 P.
- **Navarro ,L. F., 2002.** *Characterization and Ground-Water Flow Modeling Of The Mint Wash / Williamson Valley Area, Yavapai Countya* Unpublished M.Sc. Thesis, Northern Arizona University, USA, 174 P.
- **Nolan, B.Healy, R.Taber, P.Perkins, K.Hitt, K. and Wolock ,D .,2007.** *Factors Influencing Groundwater Recharge in the Eastern United States***,** Journal of Hydrology.Vol.332, pp. 187-205.
- **Padilla, A., Pulido, A. and Mangin, A., 1995**. *Relative Study of Hydrographs of Karstic Aquifers by Means of Correlation and Cross – Spectral Analysis*. Journal of Hydrology, Vol. 168, pp. 73-89.
- **Panagopoulos, G. and Lambrakis, N., 2006.** *The Contribution of Time Series Analysis to the Study of Hydrodynamic Characteristics of the Karst System : Application on the Typical Karst Aquifers of Greece (Trifilia,Almyros Crete)*,Journal of Hydrology ,Vol.329,pp.368-376.
- **Parelta,R.C., 2004 .** *Optimization Modeling for Groundwater and Conjunctive Water Policy*. Water dynamic laboratory, Utah State University Foundation, Utah State University.191 P
- **Parson, R.M. ,1957.** *Groundwater Resources of Iraq, Vol. XII: Sulaimania Liwa and area North of Khanaquin***.** R.M. Parson Co., Ministry of Development, Development Board, Gov. of Iraq, 93p.
- **Parsons,C.,2006.** *Mini Master Plan for the Public Water Supplies for the Governorate of Sulaymaniyah- Iraq* **.**Public Works/Water Sector, Contract No. W914NS-04-C-0003, 358 P.
- **Pierce, J.J., Weiner, R.F., and Vesilind, P.A., 1998**. *Environmental Pollution and Control (4th ed.).* Butterworth – Heinemann, USA, 392 P.

- **Pilla G. , Sacchi, E. , Zuppi ,G. , Braga, G. , and Cian ,G.2006.** *Hydrochemistry and Isotope Geochemistry as Tools for Groundwater Hydrodynamic Investigation in Multilayer Aquifers: A Case Study from Lomellina, Po Plain, Southwestern Lombardy, Italy.* Hydrogeology Journal, Vol. 14, No.5. pp. 795-808.
- **Qadir, K. Sh., 2001.** *Study of Erodibility of Soils in Sulaimania Region.* M.Sc. Thesis unpublished College of Agriculture, University of Sulaimani, 141P.
- **Qaradaghi , S. H. A., 2007.** *Sedimentology of Sarmord Formation from Selected Sections in Sulaimani province Kurdistan Region-NE Iraq* Unpublished M.Sc. Thesis, College of Science, University of Sulaimani, 84 P.
- **Raeisi, E. and Karami, G.,1997.** *Hydrochemographs of Berghan Karst Spring as Indicators of Aquifer Characteristics.* Journal of Cave and Karst Studies ,Vol.59.No. 3: pp. 112-118.
- **Rahnemaei, M., Zare, M., Nematollahi, A.R., and Sedghi, H., 2005.** *Application of Spectral Analysis of Daily Water Level and Spring Discharge Hydrographs Data for Comparing Physical Characteristics of Karstic Aquifers.* Journal of Hydrology,Vol. 311. pp. 106–116.
- **Rao ,N. S.,2006.** *Seasonal Variation of Groundwater Quality in a part of Guntur District, Andhra Pradesh India***,** Environmental Geology Vol.49: pp. 413–429.
- **Retallack, G.J., 1997.** *A Color Guide to Plaeosols.* Jon Wiley and Sons, London, 175 P.
- **Revesz, K. and Coplen, T. B., 2003a.** *Hydrogen Isotope Ratio Analysis of Water by Gaseous Hydrogen-Water Equilibration:* Standard Operating Procedure (SOP) No.1574, Techniques of the U. S. Geological Survey, in preparation.

- **Revesz, K. and Coplen, T. B., 2003b.** *Oxygen Isotope Ratio Analysis of Water by Gaseous Carbon Dioxide-Water Equilibration:* Standard Operating Procedure (SOP) No.489, Techniques of the U. S.Geological Survey, in preparation.

- **Rodvang, S.J. and Simpkins, W.W., 2001.** *Agricultural Contaminants in Quaternary Aquitards: a Review of Occurrence and fate in North America***.** Hydrogeology Journal, Vol. 9.No. 1: pp. 44-59.
- **Rojas, R. and Dassargues, A., 2007.** *Groundwater Flow Modelling of the Regional Aquifer of the Pampa Del Tamarugal, Northern Chile* Hydrogeology Journal, Vol. 15: pp. 537–551**.**
- **Saether, O.M. and Caritat, P.D. (eds.), 1997.** *Geochemical Processes, Weathering And Groundwater Recharge In Catchments***.** A.A. Balkama, Rotterdam, Brookfield, Holland, 400 P.
- **SAHRA. 2006.** *Isotope Hydrology***.** http://www.sahra.arizona.edu
- **Sahu,P. ,2004.** *Use of Time Series, Barometric and Tidal Analyses to Conceptualize and Model Flow in an Underground Mine: The Corning Mine Complex, OHIO***.** M.Sc. Thesis unpublished, Faculty of the College of Arts and Sciences of Ohio University 172P.
- **Salae, A.T., 2001.** *Stratigraphy and Sedimentology of the Upper Jurassic succession, NE Iraq***,** M.Sc. Thesis, Unpublished, College of Science, University of Baghdad, , 95P.
- **Samani, N. , 2001.** *Response of Karst Aquifers to Rainfall and Evaporation, Maharlu Basin, IRAN* .Journal of Cave and Karst Studies Vol.63.No.1: pp. 33-40.
- **Sarwar, A. and Eggers, H., 2007.** *Development of a Conjunctive Use Model to Evaluate Alternative Management Options for Surface and Groundwater Resources***,** Hydrogeology Journal Vol.14 No.8, pp. 1676–1687**.**

- **Scanlon, B. R. · Healy, R. W., and Cook, P. G., 2002.** *Choosing Appropriate Techniques for Quantifying Groundwater Recharge* Hydrogeology Journal, Vol.10: pp. 18–39.
- **Schaaf, S.V., 2004.** *A Single Well Pumping and Recovery Test to Measure in Situ Acrotelm Transmissivity in Raised Bogs*. Journal of Hydrology, Vol.290: pp. 152-160.
- **Schoenleber, J**.R., 2005**.** *Field Sampling Procedure Manual*, Department of Environmental Protection, New Jersey, 574 P.
- **Schwartz, F.W., 1990.** *Groundwater Models, Scientific and Regularity Applications***,** National Academic Press, Washington, D.C.320 P.
- **Sharma, K. D. and Singh, S., 1992.** *Runoff Estimation using Landsat Thematic Mapper data and the SCS Model***.** Hydrological Sciences - Journal- des Sciences Hydrologiques, Vol.37, No.1. 2, pp. 39-51.
- **Sissakian, V. K., 1997.** *Geological Map of Arbeel and Mahabad Quadrangles, scale 1:250000*. State Establishment of Geological Survey and Mining, Iraq-Baghdad.
- **Sofer, Z. and Gat, J. R., 1972.** *Activities and Concentrations of Oxygen-18 in Concentrated Aqueous Salt Solutions: Analytical and Geophysical Implications.* Earth Planetary Science Letters, Vol. 15, pp. 232-238**.**
- **Sofer, Z. and Gat, J. R., 1975.** *The Isotope Composition of Evaporating Brines: Effect Of The Isotopic Activity Ratio in Saline Solutions***.** Earth Planetary Science Letters, Vol. 26, pp. 179-186.
- **Sokolov, A. A. and Chapman, T. G.(edts),1974.** *Method for Water Balance Computation***,** A contribution to the International Hydrological Decade UNESCO Press Paris, 124 P.
- **Springer, A.E., L.E. Stevens, D.E. Anderson, R.A. Parnell, D.K. Kreamer, and S.P. Flora. , 2004.** *A Comprehensive Springs Classification System: Integrating Geomorphic, Hydrogoechemical, and Ecological Criteria,* In Press.

- **Stanton, G. P. and Clark, B. R., 2003.** *Recalibration of a Ground-Water Flow Model of the Mississippi River Valley Alluvial Aquifer in Southeastern Arkansas, 1918-1998, with Simulations of Hydraulic Heads Caused by Projected Ground-Water Withdrawals Through 2049* U.S. Geological Survey Water-Resources Investigations Report 03-4232,51P.
- **Stanton, R.E., 1966.** *Rapid Methods of Trace Elements Analysis for Geochemical Application*. Edward Arnold publ., London, 96 P.
- **Stevanovic,Z. and Markovic, ,M. ,2004a.** *Hydrogeology of Northern Iraq.Vol.1,Climate,Hydrology ,Geomorphology and Geology* **.**Food and Agriculture Organization of the United Nations, Rome. 190 P.
- **Stevanovic,Z. and Markovic,M. ,2004b.** *Hydrogeology of Northern Iraq.Vol.2, General Hydrogeology and Aquifer Systems***.** Food and Agriculture Organization of the United Nations, Rome.246 P.
- **Stoodly, K.D., Lewis, T. and Staintion, C.L., 1980.** *Applied Statistical Technique***.** John Wiley and Sons, London**.**215 P
- **Szucs, P. Civan, F. Virag, M., 2006.** *Applicability of the Most Frequent Value Method in Groundwater Modeling*, Hydrogeology Journal .Vol.14: pp. 31–43.
- **Thornthwaite ,C.W., Mather , J.R., 1955.** *The Water Balance* .Publication Climatology, 8(1).
- **Thornthwaite, C.W. and Mather , J.R. ,1957.** *Instructions and Tables for Computing Potential Evapotranspiration and the Water Balance* .3.New Jersey.
- **Todd , D.K. 1980.** *Groundwater Hydrology (2nd edition)***.**John Wiley and Sons, New York,USA,535p.
- **Todd, D.K., 2005.** *Groundwater Hydrology (3^{ed} edition)***.**John Wiley and Sons, New York, USA, 650p.
- **UNJHIC, 2002.** *Erbil, Dahhuk, and Sulaymaniyah, Rapid District Summeries*.Vol.1, 99 P.

References

- **US Salinity Laboratory Staff, 1954 .** *Diagnosis and Improvement of Saline and Alkali Soils*. US Department of Agricultural Hand Book 60, Washington.160P.
- **Wallace, M.P. and Alfaro, C., 2001**. *Geologic/hydrologic Setting and Classification of Springs,* in P.E. LaMoreauz and J.T. Tanner eds. Springs and bottled waters of the world: ancient history, source, occurrence, quality and use. Springer, Berlin, Germany.85 P.
- **Winograd, I. J., Riggs, A. C., and Coplen, T. B. ,1998 .***The Relative Contributions of Summer and Cool-Season Precipitation to Groundwater Recharge, Spring Mountains, Nevada, USA.* Hydrogeology Journal, Vol. 6, No.1. pp. 77-93.
- **World Meteorological Organization (WMO), 1994**. *Guide to Hydrological Practices*, 5th edition, WMO-No. 168, 735 P.
- **World Health Organization (WHO), 2006.** *Guidelines for Drinking-Water Quality. 3rd ed., Vol.1, Recommendations***,** Geneva, 595 P.
- **Xu, Y.n and Beekman, H. E., 2003.** *Groundwater Recharge Estimation in Southern Africa***,** UNESCO IHP Series No. 64, 206 pp
- **Yu Lu, H., Liu, T., Chen, W., Peng, T., and Wang, C., 2008**. *Use of Geochemical Modeling to Evaluate the Hydraulic Connection of Aquifers: A Case Study from Chianan Plain, Taiwan.* Hydrogeology Journal, Vol. 16, No.1. pp. 139-154.

APPENDICES

Appendix (1) Physical and Geomorphic Classification of Springs (after Springer et al., 2004), Which was used to Classify Rania Area Springs

Class Variable	Type / Criterion	Value / Descriptor	References
Hydrostratigraphic unit	Sedimentary	(bedrock or Unconsolidated sediments)	Meinzer 1923
	Igneous		Meinzer 1923
	Metamorphic		Meinzer 1923
	Mixed	(combination of above)	Meinzer 1923
Emergence environment	Cave	Special case, not ususally considered as a spring because it may not be directly exposed to the atmosphere	Springer et al., 2004
	Subaerial-floodplain	Above-ground emergence - Floodplain of primary or secondary drainage	Springer et al., 2004
	Subaerial – prairie	Above-ground emergence - Relatively flat open region	Springer et al., 2004
	Subaerial – Piedmont	Above-ground emergence - note geomorphic setting	Springer et al., 2004
	Subaerial – Channel	Above-ground emergence - Channel of secondary drainage, dry wash, no steep walls	Springer et al., 2004
	Subaerial – Canyon Floor	Above-ground emergence - Channel of steep walled canyon or primary drainage	Springer et al., 2004
	Subaerial – Canyon Wall	Above-ground emergence - Emerges from steeply sloping canyon walls	Springer et al., 2004
	Subaerial – Mountainside	Above-ground emergence – Moderately sloping hillside	Springer et al., 2004
	Subglacial	Above-ground emergence beneath a glacier	Springer et al., 2004
	Subaqueous-lentic freshwater	Aquatic emergence into pond or lake	Springer et al., 2004
	Subaqueous-lotic freshwater	Aquatic emergence into a stream or river	Springer et al., 2004
	Subaqueous-estuarine	Aquatic emergence in an estuary	Springer et al., 2004
	Subaqueous-marine	Aquatic emergence in a marine setting	Springer et al., 2004
Aperture geomorphology	Seepage or filtration spring	Groundwater exposed or discharged from numerous small openings in permeable material	Meinzer 1923
	Fracture spring	Groundwater exposed or discharged from joints or fractures	Meinzer 1923
	Tubular spring	Groundwater discharged from, or exposed in openings of channels, such as solution passages or tunnels	Meinzer 1923
	Contact spring	Flow discharged along a stratigraphic contact (e.g., a hanging garden)	Springer et al., 2004

Continued

Class Variable	Type / Criterion	Value / Descriptor	References
Sphere of discharge	Cave	Emergence in a cave	Springer et al., 2004
	Limnocrene - emerges from lentic pools	Emergence in pool(s)	Modified from Meinzer 1923
	Rheocrene - lotic channel floor	Flowing spring, emerges into one or more stream channels	Modified from Meinzer 1923
	(Carbonate) Mound-form	Emerges from a mineralized mound	Springer et al., 2004
	Helocrene (marsh) or cienega (wet meadow	Emerges from low gradient wetlands; often indistinct or multiple sources	Modified from Meinzer 1923
	Hillslope spring	Emerges from a hillslope (30-60^o slope); often indistinct or multiple sources	Springer et al., 2004
	Gushette	Discrete source flow gushes from a wall	Springer et al., 2004
	Hanging garden	Dripping flow emerges usually horizontally along a geologic contact	Springer et al., 2004
	Geyser	Explosive flow	Springer et al., 2004
	Fountain	Artesian fountain form	Springer et al., 2004
	Hypocrene	A buried spring where flow does not reach the surface	Springer et al., 2004
Spring channel	Spring-dominated stream	Little external flow impact	Springer et al., 2004
	Runoff-dominated stream	Dominated by external flow impacts	Springer et al., 2004
	Combined stream	Definite spring impact channel within runoff dominated channel	Springer et al., 2004
Forcing mechanisms	Gravity driven springs	Depression, contact, fracture, or tubular springs	Meinzer 1923
	Increased pressure due to gravity driven head pressure differential	Artesian springs	Meinzer 1923
	Geothermal springs	Springs associated with volcanism	Meinzer 1923
	Springs due to pressure produced by other forces	Springs associated with deep seated fractures	Springer et al., 2004
	Springs due to pressure produced by anthropogenic forces	Anthropogenic artesian or geyser systems (e.g., hot springs associated with Hoover Dam, Arizona- Nevada)	Springer et al., 2004
Persistence	Neorefugium	Holocene (<12,000 yr old)	Springer et al., 2004
	Paleorefugium	Pleistocene or older (>12,000 yr old)	Springer et al., 2004
	Paleospring	Pleistocene but not apparent recent flow	Springer et al., 2004

Appendix (2) Hydrological Classification of Springs (after Springer et al., 2004), Which was used to Classify Rania Area Springs

Class Variable	Type / Criterion	Value / Descriptor	References
Flow consistency	Perennial	Continuous flow	Meinzer 1923
	Intermittent-regular	Regular - flow occurs regularly on hourly or daily, seasonally, annually, or interannually	Meinzer 1923; Springer et al., 2004
	Intermittent-erratic	Flow occurs only on an erratic basis	Springer et al., 2004
	Intermittent-dry	No flow at all times of measurement for data used in classification	Springer et al., 2004
Flow rate	Unmeasureable	No discernable flow to measure	Springer et al., 2004
	First	<0.12 gpm (<10 ml/s)	Meinzer 1923
	Second	0.12 - 1.0 gpm (10 - 100 ml/s)	Meinzer 1923
	Third	1.0 – 10 gpm (0.10 - 1.0 L/s)	Meinzer 1923
	Fourth	10 – 100 gpm (1.0 - 10 L/s)	Meinzer 1923
	Fifth	100 - 448.8 gpm (10. - 100 L/s)	Meinzer 1923
	Sixth	448.8 - 4,488 gpm (0.10 - 1.0 m^3/s)	Meinzer 1923
	Seventh	4,488 - 44,880 gpm (1.0 - 10. m^3/s)	Meinzer 1923
	Eighth	>44,880 gpm (>10 m^3/s) Meinzer 1923	Meinzer 1923
Flow variability (CVR = Q10%/Q90%)	Steady (extraordinarily balanced)	1.0 - 2.5	Meinzer 1923, Netopil 1971,
	Moderately (well) balanced	2.6 - 5.0	Alvaro and Wallace 1994
	Balanced	5.1 - 7.5	Meinzer 1923, Netopil 1971,
	Moderately unbalanced	7.6 - 10.0	Meinzer 1923, Netopil 1971,
	Highly unsteady (extraordinarily unbalanced)	> 10.0	Meinzer 1923, Netopil 1971,
	Ephemeral	Infinite	Springer et al., 2004

Appendix (3) Geochemical Classification of Springs after (Springer et al., 2004), Which was used to Classify Rania area Springs

Class Variable	Type / Criterion	Value / Descriptor	References
Temperature	Cold	Below mean annual ambient temperature	Alfaro and Wallace, 1994
	Normal	Within 12.2^{o}C of the mean ambient temperature	Alfaro and Wallace, 1994
	Geothermal - warm	>12.2^{o}C warmer than mean annual ambient temperature but <37.8^{o}C	Alfaro and Wallace, 1994
	Hot	Significantly warmer than mean annual ambient temperature 37.8^o C-100^{o}C	Alfaro and Wallace, 1994
	Superheated (usually pressurized)	>100^{o}C	Springer et al., 2004
	Ambient temperature	Taken at time of spring water temperature measurment	Springer et al., 2004
Dominant cation type	Magnesium type	Magnesium (Mg) is the dominant	Springer et al., 2004
	Calcium type	Calcium (Ca) is the dominant cation	Springer et al., 2004
	Sodium type	Sodium and Potassium (Na +K) are the dominant cations	Springer et al., 2004
	No dominant type	No dominant cations	Springer et al., 2004
Dominant anion type	Sulfate type	Sulfate (SO_4) is the dominant anion	Springer et al., 2004
	Bicarbonate type	Carbonate and Bicarbonate (HCO_3 + CO_3) the dominant anions	Springer et al., 2004
	Chloride type	Chloride (Cl) is the dominant anion	Springer et al., 2004
	No dominant type	No dominant anions	Springer et al., 2004
Minor constituents		For example, borate, iron	Meinzer 1923, Clarke 1924
Pollution indicators	Polluted – mineral	Selenium, Arsenic	Springer et al., 2004
	Polluted – biological	Fecal, coliform	Springer et al., 2004
	Polluted - human	Trash, development pollution	Springer et al., 2004
	Polluted – multiple	Combination of three above	Springer et al., 2004
	No Pollution	No pollution at spring	Springer et al., 2004
Tracers		Stable isotopes, radioactive isotopes, rare earth elements	Springer et al., 2004
Alkalinity		Alkalinity	Clarke 1924

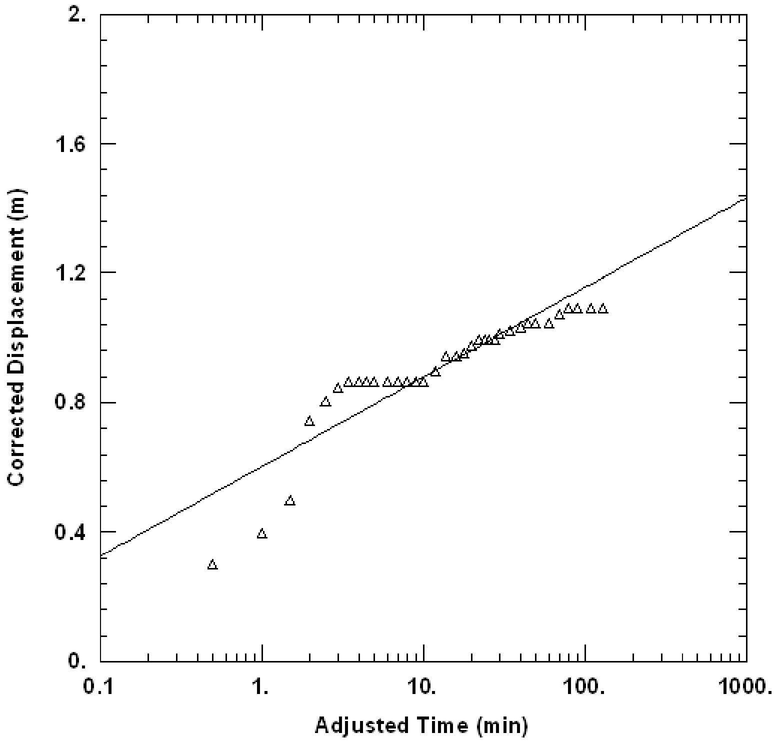
Continued

Class Variable	Type / Criterion	Value / Descriptor	References
TDS or specific conductance	Hyperfresh	0 – 100 mg/L	Springer et al., 2004
	Fresh	100 – 1000 mg/L	Fetter 1994
	Brackish	1000 – 10,000 mg/L	Fetter 1994
	Saline	10,000 – 100,000 mg/L	Fetter 1994
	Brine	> 100,000 mg/L	Fetter 1994
pH	Strongly Acidic	pH range: < 4.0	Springer et al., 2004
	Acidic	pH range: 4.0 - <6.0	Springer et al., 2004
	Neutral	pH range: 6.0 – 8.0	Springer et al., 2004
	Moderately Basic	pH range: >8.0 - 10.0	Springer et al., 2004
	Strongly Basic	pH range: >10.0	Springer et al., 2004
Nutrient concentration	High N-P	N and P concentration high	Springer et al., 2004
	High N Low P	Nitrogen concentration high	Springer et al., 2004
	High P Low N	Phosphorus concentration high	Springer et al., 2004
	Low N-P	N and P concentration low	Springer et al., 2004

Appendix (4) well test data and results

Time- drawdown Data of the Single Well Pumping Test (Girdjan Well)

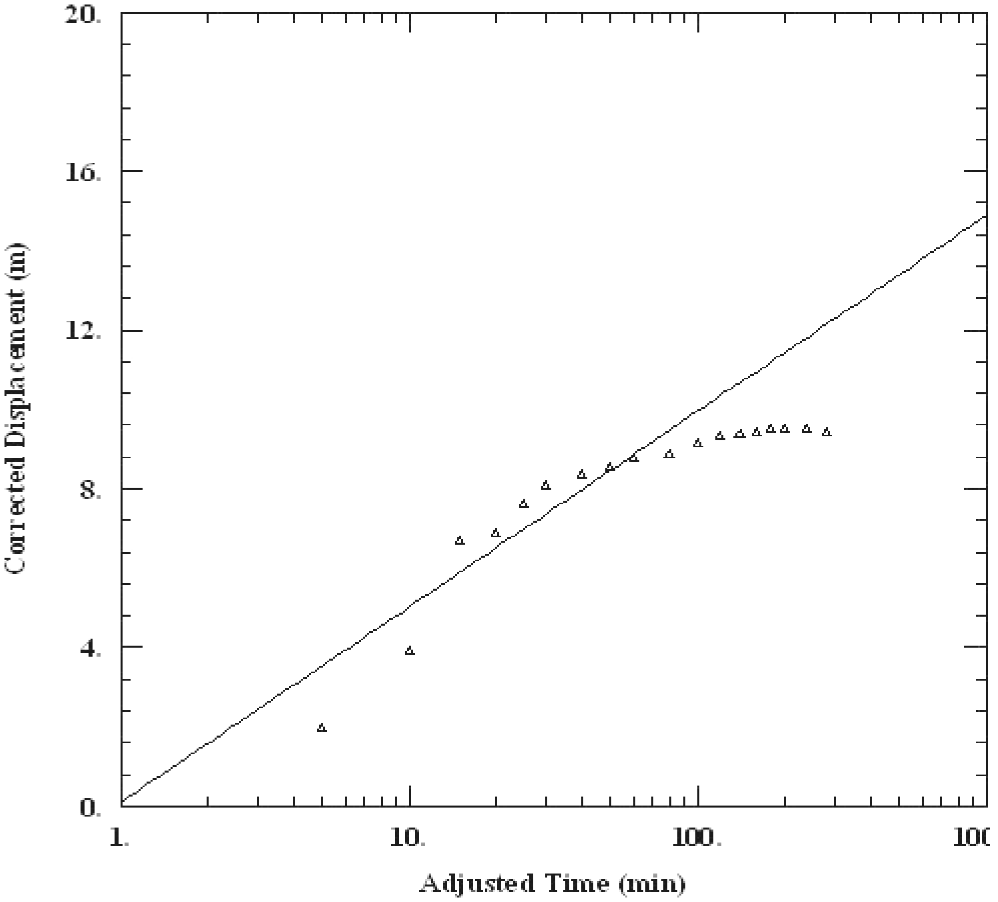
		Well Name	**Girdjan**		**Well Test**
b (m)	**S.W.L (m)**	**Q (l/sec)**	**T (m^2/day)**	**S**	**Solution**
81.2	13.8	10.5	600.8	0.0063	Cooper-Jacob
			Well Data		
Time (minute)	**Drawdown (m)**	**Time (minute)**	**Drawdown (m)**	**Time (minute)**	**Drawdown (m)**
0.5	0.3	10	0.87	50	1.05
1	0.4	12	0.9	60	1.05
1.5	0.5	14	0.95	70	1.08
2	0.75	16	0.95	80	1.1
2.5	0.81	18	0.96	90	1.1
3	0.85	20	0.98	110	1.1
3.5	0.87	22	1	130	1.1
4	0.87	24	1	150	1.1
4.5	0.87	26	1	180	1.1
5	0.87	28	1	210	1.1
6	0.87	30	1.02	240	1.1
7	0.87	35	1.03	300	1.1
8	0.87	40	1.04	360	1.1
9	0.87	45	1.05		



Time-Drawdown Graph Using (Cooper –Jacob, 1946) Method for Girdjan Well

Time- drawdown Data of the Single Well Pumping Test (Camp13Well)

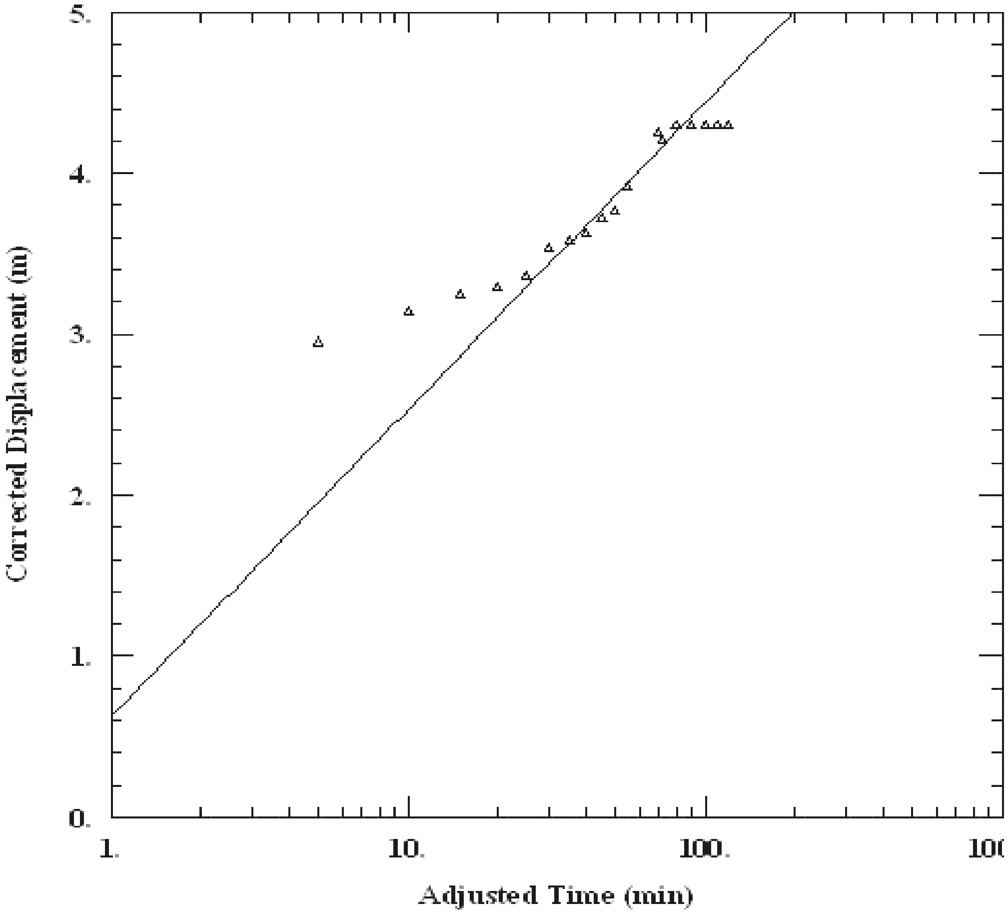
		Name	**Camp 13**		**Well Test**
B (m)	**S.W.L (m)**	**Q (l/sec)**	**T (m^2/day)**	**S**	**Solution**
87	13	13.88	44.6	0.067	**Cooper-Jacob**
Well Data					
Time (minute)	**Drawdown (m)**	**Time (minute)**	**Drawdown (m)**	**Time (minute)**	**Drawdown (m)**
5	2	60	9.3	240	10.1
10	4	80	9.4	280	10
15	7	100	9.7	300	10
20	7.2	120	9.9		
25	8	140	9.95		
30	8.5	160	10		
40	8.8	180	10.1		
50	9	200	10.1		



Time-Drawdown Graph Using (Cooper –Jacob, 1946) Method for Camp13 Well

Time- drawdown Data of the Single Well Pumping Test (Camp14 Well)

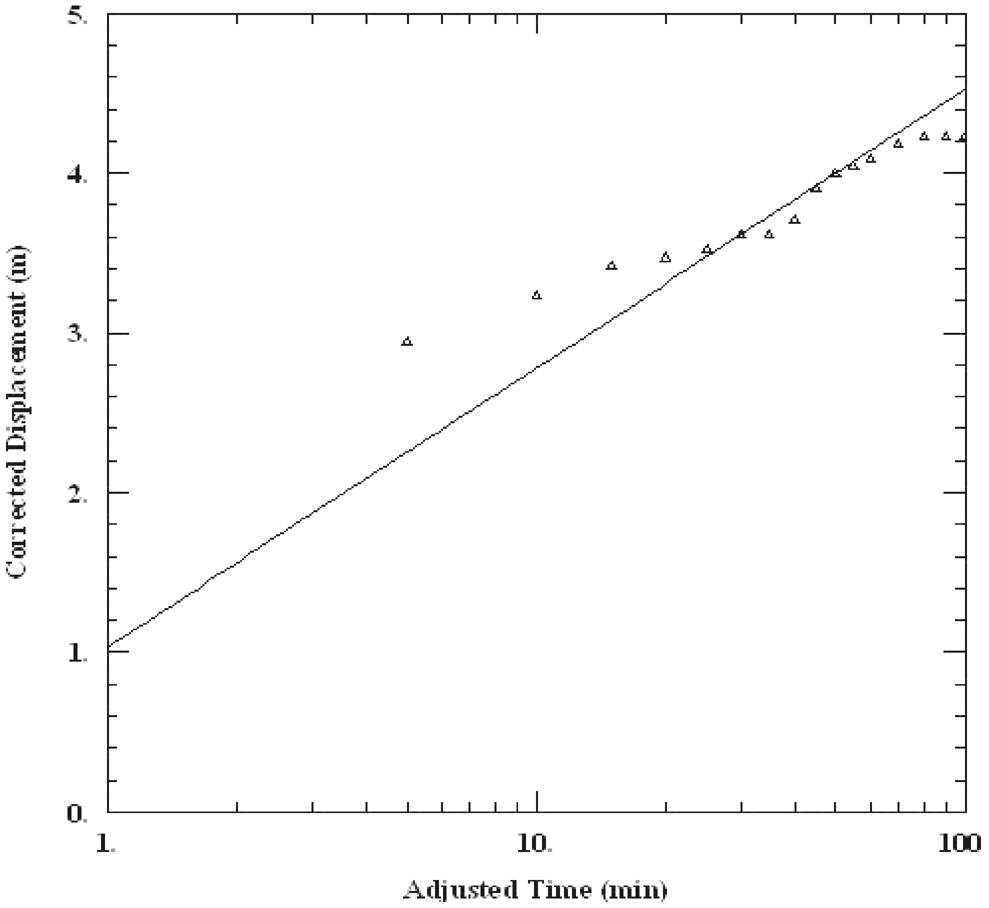
		Name	**Camp 14**		**Well Test**
b (m)	**S.W.L (m)**	**Q (l/sec)**	**T (m^2/day)**	**S**	**Solution**
100	20	15	124.5	0.09	Cooper-Jacob
Well Data					
Time (minute)	**Drawdown (m)**	**Time (minute)**	**Drawdown (m)**	**Time (minute)**	**Drawdown (m)**
5	3	35	3.65	70	4.35
10	3.2	40	3.7	80	4.4
15	3.3	45	3.8	90	4.4
20	3.35	50	3.85	100	4.4
25	3.42	55	4	110	4.4
30	3.6	72	4.3	120	4.4



Time-Drawdown Graph Using (Cooper –Jacob, 1946) Method for Camp14 Well

Time- drawdown Data of the Single Well Pumping Test (Rapareen Well)

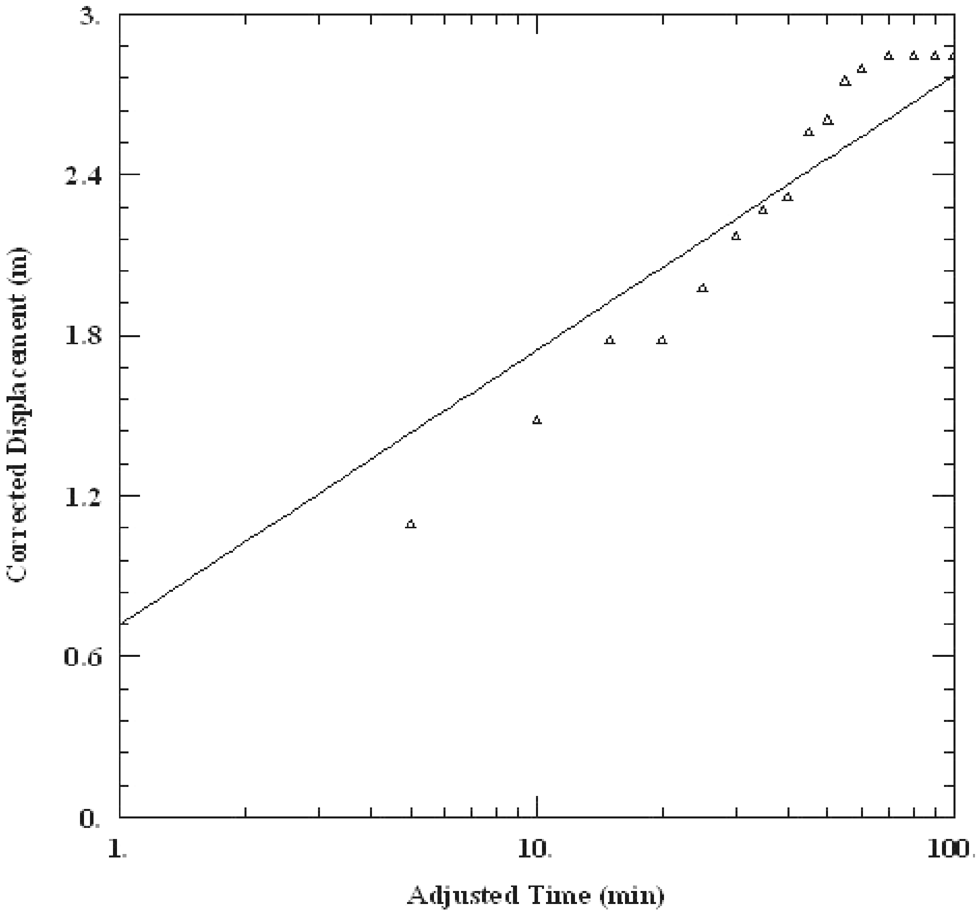
		Name	**Rapareen**		**Well Test**
b (m)	**S.W.L (m)**	**Q (l/sec)**	**T (m^2/day)**	**S**	**Solution**
84	16	22	199.3	0.079	Cooper-Jacob
Well Data					
Time (minute)	**Drawdown (m)**	**Time (minute)**	**Drawdown (m)**	**Time (minute)**	**Drawdown (m)**
5	3	35	3.7	70	4.3
10	3.3	40	3.8	80	4.35
15	3.5	45	4	90	4.35
20	3.55	50	4.1	100	4.35
25	3.6	55	4.15		
30	3.7	60	4.2		



Time-Drawdown Graph Using (Cooper –Jacob, 1946) Method for Rapareen Well

Time- drawdown Data of the Single Well Pumping Test (Saruchawa1 Well)

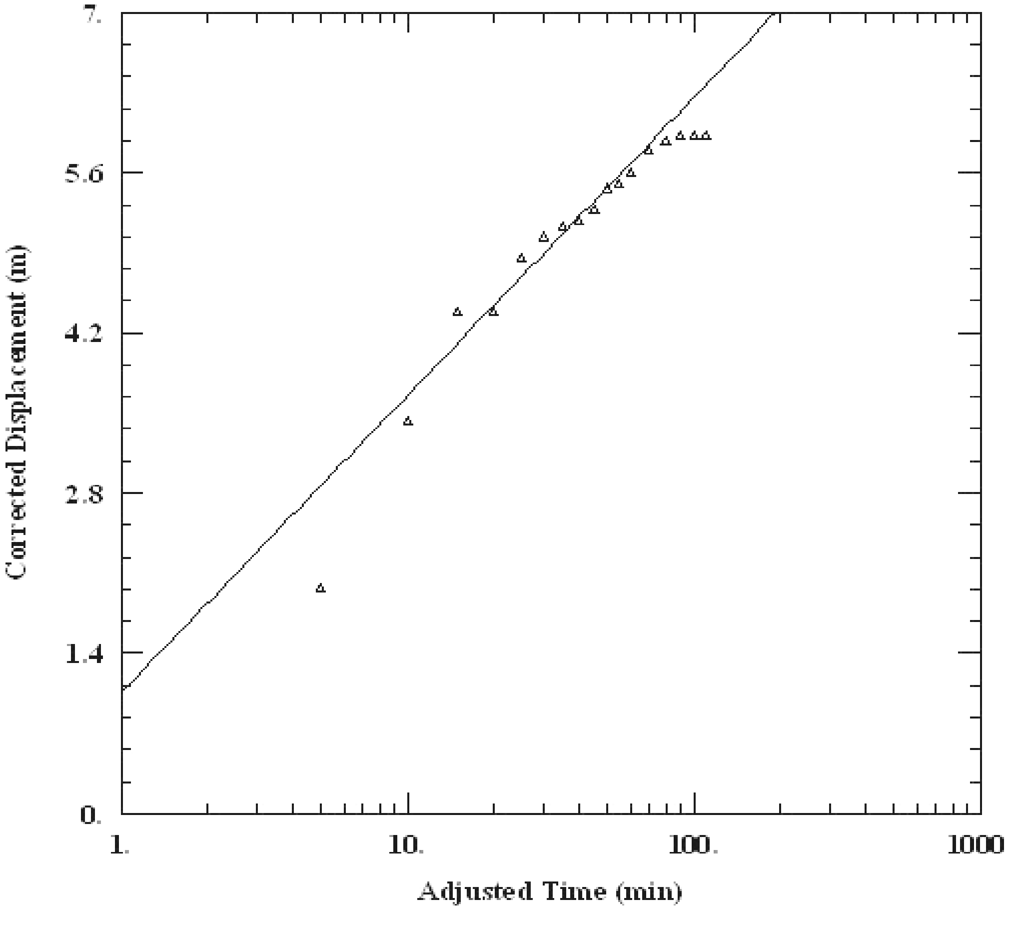
		Name	Saruchawa1		Well Test
b (m)	**S.W.L (m)**	**Q (l/sec)**	**T (m^2/day)**	**S**	**Solution**
81	43.1	11	169.6	0.053	Cooper-Jacob
Well Data					
Time (minute)	**Drawdown (m)**	**Time (minute)**	**Drawdown (m)**	**Time (minute)**	**Drawdown (m)**
5	1.1	35	2.3	70	2.9
10	1.5	40	2.35	80	2.9
15	1.8	45	2.6	90	2.9
20	1.8	50	2.65	100	2.9
25	2	55	2.8		
30	2.2	60	2.85		



Time-Drawdown Graph Using (Cooper –Jacob, 1946) Method for Saruchawa1 Well

Time- drawdown Data of the Single Well Pumping Test (Saruchawa2 Well)

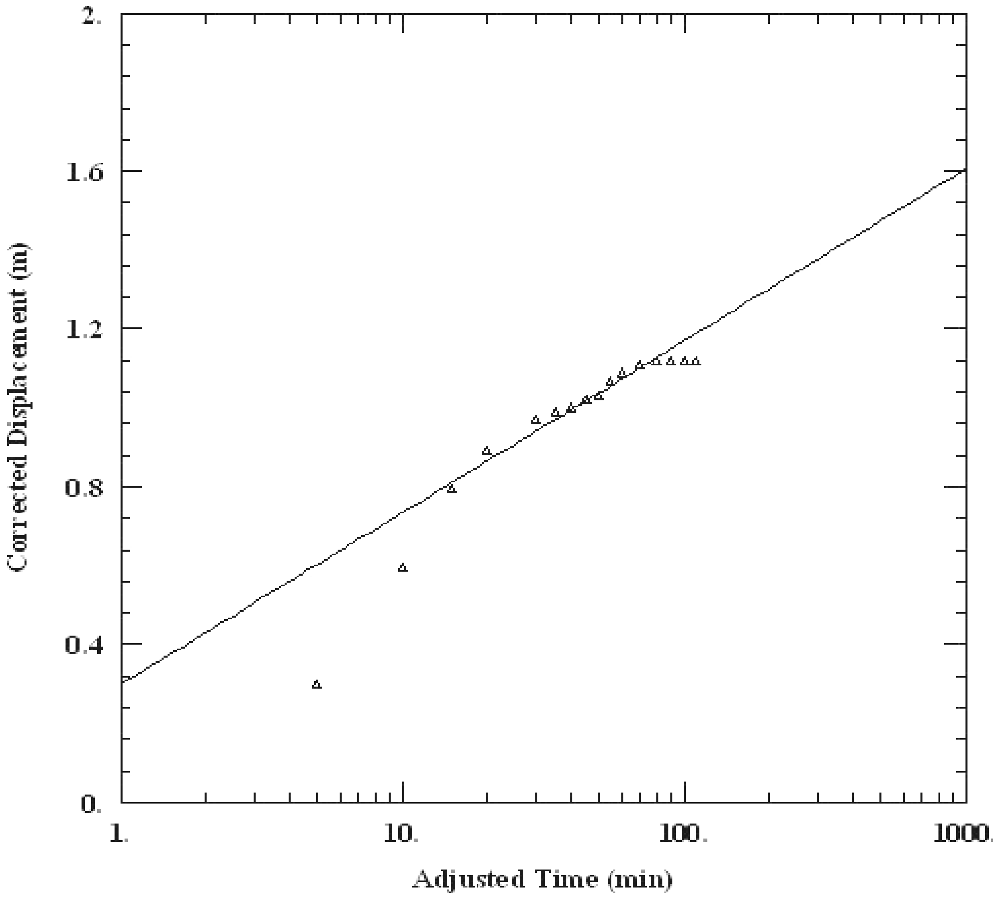
		Name	Saruchawa2		Well Test
b (m)	S.W.L (m)	Q (l/sec)	T (m^2/day)	S	Solution
86	36	13.5	82.14	0.05	Cooper-Jacob
Well Data					
Time (minute)	Drawdown (m)	Time (minute)	Drawdown (m)	Time (minute)	Drawdown (m)
5	2	35	5.3	70	6
10	3.5	40	5.35	80	6.1
15	4.5	45	5.45	90	6.15
20	4.5	50	5.65	100	6.15
25	5	55	5.7	110	6.15
30	5.2	60	5.8		



Time-Drawdown Graph Using (Cooper –Jacob, 1946) Method for Saruchawa2 Well

Time- drawdown Data of the Single Well Pumping Test (Mirabag Well)

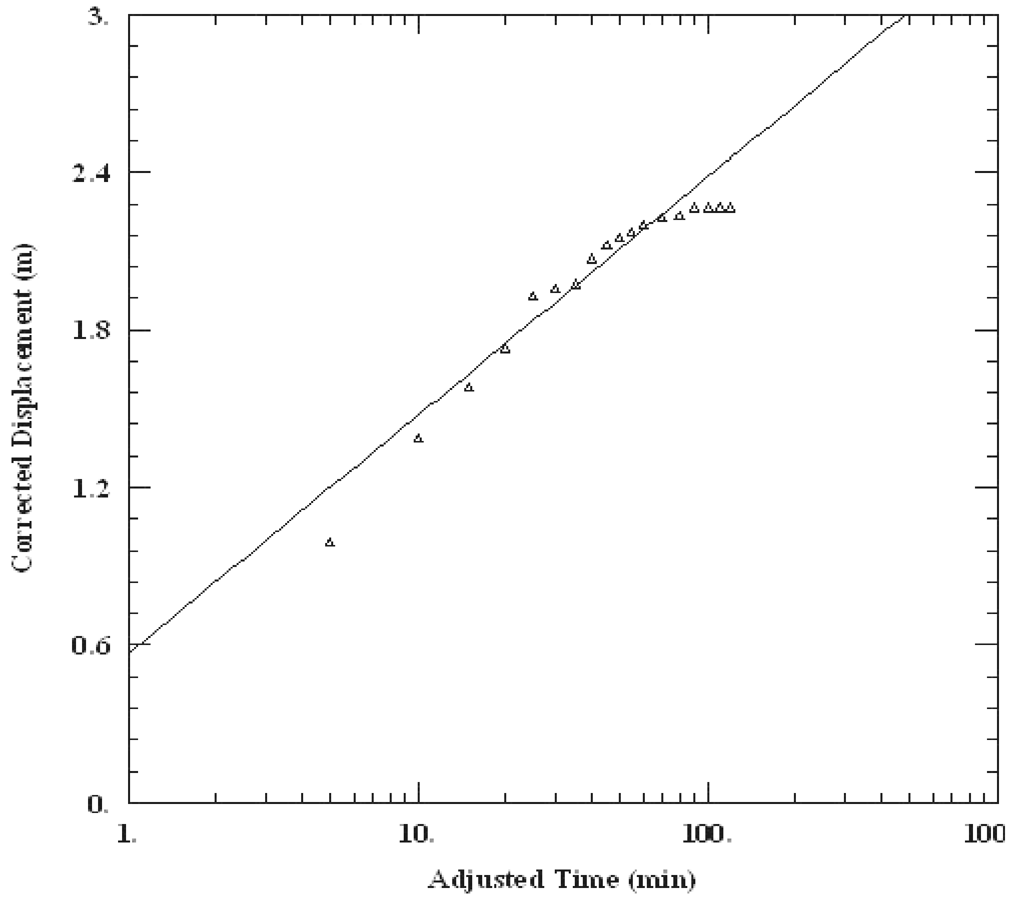
		Name	**Mirabag**		**Well Test**
b (m)	**S.W.L (m)**	**Q (l/sec)**	**T (m^2/day)**	**S**	**Solution**
58	65	6.75	245.3	0.079	Cooper-Jacob
Well Data					
Time (minute)	**Drawdown (m)**	**Time (minute)**	**Drawdown (m)**	**Time (minute)**	**Drawdown (m)**
5	0.3	35	1	70	1.12
10	0.6	40	1.01	80	1.13
15	0.8	45	1.03	90	1.13
20	0.9	50	1.04	100	1.13
25	3.95	55	1.08	110	1.13
30	0.98	60	1.1		



Time-Drawdown Graph Using (Cooper –Jacob, 1946) Method for Mirabag Well

Time- drawdown Data of the Single Well Pumping Test (Kifradol Well)

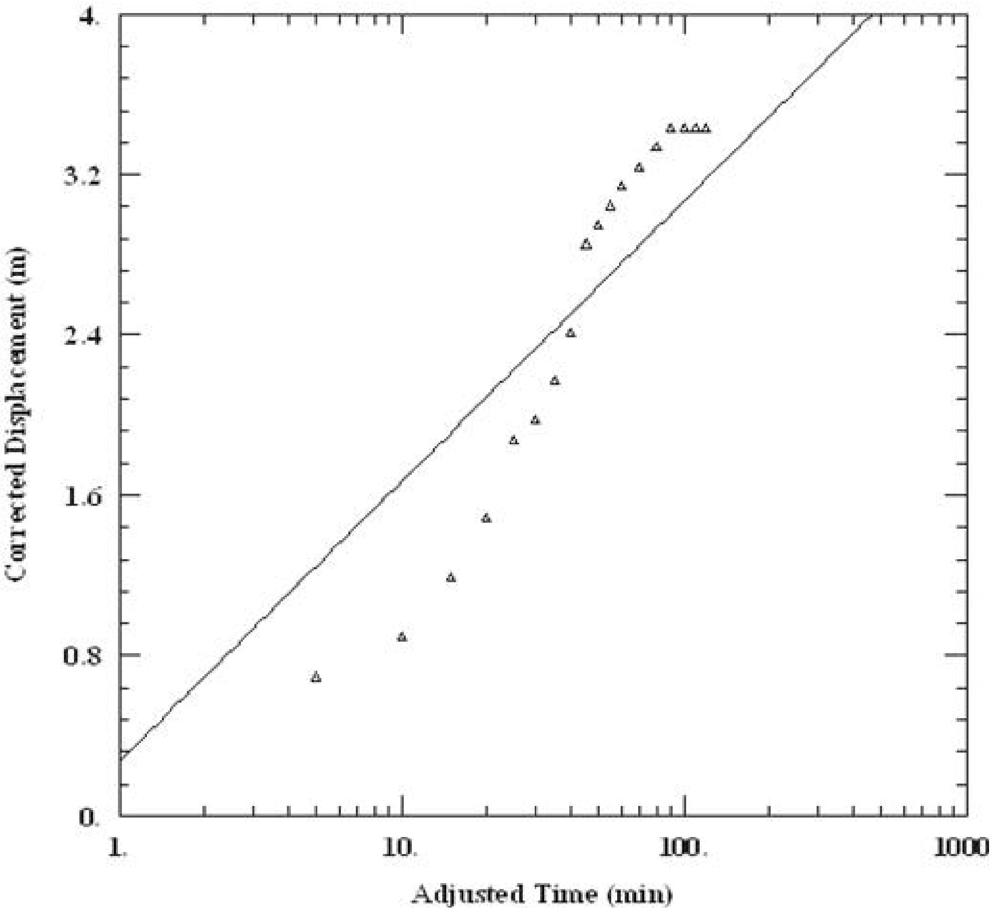
		Name	**Kifradol**		**Well Test**
b (m)	**S.W.L (m)**	**Q (l/sec)**	**T (m^2/day)**	**S**	**Solution**
78	37	13.5	235.7	0.087	Cooper-Jacob
Well Data					
Time (minute)	**Drawdown (m)**	**Time (minute)**	**Drawdown (m)**	**Time (minute)**	**Drawdown (m)**
5	1	35	2	70	2.26
10	1.4	40	2.1	80	2.27
15	1.6	45	2.15	90	2.3
20	1.75	50	2.18	100	2.3
25	1.95	55	2.2	110	2.3
30	1.98	60	2.23	120	2.3



Time-Drawdown Graph Using (Cooper –Jacob, 1946) Method for Kifradol Well

Time- drawdown Data of the Single Well Pumping Test (Tekosher Well)

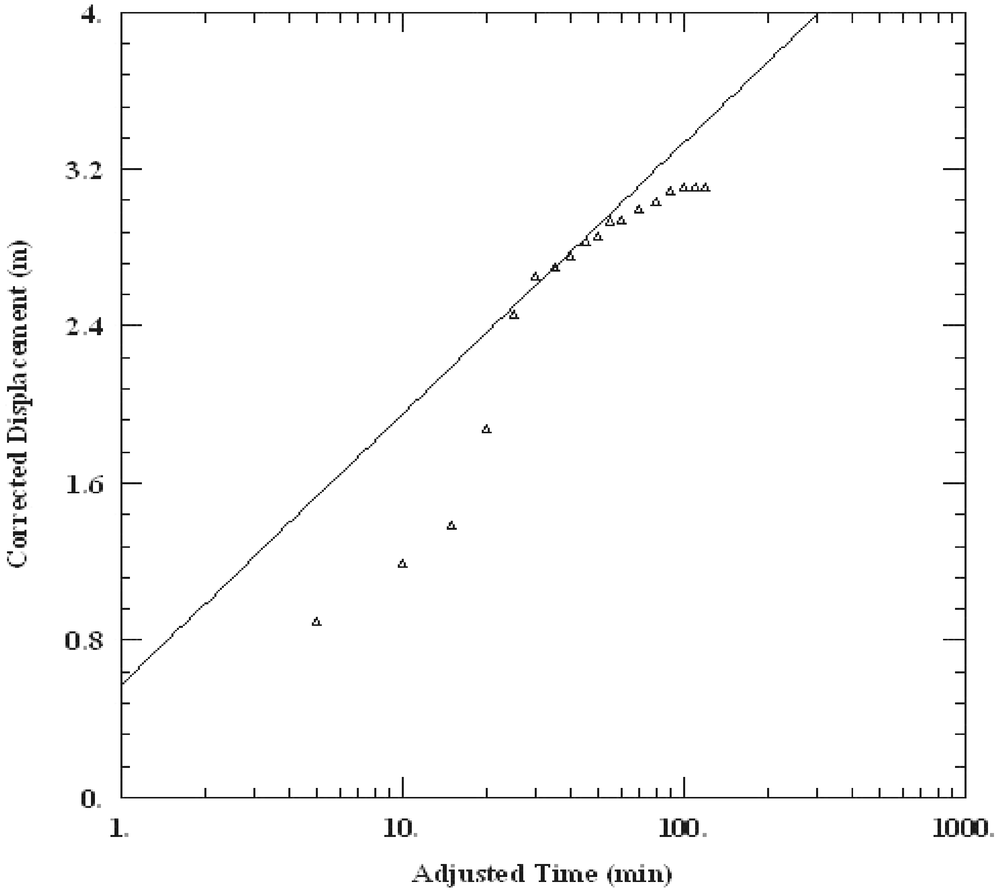
		Name	**Tekosher**		**Well Test**
b (m)	**S.W.L (m)**	**Q (l/sec)**	**T (m^2/day)**	**S**	**Solution**
92	43	13.5	152.8	0.15	Cooper-Jacob
			Well Data		
Time (minute)	**Drawdown (m)**	**Time (minute)**	**Drawdown (m)**	**Time (minute)**	**Drawdown (m)**
5	0.7	35	2.2	70	3.3
10	0.9	40	2.45	80	3.4
15	1.2	45	2.9	90	3.5
20	1.5	50	3.0	100	3.5
25	1.9	55	3.1	110	3.5
30	2	60	3.2	120	3.5



Time-Drawdown Graph Using (Cooper –Jacob, 1946) Method for Tekosher Well

Time- drawdown Data of the Single Well Pumping Test (Industrial Well)

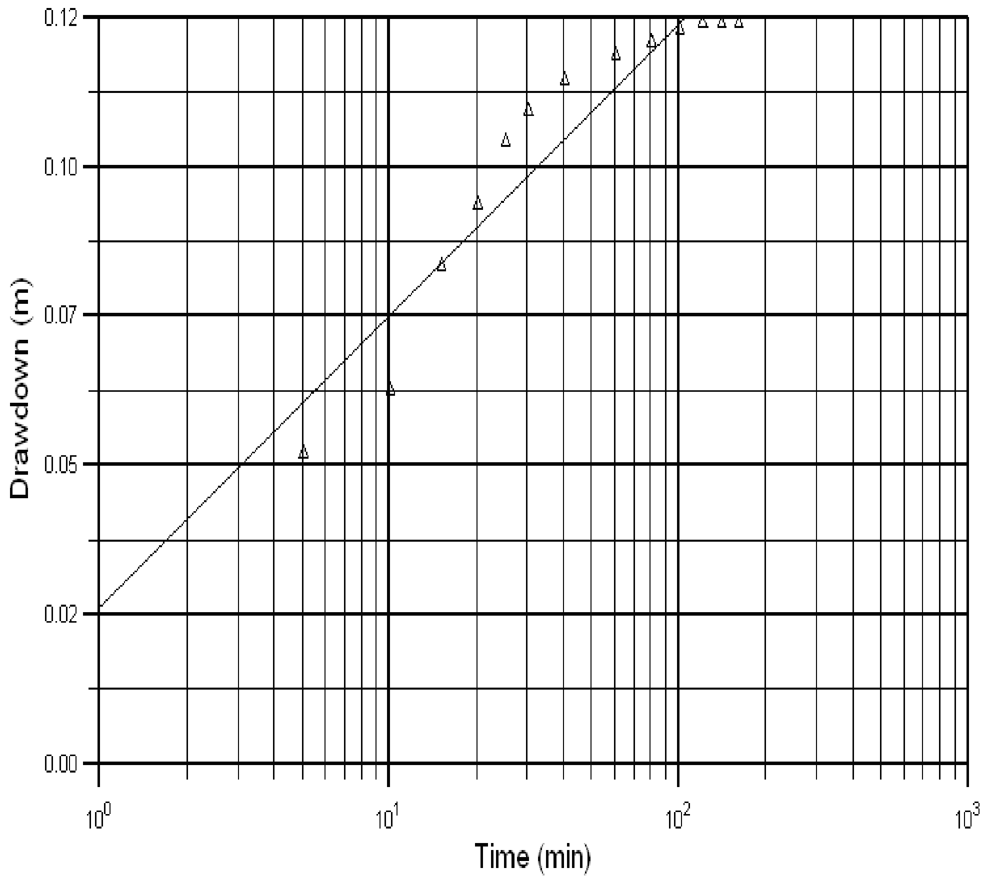
		Name	**Industrial**		**Well Test**
b (m)	**S.W.L (m)**	**Q (l/sec)**	**T (m^2/day)**	**S**	**Solution**
84	36	13.5	154.7	0.09	Cooper-Jacob
Well Data					
Time (minute)	**Drawdown (m)**	**Time (minute)**	**Drawdown (m)**	**Time (minute)**	**Drawdown (m)**
5	0.9	35	2.75	70	3.05
10	1.2	40	2.8	80	3.09
15	1.4	45	2.88	90	3.15
20	1.9	50	2.91	100	3.17
25	2.5	55	2.99	110	3.17
30	2.7	60	3	120	3.17



Time-Drawdown Graph Using (Cooper –Jacob, 1946) Method for Industrial Well

Time- drawdown Data of the Pumping Test (Bosken Well)

		Name	**Bosken**		**Pumping Test**
b (m)	**S.W.L (m)**	**Q (l/sec)**	**T (m^2/day)**	**S**	**Solution**
72.5	6.5	12.6	4260	0.0031	Cooper-Jacob
r=25m	**Well Data**				
Time (minute)	**Drawdown (m)**	**Time (minute)**	**Drawdown (m)**	**Time (minute)**	**Drawdown (m)**
5	0.05	30	0.105	120	0.119
10	0.06	40	0.11	140	0.119
15	0.08	60	0.114	160	0.119
20	0.09	80	0.116		
25	0.1	100	0.118		



Time-Drawdown Graph Using (Cooper –Jacob, 1946) Method for Bosken Well

Bosken
B=72.5
T=4260m2/day   s=0.0031 swl 6.5   r=25

Appendix (5) Physical Parameters and Major Ions Concentrations in Water Wells Samples for Dry Season (October)

No.	T^{o}C	pH	EC µs/cm	TDS mg/l	unit	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	SUM	SO4^{2-}	Cl^{-}	HCO$_3^{-}$	CO$_3^{2-}$	SUM
W1	24.5	7.18	616	394.2	ppm	86.4	7.68	49.33	3.31	146.7	42	34.7	269	0	345.7
					epm	4.32	0.64	2.14	0.08	7.2	0.88	0.96	4.4	0	6.25
					%epm	60.1	8.9	29.8	1.2	100	14	15.4	70.6	0	100
W2	20	7.41	483	309.1	ppm	67.2	9.6	6.45	0.86	84.1	26	29	222	0	277
					epm	3.36	0.80	0.28	0.02	4.5	0.54	0.81	3.6	0	4.99
					%epm	75.3	17.9	6.29	0.5	100	10.9	16.2	73	0	100
W3	19.5	7.43	472	302.1	ppm	64	15.36	6.45	0.86	86.7	32	38	218	0	288
					epm	3.2	1.28	0.28	0.02	4.8	0.67	1.06	3.57	0	5.30
					%epm	67	26.8	5.87	0.46	100	12.6	19.9	67.5	0	100
W4	21	7.43	512	327.7	ppm	67.2	11.5	14.02	1.45	94.2	41	36	226.6	0	303.6
					epm	3.36	0.96	0.61	0.04	4.97	0.85	1	3.7	0	5.57
					%epm	67.7	19.3	12.3	0.75	100	15.3	18	66.7	0	100
W5	21	7.5	508	325.1	ppm	64	17	14.02	1.6	96.6	55	33.3	235	0	323.3
					epm	3.2	1.42	0.61	0.04	5.27	1.15	0.93	3.85	0	5.92
					%epm	61	27	11.6	0.78	100	15.6	19.3	65	0	100
W6	20.5	7.4	507	324.5	ppm	70.4	9.6	16.54	1.45	98	42	39.05	226.6	0	307.7
					epm	3.52	0.80	0.72	0.04	5.08	0.88	1.08	3.7	0	5.67
					%epm	69.3	15.8	14.2	0.73	100	15.4	19	65.5	0	100
W7	21	7.39	450	288	ppm	62	11.52	6.45	0.79	80.8	27.5	31	202.2	0	260.7
					epm	3.1	0.96	0.28	0.02	4.36	0.57	0.86	3.3	0	4.75
					%epm	71.1	22.0	6.43	0.46	100	12.06	18.13	69.8	0	100
W8	23	7.37	529	338.6	ppm	64	19.2	11.5	1.38	96.1	75	33	218	0	326
					epm	3.2	1.60	0.5	0.04	5.34	1.56	0.92	3.57	0	6.05
					%epm	60	30	9.4	0.66	100	26	15	59	0	100
W9	22.5	7.48	560	358.4	ppm	71	21	14.02	1.97	108	84	42.6	230	0	356.6
					epm	3.55	1.75	0.61	0.05	5.96	1.18	1.75	3.77	0	6.70
					%epm	59.56	29.4	10.23	0.85	100	17.65	26.10	56.24	0	100
W10	20.5	7.8	460	294.4	ppm	57.6	15	8	0.86	81.5	15	14	265	0	294
					epm	2.88	1.25	0.35	0.02	4.50	0.31	0.39	4.34	0	5.05
					%epm	64	27.8	7.73	0.49	100	6.2	7.7	86.1	0	100
W11	21	7.29	561	359	ppm	70.4	13.44	16.5	1.8	70	70	32	224	0	326
					epm	3.52	1.12	0.72	0.05	5.41	1.46	0.89	3.67	0	6.02
					%epm	65	20.7	13.3	0.87	100	14.8	24.2	61	0	100
W12	21.3	7.39	550	352	ppm	67.2	17.3	14	1.53	100	82.5	38.3	202.2	0	323
					epm	3.36	1.44	0.61	0.04	5.45	1.72	11.06	3.31	0	6.1
					%epm	61.7	26.4	11.2	0.72	100	28.2	17.5	54.4	0	100
W13	22	7.4	518	331.5	ppm	60.8	19.2	14.02	1.60	95.6	62.5	34.08	226.6	0	323.2
					epm	3.04	1.60	0.61	0.04	5.29	1.30	0.95	3.71	0	5.96
					%epm	57.5	30.2	11.5	0.78	100	21.8	16	62.3	0	100
W14	21	7.4	525	336	ppm	64	17.3	14.02	1.45	96.8	52.5	38.34	226.6	0	317.4
					epm	3.2	1.4	0.61	0.04	5.3	1.09	1.07	3.71	0	5.87
					%epm	60.5	27.2	11.5	0.7	100	18	18.6	63.3	0	100

Continued

No.	TºC	pH	EC µs/cm	TDS mg/l	unit	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	SUM	$SO4^{2-}$	Cl^{-}	HCO_3^{-}	CO_3^{2-}	SUM
W15	21	7.1	510	326.4	ppm	70	13.44	16.54	1.45	101.44	20	41.18	202.2	0	263.4
					epm	3.5	1.12	0.72	0.04	5.38	0.42	1.14	3.31	0	4.88
					%epm	65.1	20.8	13.4	0.69	100	8.6	23.5	68	0	100
W16	19	7.35	374	239.4	ppm	54.4	7.68	6.45	0.79	69.32	40	25.5	153.4	0	218.9
					epm	2.72	0.64	0.28	0.02	3.66	0.83	0.71	2.51	0	4.06
					%epm	74.3	17.5	7.7	0.55	100	20.5	17.5	62	0	100
W17	17	7.28	362	231.7	ppm	51.2	13.44	6.40	1.16	72.20	42	41	150	0	233
					epm	2.56	1.12	0.28	0.03	3.99	0.88	1.14	2.46	0	4.47
					%epm	64.2	28.1	6.98	0.74	100	19.6	25.5	55	0	100
W18	18	6.92	380	243.2	ppm	48	11.52	6.45	0.93	66.91	38	28	153.4	0	219.4
					epm	2.4	0.96	0.28	0.02	3.66	0.79	0.78	2.51	0	4.08
					%epm	65.5	26.2	7.66	0.65	100	19.4	19	61.6	0	100
W19	18	7.03	384	245.8	ppm	44.8	15.36	8.98	0.93	70.07	47.5	31.2	151	0	229.7
					epm	2.24	1.28	0.39	0.02	3.93	0.99	0.87	2.48	0	4.33
					%epm	57	32.5	9.9	0.61	100	23	20	57.2	0	100
W20	18	6.65	379	242.6	ppm	44.8	15.36	8.00	1.01	69.17	35	38	129	0	202
					epm	2.24	1.28	0.35	0.03	3.89	0.73	1.06	2.11	0	3.90
					%epm	57.5	32.9	8.9	0.66	100	18.7	27.1	54.2	0	100
W21	18	6.93	388	248.3	ppm	48	13.44	6.00	1.01	68.45	28	33	152	0	213
					epm	2.4	1.12	0.26	0.03	3.81	0.58	0.92	2.49	0	3.99
					%epm	63	29.4	6.85	0.68	100	14.6	23	62.4	0	100
W22	18.5	7.21	382	244.5	ppm	41.6	17.28	4.00	1.08	63.96	29	29	155.8	0	213.8
					epm	2.08	1.44	0.17	0.03	3.72	0.60	0.81	2.55	0	3.96
					%epm	55.9	38.7	4.7	0.75	100	15.2	20.3	64.4	0	100
W23	19	7.81	377	241.3	ppm	44.8	15.2	3.00	1.01	64.o1	18	21	195	0	234
					epm	2.24	1.27	0.13	0.03	3.66	0.38	0.58	3.20	0	4.16
					%epm	61.2	34.6	3.6	0.71	100	9	14	77	0	100
W24	18	7.7	500	320	ppm	60.8	17.28	18.00	1.08	97.16	48	50.41	177.8	0	276.21
					epm	3.04	1.44	0.78	0.03	5.29	1	1.4	2.91	0	5.32
					%epm	57.5	27.2	14.8	0.52	100	18.8	26.4	54.8	0	100
W25	16	7.45	410	262.4	ppm	48	15.36	12.00	1.16	76.52	49	53.2	153.4	0	255.6
					epm	2.4	1.28	0.52	0.03	4.23	1.02	1.48	2.51	0	5.01
					%epm	56.7	30.3	12.3	0.70	100	20.4	29.5	50.2	0	100
W26	16.5	7.26	368	235.5	ppm	44.8	17.28	3.93	0.93	66.95	50	38.3	129	0	217.3
					epm	2.24	1.44	0.17	0.02	3.87	1.04	1.06	2.11	0	4.22
					%epm	57.8	37.2	4.41	0.62	100	24.7	25.2	50.1	0	100
W27	18.2	7.6	395	252.8	ppm	48	11.52	6.20	1.01	66.73	39.5	36.2	129	0	204.7
					epm	2.4	0.96	0.27	0.03	3.66	0.82	1.01	2.11	0	3.94
					%epm	65.7	26.3	7.37	0.71	100	20.9	25.50	53.6	0	100
W28	18	7.65	391	250.2	ppm	47	14	1.41	1.01	63.42	38	29	153.4	0	220.4
					epm	2.35	1.17	0.06	0.03	3.60	0.79	0.81	2.51	0	4.11
					%epm	65.21	32.37	1.70	0.72	100	19.3	19.6	61.2	0	100
W29	20.2	7.32	587	375.7	ppm	76.8	17.28	30.00	0.93	125.01	50.5	70	251	0	371.5
					epm	3.84	1.44	1.30	0.02	6.61	1.05	1.94	4.11	0	7.11
					%epm	58.1	21.8	19.7	0.36	100	14.8	27.3	57.9	0	100

Continued

No.	T°C	pH	EC µs/cm	TDS mg/l	unit	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	SUM	$SO4^{2-}$	Cl^{-}	HCO_3^{-}	CO_3^{2-}	SUM
W30	20.5	7.31	416	266.2	ppm	57.6	11.52	9.00	1.01	79.13	24	36.5	202.2	0	262.7
					epm	2.88	0.96	0.39	0.03	4.26	0.50	1.01	3.31	0	4.83
					%epm	67.7	22.6	9.2	0.61	100	10.4	21	68.7	0	100
W31	19	7.36	455	291.2	ppm	51.2	19.2	10	1.16	81.56	45	36	200	0	281
					epm	2.56	1.60	0.43	0.03	4.62	0.94	1.00	3.28	0	5.22
					%epm	55.4	34.60	9.40	0.64	100	18	19.2	63	0	100
W32	20	6.95	442	283	ppm	54.4	13.44	9.20	1.23	78.27	40	43.5	172	0	255.5
					epm	2.72	1.12	0.40	0.03	4.27	0.83	1.21	2.82	0	4.86
					%epm	63.7	26.2	9.4	0.74	100	17.1	25	58	0	100
W33	19.4	7.43	487	311.7	ppm	60.8	18	13.00	1.31	93.11	47	46.86	202.2	0	296.06
					epm	3.04	1.50	0.57	0.03	5.14	0.98	1.30	3.31	0	5.60
					%epm	59.2	29.2	11	0.7	100	17.5	23.3	59.2	0	100
W34	18	7.15	438	280.3	ppm	51.2	15.36	15	1.16	82.72	5.9	56.8	202.2	0	264.9
					epm	2.56	1.28	0.65	0.03	4.52	0.12	1.58	3.31	0	5.02
					%epm	56.6	28.3	14.4	0.7	100	2.5	31.5	66.1	0	100
W35	20.5	7.22	628	402	ppm	89.6	13.44	28	1.20	132.24	70	62.48	270	0	402.48
					epm	4.48	1.12	1.22	0.03	6.85	1.46	1.74	4.43	0	7.62
					%epm	65.4	16.4	17.8	0.45	100	19.1	22.8	58.1	0	100
W36	21	7.15	649	415.4	ppm	96	19.2	38	1.80	155.00	73	62.48	290	0	425.48
					epm	73	62.48	290	0	425.48	1.52	1.74	4.75	0	8.01
					%epm	59.3	19.8	20.4	0.57	100	19	21.7	59.4	0	100
W37	20	7.37	504	322.6	ppm	54.4	21.12	8.98	1.45	85.95	43	50.41	177.8	0	271.21
					epm	2.72	1.76	0.39	0.04	4.91	0.90	1.40	2.91	0	5.21
					%epm	55.4	36	8	0.76	100	17.2	27	55.9	0	100
W38	18	7.51	422	270.1	ppm	48	23.04	15	1.16	87.20	46	50	177.8	0	273.8
					epm	2.4	1.92	0.65	0.03	5.00	0.96	1.39	2.91	0	5.26
					%epm	48	38.4	13.0	0.6	100	18.2	26.4	55.4	0	100
W39	19	7.35	447	286.1	ppm	60.8	17.28	15.20	1.23	94.51	37.3	44	225	0	306.3
					epm	3.04	1.44	0.66	0.03	5.17	0.78	1.22	3.69	0	5.69
					%epm	58.8	27.8	12.8	0.61	100	13.7	21.5	65	0	100
W40	19.8	8	488	312.3	ppm	56	18	13.20	1.53	88.73	39.3	30	240	0	309.3
					epm	2.8	1.50	0.57	0.04	4.91	0.82	0.83	3.93	0	5.59
					%epm	57	30.5	11.7	0.80	100	14.7	14.9	70.4	0	100
W41	20	7.33	493	315.5	ppm	64	11.52	8.98	2.49	86.99	21	51.83	202.2	0	275.03
					epm	3.2	0.96	0.39	0.06	4.61	0.44	1.44	3.31	0	5.19
					%epm	69.4	20.8	8.5	1.4	100	8.4	27.7	63.8	0	100
Min.	**16**	**6.65**	**362**	**232**		**41.60**	**7.7**	**1.4**	**0.79**		**5.90**	**14**	**129**	**0**	
Max.	**24.50**	**8**	**649**	**415**		**96**	**30.7**	**49.3**	**3.31**		**84.0**	**70**	**290**	**0**	
Median	**20**	**7.37**	**472**	**302.1**		**60.8**	**15.4**	**11.5**	**1.16**		**45.14**	**38**	**202**	**0**	

Appendix (6) Physical Parameters and Major Ions Concentrations in Water Wells Samples for Wet Season (April)

No.	T°C	pH	EC µs/cm	TDS mg/l	unit	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	SUM	$SO4^{2-}$	Cl^{-}	HCO_3^{-}	CO_3^{2-}	SUM
W1	22	7.3	601	384.6	ppm	80	7	44	3.10	134.10	38	31	275	0	344
					epm	4	0.58	1.91	0.08	6.58	0.79	0.86	4.51	0	6.16
					%epm	60.83	8.87	29.09	1.21	100	12.85	13.98	73.17	0	100
W2	18.5	7.4	469	300.2	ppm	61	7.80	5.10	0.70	74.60	18	21	233	0	272
					epm	3.05	0.65	0.22	0.02	3.94	0.38	0.58	3.82	0	4.78
					%epm	77.42	16.50	5.63	0.46	100	7.85	12.21	79.94	0	100
W3	18.7	7.48	462	295.7	ppm	59	14.70	6.00	0.82	80.52	28	31	223	0	282
					epm	2.95	1.23	0.26	0.02	4.46	0.58	0.86	3.66	0	5.10
					%epm	66.19	27.49	5.85	0.47	100	11.44	16.88	71.68	0	100
W4	19.2	7.45	500	320	ppm	65	11.10	13.70	1.42	91.22	38	31	228	0	297.
					epm	3.25	0.93	0.60	0.04	4.81	0.79	0.86	3.74	0	5.39
					%epm	67.61	19.24	12.39	0.76	100	14.69	15.97	69.34	0	100
W5	20	7.6	501	320.6	ppm	60	16	13.70	1.40	91.10	49.50	30.20	237	0	316.70
					epm	3.00	1.33	0.60	0.04	4.96	1.03	0.84	3.89	0	5.76
					%epm	60.42	26.86	12	0.72	100	17.92	14.58	67.51	0	100
W6	20.2	7.48	499	319.4	ppm	68	9.50	15.80	1.45	94.75	39	35	230	0	304
					epm	3.40	0.79	0.69	0.04	4.92	0.81	0.97	3.77	0	5.56
					%epm	69.16	16.10	13.97	0.76	100	14.63	17.50	67.87	0	100
W7	18.6	7.46	444	284.2	ppm	60	11	7	0.79	78.79	26	28	205	0	259
					epm	3	0.92	0.30	0.02	4.24	0.54	0.78	3.36	0	4.68
					%epm	70.74	21.61	7.18	0.47	100	11.57	16.62	71.81	0	100
W8	21.3	7.4	520	332.8	ppm	61	18.20	11	1.25	91.45	67	28.00	223	0	318
					epm	3.05	1.52	0.48	0.03	5.08	1.40	0.78	3.66	0	5.83
					%epm	60.08	29.87	9.42	0.63	100	23.94	13.34	62.71	0	100
W9	21.5	7.51	549	351.4	ppm	68	19.50	13	1.80	102.30	77	35	231	0	343
					epm	3.40	1.63	0.57	0.05	5.64	1.60	0.97	3.8	0	6.36
					%epm	60.32	28.83	10.03	0.82	100	25.2	15.3	59.51	0	100.
W10	20	7.9	445	284.8	ppm	54.40	14.20	8.50	0.70	77.80	11	12.50	267	0	290.50
					epm	2.72	1.18	0.37	0.02	4.29	0.23	0.35	4.38	0	4.95
					%epm	63.39	27.58	8.61	0.42	100	4.63	7.01	88.36	0	100
W11	19	7.4	547	350.1	ppm	66.40	12.80	16.00	1.78	96.98	61	26	227	0	314
					epm	3.32	1.07	0.70	0.05	5.13	0.72	1.27	3.72	0	5.71
					%epm	64.74	20.80	13.57	0.89	100	12.64	22.24	65.12	0	100
W12	20	7.51	536	343	ppm	65.10	16.70	13.80	1.47	97.07	76.40	35.80	206.20	0	318.40
					epm	3.26	1.39	0.60	0.04	5.28	0.99	1.59	3.38	0	5.97
					%epm	61.60	26.34	11.35	0.71	100	16.67	26.68	56.66	0	100
W13	20.1	7.48	508	252.1	ppm	58.80	18.70	13.60	1.50	92.60	55.00	30	230	0	315
					epm	2.94	1.56	0.59	0.04	5.13	0.83	1.15	3.77	0	5.75
					%epm	57.33	30.39	11.53	0.75	100	14.49	19.93	65.58	0	100
W14	19.5	7.45	520	332.8	ppm	59	16.30	13.20	1.40	89.90	48.10	32	227.20	0	307.30
					epm	2.95	1.36	0.57	0.04	4.92	1	0.89	3.72	0	5.62
					%epm	59.98	27.62	11.67	0.73	100	17.84	15.83	66.33	0	100

Continued

No.	T^{o}C	pH	EC µs/cm	TDS mg/l	unit	Ca^{2+}	Mg^{2+}	Na$^+$	K$^+$	SUM	SO4^{2-}	Cl$^-$	HCO$_3^-$	CO$_3^{2-}$	SUM
W15	18.9	7.23	502	321.3	ppm	68.60	13	16	1.50	99.10	17.40	39.1	205	0	261.50
					epm	3.43	1.08	0.70	0.04	5.25	0.36	1.09	3.36	0	4.81
					%epm	65.37	20.64	13.26	0.73	100	7.54	22.58	69.88	0	100
W16	17.8	7.44	369	236.2	ppm	51	7.40	6	0.79	65.19	36	22.40	157	0	215.40
					epm	2.55	0.62	0.26	0.02	3.45	0.75	0.62	2.57	0	3.95
					%epm	73.96	17.89	7.57	0.58	100	19.01	15.77	65.22	0	100
W17	15.4	7.38	354	226.6	ppm	50	12.30	6.20	1.10	69.60	35.60	36.70	155	0	227.30
					epm	2.50	1.03	0.27	0.03	3.82	0.74	1.02	2.54	0	4.30
					%epm	65.40	26.81	7.05	0.74	100	17.24	23.70	59.06	0	100
W18	16.1	7.11	371	237.4	ppm	46	11.10	6.31	0.90	64.31	33.30	25	156.20	0	214.50
					epm	2.30	0.93	0.27	0.02	3.52	0.69	0.69	2.56	0	3.95
					%epm	65.30	26.26	7.79	0.66	100	17.57	17.59	64.85	0	100
W19	16.7	7.15	376	240.6	ppm	43	14.90	8.60	0.90	67.40	42	31	155	0	228
					epm	2.15	1.24	0.37	0.02	3.79	0.88	0.86	2.54	0	4.28
					%epm	56.75	32.77	9.87	0.61	100	20.46	20.13	59.41	0	100
W20	17	6.8	372	238.1	ppm	42.80	15	7.90	0.99	66.69	31.30	33.10	133	0	197.40
					epm	2.14	1.25	0.34	0.03	3.76	0.65	0.92	2.18	0	3.75
					%epm	56.93	33.25	9.14	0.68	100	17.38	24.51	58.11	0	100
W21	17.5	7.06	374	239.4	ppm	46	12.80	5.50	1.00	65.30	26.00	29.00	155.40	0	210.40
					epm	2.30	1.07	0.24	0.03	3.63	0.54	0.81	2.55	0	3.89
					%epm	63.34	29.37	6.59	0.71	100	13.91	20.68	65.41	0	100
W22	17.2	7.3	369	236.2	ppm	40	16.60	3.85	1.01	61.46	25	25.80	158	0	208.80
					epm	2	1.38	0.17	0.03	3.58	0.52	0.72	2.59	0	3.83
					%epm	55.92	38.68	4.68	0.72	100	13.61	18.72	67.67	0	100
W23	17.5	7.88	368	235.5	ppm	42	14.70	2.80	0.99	60.49	15.30	17	198	0	230.30
					epm	2.10	1.23	0.12	0.03	3.47	1.42	0.77	5.08	0	7.26
					%epm	60.48	35.28	3.51	0.73	100	19.52	10.54	69.94	0	100
W24	16	7.75	492	315	ppm	58	16.30	17	1	92.30	40	44	183	0	267
					epm	2.90	1.36	0.74	0.03	5.02	0.83	1.22	3	0	5.06
					%epm	57.73	27.04	14.71	0.51	100	16.48	24.18	59.34	0	100
W25	14.7	7.5	402	257.3	ppm	46.20	14.50	11.20	1.06	72.96	42	47.40	156	0	245.40
					epm	2.31	1.21	0.49	0.03	4.03	0.88	1.32	2.56	0	4.75
					%epm	57.28	29.97	12.08	0.67	100	18.42	27.72	53.85	0	100
W26	15.2	7.39	360	230.4	ppm	41.30	16.80	3.50	0.88	62.48	47	33.50	134	0	214.5
					epm	2.07	1.40	0.15	0.02	3.64	0.93	0.98	2.20	0	4.11
					%epm	56.73	38.46	4.18	0.62	100	22.66	23.84	53.49	0	100
W27	17.3	7.69	388	248.3	ppm	45.80	10.80	5.70	1.00	63.30	33.80	34.00	132	0	199.8
					epm	2.29	0.90	0.25	0.03	3.46	0.94	0.70	2.16	0	3.81
					%epm	66.12	25.99	7.16	0.74	100	24.77	18.47	56.76	0	100
W28	16.4	7.72	380	243.2	ppm	44.10	12.80	1.30	0.98	59.18	34	26	15	0	215
					epm	2.21	1.07	0.06	0.03	3.35	0.72	0.71	2.54	0	3.97
					%epm	65.76	31.81	1.69	0.75	100	18.18	17.84	63.98	0	100
W29	19	7.41	578	370	ppm	72	16.10	28	0.88	116.98	45.20	63.10	255	0	363.30
					epm	3.60	1.34	1.22	0.02	6.18	0.94	1.75	4.18	0	6.87
					%epm	58.24	21.70	19.69	0.37	100	13.70	25.50	60.81	0	100

Continued

No.	T^{o}C	pH	EC µs/cm	TDS mg/l	unit	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	SUM	SO4^{2-}	Cl^{-}	HCO$_3^{-}$	CO$_3^{2-}$	SUM
W30	19.5	7.35	400	256	ppm	53.4	10.50	8.50	1.01	73.41	19.50	29.20	205	0	253.70
					epm	2.67	0.88	0.37	0.03	3.94	0.41	0.81	3.36	0	4.58
					%epm	67.76	22.21	9.38	0.66		8.87	17.72	73.41	0	100
W31	17.8	7.4	443	283.5	ppm	48	19	9.60	1.12	77.72	42	31	204	0	277
					epm	2.40	1.58	0.42	0.03	4.43	0.88	0.86	3.34	0	5.08
					%epm	54.18	35.75	9.42	0.65	100	17.22	16.95	65.83	0	100
W32	19	7	435	278.4	ppm	54.40	13.44	9.20	1.23	78.27	40	43.50	172	0	255.50
					epm	2.72	1.12	0.40	0.03	4.27	0.83	1.21	2.82	0	4.86
					%epm	63.68	26.22	9.36	0.74	100	17.14	24.86	58	0	100
W33	18.5	7.4	480	307.2	ppm	58.10	17	12	1.20	88.30	42	42	205	0	289
					epm	2.91	1.42	0.52	0.03	4.87	0.88	1.17	3.36	0	5.40
					%epm	59.60	29.06	10.70	0.63	100	16.20	21.60	62.21	0	100
W34	17.1	7.19	428	274	ppm	48	17.80	13.90	1.06	80.76	5.30	50.60	204	0	259.90
					epm	2.40	1.48	0.60	0.03	4.51	0.11	1.41	3.34	0	4.86
					%epm	53.16	32.85	13.39	0.60	100	2.27	28.92	68.81	0	100
W35	19.3	7.29	618	395.5	ppm	86.10	12.70	26	1.10	125.90	60	57	274	0	391
					epm	4.31	1.06	1.13	0.03	6.52	1.25	1.58	4.49	0	7.33
					%epm	66.01	16.23	17.33	0.43	100	17.06	21.62	61.32	0	100
W36	20	7.2	632	404.5	ppm	90	18	35	1.60	144.60	68	58	296	0	422
					epm	4.50	1.50	1.52	0.04	7.56	1.42	1.61	4.85	0	7.88
					%epm	59.50	19.83	20.12	0.54	100	17.98	20.44	61.58	0	100
W37	19	7.39	496	317.4	ppm	51.30	20	8	1.35	80.65	40	48	179	0	267
					epm	2.57	1.67	0.35	0.03	4.61	0.83	1.33	2.93	0	5.10
					%epm	55.59	36.12	7.54	0.75	100	16.34	26.14	57.53	0	100
W38	16.9	7.6	418	267.5	ppm	46.00	23.00	13.00	1.11	83.11	41	40	185	0	266
					epm	2.30	1.92	0.57	0.03	4.81	0.85	1.11	3.03	0	5
					%epm	47.81	39.84	11.75	0.59	100	17.09	22.23	60.68	0	100
W39	17.6	7.42	438	280.3	ppm	59.20	17	14.70	1.20	92.10	33.80	41.20	227	0	302
					epm	2.96	1.42	0.64	0.03	5.05	0.70	1.14	3.72	0	5.57
					%epm	58.65	28.07	12.66	0.61	100	12.64	20.55	66.81	0	100
W40	19	8.12	475	304	ppm	53	17	12.50	1.30	83.80	33	27	244	0	304
					epm	2.65	1.42	0.54	0.03	4.64	0.69	0.75	4	0	5.44
					%epm	57.07	30.51	11.70	0.72	100	12.64	13.79	73.56	0	100
W41	17.9	7.38	480	307.2	ppm	60	10.2	8.00	2.30	80.50	18	44.5	208	0	270.5
					epm	3	0.85	0.35	0.06	4.26	0.38	1.24	3.41	0	5.02
					%epm	70.48	19.97	8.17	1.39	100	7.47	24.62	67.91	0	100
Min.	**14.7**	**6.8**	**354**	**226.5**		**40**	**7**	**1.3**	**0.7**		**5.3**	**12.5**	**0**	**132**	
Max.	**22**	**8.12**	**632**	**404.5**		**90**	**29.8**	**44**	**3.1**		**77**	**63.1**	**0**	**296**	
Median	**18.6**	**7.4**	**462**	**295.7**		**58**	**14.7**	**12.09**	**1.1**		**38**	**32**	**0**	**205**	

Appendix (7) Physical Parameters and Major Ions Concentrations in Springs Water Samples for Dry Season (October)

No.	T°C	pH	EC µs/cm	TDS mg/l	unit	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	SUM	$SO4^{2-}$	Cl^{-}	HCO_3^{-}	CO_3^{2-}	SUM
Qulai Rania	16.40	7.25	514.00	329	ppm	70.40	19.20	6.45	0.79	96.84	35	22.01	280	0	337.01
					epm	3.52	1.60	0.28	0.02	5.42	0.73	0.61	4.59	0	5.93
					%epm	64.94	29.52	5.18	0.37	100	12.29	10.31	77.40	0	100
Saruchawa	16.50	7.30	548.00	350.7	ppm	73.60	24.96	24	1.08	123.64	76	50.41	270	0	396.41
					epm	3.68	2.08	1.04	0.03	6.83	1.58	1.40	4.43	0	7.41
					%epm	53.87	30.45	15.28	0.41	100.	21.37	18.90	59.73	0	100
Shkarta	22.50	7.40	672.00	430.1	ppm	92.80	11.52	29.15	5.09	138.57	44	72.42	230	0	346.42
					epm	4.64	0.96	1.27	0.13	7.00	0.92	2.01	3.77	0	6.70
					%epm	66.30	13.72	18.11	1.87	100	13.68	30.03	56.29	0	100
Betwata	15.00	8.14	384.00	245.8	ppm	48	15.36	1.41	0.79	65.55	14	23	177.80	0	214.80
					epm	2.40	1.28	0.06	0.02	3.76	0.29	0.64	2.91	0	3.85
					%epm	63.81	34.03	1.63	0.54	100.00	7.58	16.61	75.80	0	100
Qulai Kanimaran	20.50	7.20	613.00	392.3	ppm	73.60	13.44	49.33	2.42	138.79	86	59.64	251	0	396.64
					epm	3.68	1.12	2.14	0.06	7.01	1.79	1.66	4.11	0	7.56
					%epm	52.52	15.98	30.61	0.89	100	23.69	21.90	54.41	0	100
Kwera Kani	16.20	7.23	512.00	327.7	ppm	70	19	6.30	0.75	96.05	34.50	21.80	279	0	335.30
					epm	3.50	1.58	0.27	0.02	5.38	0.72	0.61	4.57	0	5.90
					%epm	65.10	29.45	5.09	0.36	100	12.19	10.27	77.55	0	100
Ganau	22.00	6.70	2050.00	1312	ppm	248	39	52	27	366	257	305	402	0	964
					epm	12.40	3.25	2.26	0.69	18.60	5.35	8.47	6.59	0	20.42
					%epm	66.66	17.47	12.15	3.72	100	26.22	41.50	32.28	0	100
Min.	**15.00**	**6.70**	**384**	**245.8**		**48**	**11.5**	**1.41**	**0.75**		**14**	**21.80**	**177.80**	**0**	
Max.	**22.50**	**8.14**	**2050**	**1312**		**248**	**39**	**52**	**27**		**257**	**305**	**402**	**0**	
Median	**16.5**	**7.25**	**548**	**350.7**		**73.6**	**19**	**24**	**1.08**		**44**	**50.4**	**270**	**0**	

Appendix (8) Physical Parameters and Major Ions Concentrations in Shaoor Stream for Dry Season (October)

No.	T°C	pH	EC µs/cm	TDS mg/l	unit	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	SUM	$SO4^{2-}$	Cl^{-}	HCO_3^{-}	CO_3^{2-}	SUM
Shaoor	22	7.32	603	385.9	ppm	57.6	30.72	14.02	1.82	104.2	125	36.21	202.2	0	363.4
					epm	2.88	2.56	0.61	0.05	6.10	2.60	1.01	3.3	0	6.92
					%epm	47.2	42	10	0.77	100	37.6	14.5	48	0	100

Appendix (9) Physical Parameters and Major Ions Concentrations in Springs Water Samples for Wet Season (April)

No.	T^{o}C	pH	EC µs/cm	TDS mg/l	unit	Ca^{2+}	Mg^{2+}	Na$^+$	K$^+$	SUM	SO4^{2-}	Cl$^-$	HCO$_3^-$	CO$_3^{2-}$	SUM
Qulai Rania	14.70	7.35	488	312	ppm	67	18	5.90	0.77	91.67	31	20	284	0	335
					epm	3.35	1.50	0.26	0.02	5.13	0.65	0.56	4.66	0	5.86
					%epm	65.35	29.26	5	0.39	100	11.03	9.49	79.49	0	100
Saruchawa	15.20	7.41	530	339	ppm	70	23.10	22.50	1.00	116.60	70	45	273	0	388
					epm	3.50	1.93	0.98	0.03	6.43	1.46	1.25	4.48	0	7.18
					%epm	54.44	29.94	15.22	0.40	100	20.30	17.40	62.30	0	100
Shkarta	21.40	7.42	666	426	ppm	87	10	26	4.50	127.50	38	62	236	0	336
					epm	4.35	0.83	1.13	0.12	6.43	0.79	1.72	3.87	0	6.38
					%epm	67.66	12.96	17.58	1.79	100	12.40	26.98	60.61	0	100
Betwata	13.20	8.21	371	237	ppm	47	15	1.30	0.79	64.09	13	20	179	0	212
					epm	2.35	1.25	0.06	0.02	3.68	0.27	0.56	2.93	0	3.76
					%epm	63.92	34	1.54	0.55	100	7.20	14.77	78.03	0	100
Qulai Kanimaran	20.50	7.20	613	392	ppm	69	12.30	45	2.20	128.50	80	51	255	0	386
					epm	3.45	1.03	1.96	0.06	6.49	1.67	1.42	4.18	0	7.26
					%epm	53.18	15.80	30.16	0.87	100	22.95	19.50	57.55	0	100
Kwera Kani	14.50	7.33	486	311	ppm	66.70	17	5.70	0.77	90.17	30.50	19.20	283	0	332.70
					epm	3.34	1.42	0.25	0.02	5.02	0.64	0.53	4.64	0	5.81
					%epm	66.44	28.22	4.94	0.39	100	10.94	9.18	79.88	0	100
Ganau	21.50	6.80	2000	1280	ppm	238.40	30	50	24.00	342.40	248	300	410	0	958
					epm	11.92	2.50	2.17	0.62	17.21	5.17	8.33	6.72	0	20.22
					%epm	69.26	14.53	12.63	3.58	100	25.55	41.21	33.24	0	100
Min.	**13.20**	**6.80**	**371**	**237.4**		**47**	**10.00**	**1.30**	**0.77**		**13**	**19.20**	**179**	**0**	
Max.	**21.50**	**8.21**	**2000**	**1280**		**238.40**	**30**	**50.00**	**24**		**248**	**300**	**410**	**0**	
Median	**15.2**	**7.35**	**530**	**339**		**69**	**17**	**22.5**	**1**		**38**	**45**	**273**	**0**	

Appendix (10) Physical Parameters and Major Ions Concentrations in Shaoor Stream for Wet Season (April)

No.	T^{o}C	pH	EC µs/cm	TDS mg/l	unit	Ca^{2+}	Mg^{2+}	Na$^+$	K$^+$	SUM	SO4^{2-}	Cl$^-$	HCO$_3^-$	CO$_3^{2-}$	SUM
Shaoor	19	7.4	596	381.4	ppm	57	29.80	13	1.80	101.60	115	31	210	0	356
					epm	2.85	2.48	0.57	0.05	5.94	2.40	0.86	3.44	0	6.70
					%epm	47.94	41.77	9.51	0.78	100	35.76	12.85	51.39	0	100

Appendix (11) Minor Ions Concentrations, SAR_{adj}, TU and TH of Water Wells Samples

No.	Dry Season(October)					Wet season(April)				
	PO_4^{3-}	NO_3^-	SAR_{adj}	TU	TH	PO_4^{3-}	NO_3^-	SAR_{adj}	TU	TH
W1	0.1	29.6	3.03	0.5	247	0.09	29	2.79	0.55	229
W2	0.08	14.4	0.40	1.2	207	0.07	14	0.34	1.25	184
W3	0.05	13.0	0.39	1.5	223	0.05	12.5	0.38	1.5	208
W4	0.09	20.4	0.87	0.8	215	0.08	19.1	0.86	0.7	208
W5	0.07	18.3	0.86	0.9	230	0.07	17.5	0.86	1	216
W6	0.09	19.95	1.03	2	215	0.085	19	0.99	2.1	209
W7	0.02	18.18	0.40	1.3	202	0.015	18	0.44	1.4	195
W8	0.05	12.38	0.68	0.6	239	0.04	11.4	0.67	0.6	227
W9	0.02	12.7	0.82	0.4	264	0.012	12.2	0.77	0.3	250
W10	0.06	14.7	0.52	1.1	206	0.055	14.2	0.56	1.1	194
W11	0.07	16.8	1.00	1.3	231	0.06	16	0.99	1.2	218
W12	0.08	18	0.82	1	239	0.07	17.1	0.82	1.2	231
W13	0.075	19.7	0.85	0.9	231	0.04	19	0.84	1	224
W14	0.1	22.7	0.85	0.7	231	0.1	21	0.82	0.78	214
W15	0.11	22.7	0.98	0.2	230	0.09	20	0.96	0.2	225
W16	0.12	24	0.40	1.1	167	0.1	22	0.38	1.3	158
W17	0.09	12.6	0.38	0.3	183	0.08	12	0.38	0.3	175
W18	0.04	10.0	0.40	2.1	167	0.02	9.3	0.40	2	161
W19	0.06	17.2	0.54	0.6	175	0.04	16.2	0.53	0.65	169
W20	0.04	12.7	0.47	0.7	175	0.03	12.2	0.47	0.8	169
W21	0.06	16.8	0.36	1.4	175	0.06	16.1	0.34	1.6	168
W22	0.02	12.5	0.24	1.6	175	n.d	12	0.24	1.8	168
W23	0.05	13.9	0.19	0.8	174	n.d	13.2	0.18	0.85	165
W24	0.15	33.5	1.05	0.7	223	0.01	33	1.01	0.75	212
W25	0.08	16.2	0.72	1.4	183	0.06	16	0.68	1.5	175
W26	0.06	11.5	0.23	2.1	183	0.01	11.1	0.21	2	172
W27	0.09	15.6	0.37	2.3	167	0.04	15	0.34	2.4	159
W28	0.04	12.7	0.09	0.6	175	0.02	12.1	0.08	0.65	163
W29	0.14	32	1.78	0.7	263	0.12	31	1.70	0.7	246
W30	0.11	20.9	0.57	0.3	191	0.1	20	0.55	0.4	177
W31	0.08	16.2	0.61	0.9	207	0.05	15.1	0.60	0.85	198
W32	0.07	15.2	0.56	1.1	191	0.02	14.3	0.56	1.25	191
W33	0.09	24.7	0.78	0.28	226	0.06	24	0.73	0.3	215
W34	0.04	11.5	0.95	0.7	191	n.d	11.2	0.87	0.75	193
W35	0.1	19.7	1.65	0.36	279	0.08	16.3	1.56	0.4	267
W36	0.05	18.6	2.17	0.85	319	0.02	18.2	2.05	1	299
W37	0.35	43.9	0.52	1.2	223	0.3	41	0.48	1.4	210
W38	0.04	17.5	0.88	1	215	n.d	17	0.78	1.2	210
W39	0.01	14.7	0.93	1.1	223	n.d	14.1	0.91	1	218
W40	0.0.3	15.3	0.83	2	214	n.d	15	0.80	2.3	202
W41	0.4	46	0.55	2.3	207	0.055	42	0.51	2.5	192
Min.	0.01	10	0.09	0.2	167	n.d	9.3	0.08	0.2	158
Max.	0.4	46	3.03	2.3	319	0.3	42	2.79	2.5	299
Med.	0.07	16.8	0.68	0.9	214	0.06	16.1	0.67	1	202

***Note**: PO_4^{3-}, NO_3^-,F^- in mg/l TU: Turbidity in(NTU)units TH: Total hardness n.d(not detectable)**

Appendix (12) Minor Ions Concentrations, SAR_{adj}, TU and TH of Springs Water Samples

No.		PO_4^{3-}	NO_3^-	SAR_{adj}	TU	TH		PO_4^{3-}	NO_3^-	SAR_{adj}	TU	TH
Qulai Rania	**Dry Season(October)**	0.08	15.2	0.39	2.8	255	**Wet season(April)**	0.07	14.8	0.37	3.1	241
Saruchawa		n.d	6.8	1.40	3	286		n.d	6.1	1.34	3.5	270
Shkarta		0.8	58.5	1.67	2.2	279		0.6	57	1.53	2.4	258
Betwata		n.d	8.3	0.09	2.5	183		n.d	8	0.08	2.6	179
Qulai Kanimaran		0.1	17.6	3.02	2.2	239		0.09	17.1	2.83	2.5	223
Kwera Kani		0.08	15.2	0.39	2.7	253		0.04	15	2.26	3	237
Ganau		0.5	10.4	2.27	10	780		0.4	10	0.36	11	719
Min.		0.08	6.8	0.09	2.2	183		n.d	6.1	0.08	2.4	179
Max.		0.8	58.5	3.02	10	780		0.6	57	2.83	11	719
Med.		0. 1	15.2	1.4	2.7	255		0.09	14.8	1.34	3	241

***Note: PO_4^{3-}, NO_3^-, F^- in mg/l TU: Turbidity in(NTU)units TH: Total hardness n.d(not detectable)**

Appendix (13) Minor Ions Concentrations, SAR_{adj}, TU and TH of Shaoor Stream

No.		PO_4^{3-}	NO_3^-	SAR_{adj}	TU	TH		PO_4^{3-}	NO_3^-	SAR_{adj}	TU	TH
Shaoor	**Dry Season**	0.07	5.5	0.79	2.5	270	**Wet Season**	n.d	5.3	0.74	2.8	265

Appendix (14) Durov Diagram

The diagram is normally based upon percentage of major ions in millequivalent values, where the cations and anions together total 100 per cent. The cation and anion values are plotted in the appropriate triangle and projected onto the main square field. An expanded version of the Durov diagram(1948) developed by Burdon and Mazlounr (1958) and Lloyd (1965) Fig. (1), tile cation and anion triangles are recognized and are separated along the 25 per cent axes so that the main field is conveniently divided. The expanded Durov diagram has the distinct advantage over the Piper diagram in that it provides a better display of hydrochemical types and some processes, and in practical terms has less line work in the main field. As shown in Fig. (1), waters with a 25 percent concentration of a certain ion can theoretically plot ambiguously, and in practice the ambiguity has little relevance and can be solved by the association of the problem water with neighboring waters. The significance of nine fields on the expanded Durov diagram can be discussed with respect to Fig. (1) as follows:

1. Domination of HCO_3^- and Ca^{2+} frequently indicates occurrence of recharge in limestone, sandstone, and many other aquifers.

2. Domination of HCO_3^- and Mg^{2+} or cations indiscriminant, with Mg^{2+} dominant or Ca^{2+} and Mg^{2+} important, indicates waters often associated with dolomite, where Ca^{2+} and Na^+ with important partial ion exchange may be indicated.

3. HCO_3^- and Na^+ domination normally indicates ion-exchanged waters although the generation of CO_2 at depth can produce HCO_3^- where Na+ is dominant under certain circumstances.

4.SO_4^{2-} domination or anions indiscriminant and Ca^{2+} dominant, $Ca^{2+}$and SO_4^{2-} domination frequently indicates a recharge water in lava and gypsiferous deposits, otherwise a mixed water or a water exhibiting simple dissolution may be indicated

5- No domination of anion or cation, indicates waters exhibiting simple dissolution or mixing.

6- SO_4^{2-} domination or anions indiscriminant and Na^+ dominant, is a water type not frequently encountered and indicates probable mixing influences.

7-Cl^- and Ca^{2+} domination, is infrequently encountered unless cement pollution is present in a well; otherwise the waters may result from reverse ion exchange of Na^+- Cl^- waters.

8-Cl^- domination and no domination cation indicate that the groundwater may be related to reverse ion exchange of Na^+- Cl^- waters.

9- Cl^- and Na^+ domination frequently indicate end-point waters. The Durov diagram does not permit much distinction between Na^+- Cl^- waters.

The arrows indicate possible process paths such as ion exchange or dissolution.

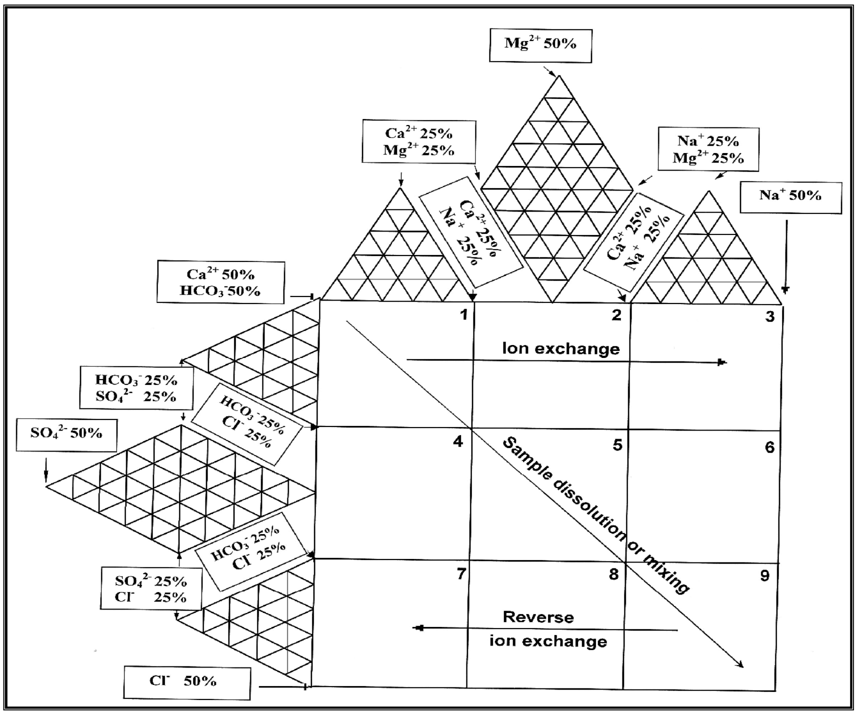


Fig. (1) Expanded Durov Diagram
(After Burdon and Mazlounr (1958) and Lloyd (1965))

Appendix (15) Chadha Diagram

The diagram shown in Fig. (2), is a somewhat modified version of the Piper diagram and the expanded Durov diagram. The difference is that the two equilateral triangles are omitted, and the shape of the main study-field is different.

In the Piper diagram, the milliequivalent percentages of the major cations and anions (percentage reacting values) are plotted in each triangle and the type of water is determined on the basis of position of the data plot in the respective cationic and anionic triangular fields. The plotting from triangular fields is extended further into the central diamond field, which provides the overall character of the water.

In contrast, in this diagram, the difference in milliequivalent percentage between alkaline earths (calcium plus magnesium) and alkali metals (sodium plus potassium), expressed as percentage reacting values, is plotted on the X axis, and the difference in milliequivalent percentage between weak acidic anions (carbonate plus bicarbonate) and strong acidic anions (chloride plus sulphate) is plotted on the Y axis. The resulting field of study is a square or rectangle, depending upon the size of the scales chosen for X and Y co-ordinates. The milliequivalent percentage differences between alkaline earths and alkali metals, and between weak acidic anions and strong acidic anions, would plot in one of the four possible sub-fields of the proposed diagram. The main advantage of the proposed diagram is that it can be made simply on most spreadsheet software packages (Chadha, 1999).

The square or rectangular field describes the overall character of the water. The diagram has all the advantages of the diamond-shaped field of the Piper diagram and can be used to study various hydrochemical processes, such as base cation exchange, cement pollution, mixing of natural waters, sulphate reduction, saline water (end-product water), and other related hydroehemical problems. In order to define the primary character of water, the rectangular field is divided into eight sub-fields, each of which represents a water type, as follows (Chadha, 1999);

1. Alkaline earths exceed alkali metals.
2. Alkali metals exceed alkaline earths.
3. Weak acidic anions exceed strong acidic anions.
4. Strong acidic anions exceed weak acidic anions.
5. Alkaline earths and weak acidic anions exceed both alkali metals and strong

acidic anions,respectively. Such water has temporary hardness. The positions of data points in the diagram represent Ca^{2+}-Mg^{2+}-HCO_3^-type ,Ca^{2+}-Mg^{2+}-dominant HCO_3^--type, or HCO_3^-dominant Ca^{2+}-Mg^{2+} -type waters.

6. Alkaline earths exceed alkali metals and strong acidic anions exceed weak acidic anions. Such water has permanent hardness and does not deposit residual sodium carbonate in irrigation use. The positions of data points in the diagram represent Ca^{2+}-Mg^{2+}-Cl^- type, Ca^{2+}-Mg^{2+}-dominant Cl^-type, or Cl—dominant Ca^{2+}-Mg^{2+}-type waters.

7. Alkali metals exceed alkaline earths and strong acidic anions exceed weak acidic anions. Such water generally creates salinity problems both in irrigation and drinking uses. The positions of data points in the proposed diagram represent Na^+-Cl^--type, $Na_2SO_4^{2-}$type, Na^+-dominant Cl—type, or Cl^-dominant Na^+-type waters.

8. Alkali metals exceed alkaline earths and weak acidic anions exceed strong acidic anions. Such waters deposit residual sodium carbonate in irrigation use and cause foaming problems. The positions of data points in the proposed diagram represent Na^+ -HCO_3^- -type, Na^+-dominant HCO_3^--type, or HCO_3^--dominant Na^+-type waters.

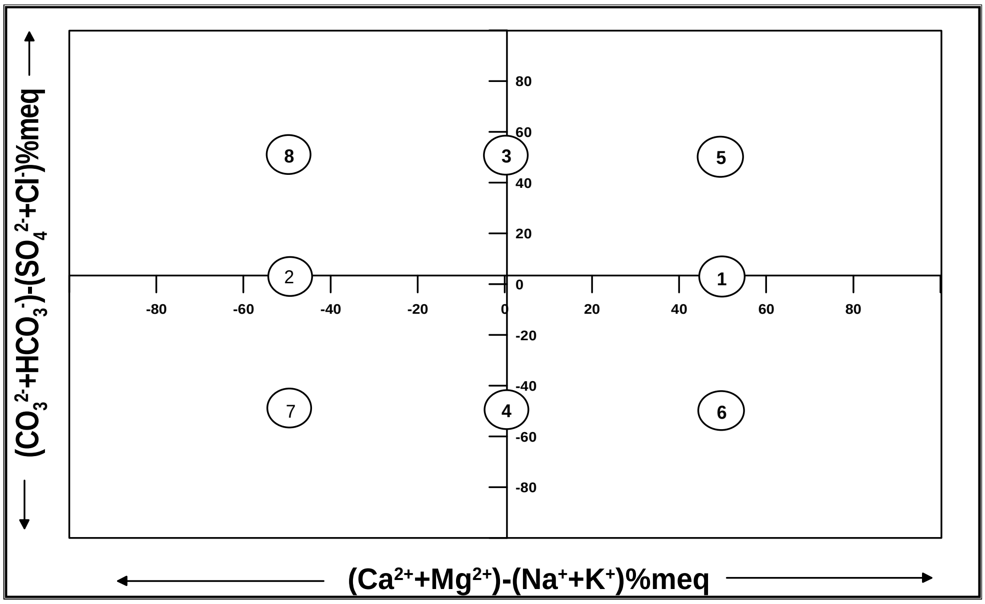


Fig. (2)Chadha Diagram(1999)

Appendix (16) Ionic Strength, Log P_{CO2}, and Mineral Saturation Indices for Deep Wells Dry Season

No.	Ionic Strength	Log P_{CO2}	SI Anhydrite	SI Aragonite	SI Calcite	SI Dolomite	SI Gypsum	SI Halite	SI Magnisite
W1	0.0094	-1.77	-2.12	-0.09	0.05	-0.61	-1.90	-7.35	-1.24
W2	0.0069	-2.11	-2.39	-0.09	0.06	-0.45	-2.16	-8.29	-1.07
W3	0.0073	-2.14	-2.34	-0.11	0.03	-0.28	-2.10	-8.17	-0.87
W4	0.0076	-2.11	-2.21	-0.06	0.09	-0.29	-1.98	-7.86	-0.95
W5	0.0081	-2.17	-2.12	-0.01	0.14	0.00	-1.89	-7.90	-0.71
W6	0.0077	-2.09	-2.18	-0.08	0.07	-0.44	-1.95	-7.75	-1.07
W7	0.0067	-2.12	-2.40	-0.17	-0.02	-0.48	-2.16	-8.26	-1.02
W8	0.0083	-2.06	-2.00	-0.15	0.00	-0.20	-1.77	-7.99	-0.78
W9	0.0091	-2.15	-1.92	0.01	0.16	0.11	-1.69	-7.80	-0.63
W10	0.0068	-2.42	-2.70	0.31	0.46	0.63	-2.46	-8.51	-0.40
W11	0.0083	-1.98	-1.98	-0.20	-0.05	-0.53	-1.75	-7.84	-1.05
W12	0.0084	-2.12	-1.94	-0.17	-0.02	-0.33	-1.71	-7.84	-0.88
W13	0.0082	-2.08	-2.09	-0.13	0.02	-0.16	-1.86	-7.89	-0.75
W14	0.0081	-2.09	-2.14	-0.12	0.03	-0.22	-1.91	-7.84	-0.81
W15	0.0075	-1.83	-2.50	-0.41	-0.26	-0.95	-2.27	-7.73	-1.25
W16	0.0058	-2.21	-2.27	-0.41	-0.26	-1.10	-2.03	-8.33	-1.40
W17	0.0063	-2.16	-2.29	-0.55	-0.40	-1.14	-2.04	-8.13	-1.29
W18	0.0057	-1.78	-2.34	-0.90	-0.75	-1.87	-2.10	-8.29	-1.68
W19	0.0062	-1.90	-2.29	-0.84	-0.69	-1.59	-2.05	-8.10	-1.46
W20	0.0058	-1.59	-2.41	-1.27	-1.13	-2.46	-2.17	-8.07	-1.90
W21	0.0058	-1.80	-2.48	-0.89	-0.74	-1.79	-2.24	-8.25	-1.60
W22	0.0057	-2.07	-2.52	-0.66	-0.51	-1.14	-2.28	-8.48	-1.19
W23	0.0057	-2.57	-2.70	0.08	0.22	0.25	-2.46	-8.75	-0.54
W24	0.0079	-2.51	-2.20	0.01	0.16	0.03	-1.95	-7.60	-0.69
W25	0.0067	-2.33	-2.26	-0.42	-0.27	-0.81	-2.01	-7.74	-1.09
W26	0.0061	-2.21	-2.27	-0.70	-0.55	-1.28	-2.02	-8.37	-1.28
W27	0.0057	-2.54	-2.33	-0.30	-0.15	-0.66	-2.09	-8.20	-1.07
W28	0.0058	-2.52	-2.36	-0.19	-0.04	-0.34	-2.12	-8.94	-0.87
W29	0.0097	-1.97	-2.11	-0.10	0.04	-0.27	-1.88	-7.25	-0.88
W30	0.0066	-2.04	-2.48	-0.28	-0.14	-0.68	-2.25	-8.04	-1.11
W31	0.0072	-2.11	-2.28	-0.33	-0.18	-0.51	-2.04	-8.00	-0.90
W32	0.0067	-1.76	-2.29	-0.75	-0.60	-1.53	-2.05	-7.96	-1.49
W33	0.0079	-2.17	-2.21	-0.18	-0.03	-0.32	-1.97	-7.78	-0.85
W34	0.0067	-1.90	-3.14	-0.53	-0.38	-1.02	-2.90	-7.62	-1.21
W35	0.0102	-1.84	-1.92	-0.11	0.04	-0.46	-1.68	-7.33	-1.07
W36	0.0113	-1.74	-1.89	-0.12	0.02	-0.35	-1.66	-7.20	-0.95
W37	0.0077	-2.17	-2.29	-0.33	-0.18	-0.49	-2.05	-7.91	-0.88
W38	0.0075	-2.32	-2.31	-0.27	-0.13	-0.31	-2.07	-7.68	-0.75
W39	0.0078	-2.05	-2.30	-0.22	-0.07	-0.41	-2.06	-7.73	-0.91
W40	0.0074	-2.78	-2.34	0.54	0.66	1.13	-2.15	-8.00	-1.10
W41	0.0078	-2.11	-2.58	-0.22	-0.07	-0.65	-2.34	-7.90	-1.16
Min.	**0.0057**	**-2.78**	**-3.14**	**-1.27**	**-1.13**	**-2.46**	**-2.90**	**-8.94**	**-1.90**
Max.	**0.0113**	**-1.59**	**-1.86**	**0.54**	**0.66**	**1.13**	**-1.63**	**-7.20**	**-0.40**
Median	**0.0074**	**-2.11**	**-2.29**	**-0.19**	**-0.04**	**-0.46**	**-2.05**	**-7.91**	**-1.05**

Appendix (17) Ionic Strength, Log P_{CO2}, and Mineral Saturation Indices for Deep Wells Wet Season

No.	Ionic Strength	Log P_{CO2}	SI Anhydrite	SI Aragonite	SI Calcite	SI Dolomite	SI Gypsum	SI Halite	SI Magnisite
W1	0.0088	-1.90	-2.19	-0.03	0.12	-0.51	-1.96	-7.44	-1.20
W2	0.0063	-2.08	-2.58	-0.13	0.02	-0.60	-2.34	-8.52	-1.18
W3	0.0069	-2.18	-2.42	-0.10	0.05	-0.23	-2.18	-8.29	-0.85
W4	0.0073	-2.14	-2.26	-0.08	0.07	-0.35	-2.02	-7.93	-0.99
W5	0.0077	-2.27	-2.19	0.06	0.21	0.12	-1.95	-7.95	-0.65
W6	0.0075	-2.16	-2.23	-0.01	0.14	-0.29	-1.99	-7.82	-1.00
W7	0.0065	-2.20	-2.43	-0.14	0.01	-0.46	-2.19	-8.26	-1.03
W8	0.0079	-2.09	-2.06	-0.15	0.00	-0.22	-1.82	-8.08	-0.79
W9	0.0087	-2.19	-1.97	0.02	0.16	0.09	-1.74	-7.91	-0.65
W10	0.0065	-2.52	-2.85	0.39	0.53	0.77	-2.61	-8.53	-0.33
W11	0.0078	-2.10	-2.06	-0.13	0.02	-0.41	-1.82	-7.94	-0.99
W12	0.0082	-2.24	-1.98	-0.07	0.08	-0.15	-1.74	-7.87	-0.79
W13	0.0079	-2.16	-2.16	-0.08	0.07	-0.08	-1.92	-7.95	-0.72
W14	0.0076	-2.14	-2.20	-0.12	0.03	-0.23	-1.97	-7.94	-0.82
W15	0.0074	-1.97	-2.57	-0.31	-0.17	-0.78	-2.33	-7.76	-1.18
W16	0.0056	-2.30	-2.34	-0.35	-0.20	-0.98	-2.09	-8.42	-1.34
W17	0.0060	-2.26	-2.36	-0.46	-0.31	-1.02	-2.11	-8.19	-1.26
W18	0.0055	-1.98	-2.41	-0.75	-0.60	-1.58	-2.17	-8.34	-1.54
W19	0.0060	-2.02	-2.36	-0.74	-0.59	-1.40	-2.11	-8.12	-1.37
W20	0.0056	-1.73	-2.47	-1.14	-0.99	-2.20	-2.23	-8.13	-1.77
W21	0.0056	-1.92	-2.52	-0.78	-0.63	-1.56	-2.28	-8.34	-1.49
W22	0.0055	-2.16	-2.60	-0.59	-0.44	-1.03	-2.35	-8.55	-1.14
W23	0.0055	-2.64	-2.79	0.11	0.25	0.30	-2.55	-8.87	-0.51
W24	0.0075	-2.56	-2.29	0.03	0.18	0.03	-2.04	-7.68	-0.70
W25	0.0064	-2.38	-2.33	-0.39	-0.24	-0.78	-2.08	-7.82	-1.09
W26	0.0058	-2.33	-2.32	-0.60	-0.45	-1.08	-2.07	-8.47	-1.18
W27	0.0055	-2.63	-2.41	-0.23	-0.08	-0.54	-2.16	-8.26	-1.02
W28	0.0055	-2.59	-2.42	-0.16	-0.01	-0.32	-2.18	-9.01	-0.87
W29	0.0092	-2.06	-2.18	-0.05	0.10	-0.18	-1.94	-7.32	-0.84
W30	0.0062	-2.08	-2.59	-0.28	-0.13	-0.69	-2.36	-8.16	-1.13
W31	0.0069	-2.15	-2.34	-0.32	-0.17	-0.49	-2.09	-8.08	-0.88
W32	0.0067	-1.81	-2.29	-0.72	-0.57	-1.47	-2.05	-7.95	-1.47
W33	0.0075	-2.14	-2.27	-0.23	-0.08	-0.44	-2.03	-7.86	-0.92
W34	0.0066	-1.94	-3.22	-0.52	-0.37	-0.94	-2.97	-7.70	-1.12
W35	0.0097	-1.91	-1.99	-0.06	0.09	-0.39	-1.75	-7.40	-1.04
W36	0.0108	-1.78	-1.94	-0.10	0.05	-0.32	-1.70	-7.27	-0.94
W37	0.0073	-2.19	-2.34	-0.34	-0.20	-0.53	-2.10	-7.97	-0.90
W38	0.0072	-2.40	-2.37	-0.20	-0.05	-0.16	-2.13	-7.84	-0.67
W39	0.0076	-2.12	-2.35	-0.17	-0.02	-0.34	-2.11	-7.77	-0.87
W40	0.0071	-2.79	-2.41	0.52	0.67	1.12	-2.17	-8.03	-0.12
W41	0.0069	-2.12	-2.60	-0.23	-0.08	-0.67	-2.35	-8.00	-1.15
Min.	**0.0055**	**-2.79**	**-3.22**	**-1.14**	**-0.99**	**-2.20**	**-2.97**	**-9.01**	**-1.77**
Max.	**0.0108**	**-1.73**	**-1.89**	**0.52**	**0.67**	**1.12**	**-1.65**	**-7.27**	**-0.12**
Median	**0.0069**	**-2.15**	**-2.34**	**-0.16**	**-0.01**	**-0.44**	**-2.1**	**-7.97**	**-0.99**

Appendix (18) Ionic Strength, Log P_{CO2}, and Mineral Saturation Indices for springs Dry Season(October)

No.	Ionic Strength	Log P_{CO2}	SI Anhydrite	SI Aragonite	SI Calcite	SI Dolomite	SI Gypsum	SI Halite	SI Magnisite
Qulai Rania	0.0083	-1.87	-2.29	-0.20	-0.05	-0.44	-2.04	-8.40	-0.94
Saruchawa	0.0101	-1.94	-1.97	-0.18	-0.03	-0.29	-1.72	-7.48	-0.82
Shkarta	0.0101	-2.08	-2.09	0.05	0.20	-0.19	-1.86	-7.25	-0.96
Betwata	0.0056	-2.97	-2.78	0.33	0.48	0.68	-2.53	-9.03	-0.35
Qulai Kanimaran	0.01	-1.85	-1.90	-0.25	-0.10	-0.65	-1.67	-7.11	-1.12
Kwera Kani	0.0082	-1.85	-2.29	-0.23	-0.08	-0.50	-2.05	-8.42	-0.97
Ganau	0.0264	-1.16	-1.16	-0.13	0.02	-0.46	-0.93	-6.42	-1.05
Min.	**0.0056**	**-2.97**	**-2.78**	**-0.25**	**-0.10**	**-0.65**	**-2.53**	**-9.03**	**-1.12**
Max.	**0.0264**	**-1.16**	**-1.16**	**0.33**	**0.48**	**0.68**	**-0.93**	**-6.42**	**-0.35**
Median	**0.0100**	**-1.87**	**-2.09**	**-0.18**	**-0.03**	**-0.44**	**-1.86**	**-7.48**	**-0.96**

Appendix (19) Ionic Strength, Log P_{CO2}, and Mineral Saturation Indices for springs Wet Season(April)

No.	Ionic Strength	Log P_{CO2}	SI Anhydrite	SI Aragonite	SI Calcite	SI Dolomite	SI Gypsum	SI Halite	SI Magnisite
Qulai Rania	0.0080	-1.97	-2.24	-0.14	0.01	-0.35	-2.10	-8.48	-0.90
Saruchawa	0.0096	-2.05	-2.02	-0.10	0.05	-0.17	-1.77	-7.55	-0.77
Shkarta	0.0094	-2.09	-2.17	0.05	0.19	-0.25	-1.94	-7.37	-1.01
Betwata	0.0055	-3.04	-2.82	0.37	0.52	0.72	-2.56	-9.12	-0.34
Qulai Kanimaran	0.0094	-1.84	-1.95	-0.26	-0.12	-0.69	-1.72	-7.21	-1.14
Kwera Kani	0.0078	-1.95	-2.35	-0.17	-0.02	-0.42	-2.10	-8.51	-0.95
Ganau	0.0252	-1.26	-1.18	-0.05	0.10	-0.39	-0.94	-6.44	-1.07
Min.	**0.0055**	**-3.04**	**-2.82**	**-0.26**	**-0.12**	**-0.69**	**-2.56**	**-9.12**	**-1.14**
Max.	**0.0252**	**-1.26**	**-1.18**	**0.37**	**0.52**	**0.72**	**-0.94**	**-6.44**	**-0.34**
Median	**0.0094**	**-1.97**	**-2.17**	**-0.10**	**0.05**	**-0.35**	**-1.94**	**-7.55**	**-0.95**

Appendix (20) Ionic Strength, Log P_{CO2}, and Mineral Saturation Indices for Shaoor Stream Dry Season (October)

No.	Ionic Strength	Log P_{CO2}	SI Anhydrite	SI Aragonite	SI Calcite	SI Dolomite	SI Gypsum	SI Halite	SI Magnisite
Shaoor	0.0095	-2.05	-1.86	-0.31	-0.17	-0.30	-1.63	-7.87	-0.70

Appendix (21) Ionic Strength, Log P_{CO2}, and Mineral Saturation Indices for Shaoor Stream Wet Season (April)

No.	Ionic Strength	Log P_{CO2}	SI Anhydrite	SI Aragonite	SI Calcite	SI Dolomite	SI Gypsum	SI Halite	SI Magnisite
Shaoor	0.0092	-2.13	-1.89	-0.26	-0.11	-0.24	-1.65	-7.96	-0.69