Hydrogeochemical and Isotopical Study of Groundwater Wells and Springs in Marj Na'ja Area

Prepared By:
Taher Mohammad Hamed Danoun

B.Sc. In Chemical Engineering from Far Eastern University,Manila-Philippines

Supervisor: Dr Qasem Abdul-Jaber
Co-Supervisor: Dr. Amer Marei

A thesis Submitted in Partial fulfillment of requirements for the degree of Master of Science in Environmental Studies Department of Appleied Earth and Environmental Studies Faculty of Science and Technology/Al- Quds University

1427/2006

Al- Quds University
Deanship of Graduate Studies
Department of Appleied Earth and Environmental Studies

Thesis Approval

Hydrogeochemical and Isotopical Study of Groundwater Wells and Springs in Marj Na'ja Area

Prepared By: Taher Mohammad Hamed Danoun
Registration No: 20111641

Supervisor: Dr Qassem Abdul-Jaber
Co-Supervisor: Dr. Amer Marei

Master thesis submitted and accepted, Date: 25/6/2006
The names and signatures of the examining committee members are as follows:

1- Head of Committee: Dr Qasem Abdul-Jaber Signature.....
2- Internal Examiner: Adnan Rasheed Signature.....
3- External Examiner: Dr Marwan Ghanem Signature.....

Jerusalem- Palestine

1427/2006

Declaration

I Certify that this thesis submitted for the degree of Master is the result of my own research, except where otherwise acknowledged, and that this thesis (or any part of the same) has not been submitted for a higher degree to any other university or institution.

Signed _____

Taher Mohammad Hamed Danoun

Date: 25 June 2006

ACKNOWLEDGMENTS

Before all and above, I would like to express my endless thanks to GOD for conciliation, and providing patience.

I owe a great deal of thanks to my supervisors Dr. Qassem Abdul –Jaber, for his fruitful discussion, supervision, invaluable guidance, directions and kindness throughout this study. My appreciation is extended to Dr. Amer Marei for his support and his advices during this study.

I also express my deepest and sincere gratitude to Mss. Sahar Edekadek for her fruitful helpful, encouragement and continuous support.

Sincere thanks goes to Mr. Mohammad Sbieh and all members in Laboratories of the Department of Earth and Environmental Sciences of Al Quds University and members of laboratories of Biological and Chemical Analyses Center for helpful in the lap work, and also I would like to thank the Team Work of UFZ/ Germany. I send my thanks also to the Palestinian Meteorological Station and Palestinian Water Authority (PWA) for all the information and facilities that gave me for my graduate study.

Many thanks to Al–Quds University, to My colleges and all my instructors throughout the years of studying the Master Degree in the Department of Applied Earth and Environmental Studies.

I would like to Dr. Adnan Rasheed for accepting to be my internal examiner.

Thanks to Dr. Marwan Ghanem who accepted to be my external examiner.

The wormiest feelings are extending to my family; again I want to thank my Parents, Wife, Children, Sisters, Brothers, Sons and Daughters of Brothers and Sisters for their moral support.

Last, and by no means least, my heartfelt thanks to everyone contribute towards the progress of this work, provides help, moral support, love, and encouragement.

ABSTRACT

Water is a crucial and highly politically sensitive issue among Palestinians. Largest available source of fresh water in Palestine is groundwater.

The study area selected is situated in the northern part of Jericho district which represent the eastern part of the West Bank /Palestine between 32°10/ and 32°12/ latitude N and 35°27/ and 35°32/ E longitude.

The aim of this research is to study the characteristics and genesis of the groundwater in Marj Na'ja Area.

Thirty –eight samples were collected between July 2003 and May 2004 from wells and springs in the area as there are a limited number of studies concerning groundwater quality. The EC, pH and Temp. were measured in the field. The chemical analyses for major ions were carried out in Al-Quds Laboratories.

The results show a great diversity in the physical and chemical characteristics of the wells and springs. The EC ranges between 663 µS/cm and 7580 µS/cm, Sodium and Cl^- ranges between 65 mg/L and 798.8 mg/L and between 99 and 1765.5 mg/L, respectively.

On Piper Diagram, the most abundant water type of the study is the "Alkaline water with prevailing chloride". Other samples of wells and springs plot on a piper diagram in area of "Earth alkaline water with increased portions of alkalis with prevailing chloride" and only Al Maleh Cold samples plot in the area of "Earth alkaline water with increased portions of alkalis with prevailing bicarbonate".

The water parameters interrelationships between different analyzed parameters show correlations from very significant relationship for the variables that have correlation coefficient ≥0.9 to poor relationship for the variables. The correlation between Cl^- and Na^+ appears very high.

Four clusters appear depending on the common characteristics between variables of the same cluster. Study Area was dominated by Sodium cation and Chloride anion.

The water of the groundwater of the study area are not suitable for drinking purposes except the spring of Al Maleh cold and they are ranged from "hard" to "very hard" of hardness. In the EC-SAR classification these wells and springs are suitable for irrigation with limitation except springs of Al -Maleh Warm which are not suitable for irrigation and Al-Maleh Cold that is suitable for irrigation without any limitation.

The majority of the wells and springs of the study area plots in the Field 8 on Durov diagram "Cl dominant anion and Na dominant cation, indicating that the ground waters be related to reverse ion exchange of Na-Cl waters". Other wells and springs plots in the Field 5 on Durov diagram "No dominant anion or cation, indicates water exhibiting simple dissolution".

The most abundant water type of groundwater of the study area was sodium-chloride water. However, water type of Al Maleh Cold was Sodium and Bicarbonate.

Most of the sample of wells and spring undersaturated with respect to anhydrate, gypsum and aragonite, and oversaturated with respect to calcite and dolomite mineral phases.

Mg^{+2}/Ca^{+2} ratios reflect water movement through limestone and dolomitic limestone. HCO_3^- / Cl^- ratios indicate dissolution from the evaporites in the rocks except in Al Maleh Cold indicate moderate water-rock interaction. In addition, Na^+/Cl^- ratios either lower than that of water in the hydrological cycle indicate (Cationic exchange) or close to that of the precipitation water.

The results of ^{18}O, and ^{2}H analyses show that the isotopic contents of the water samples plot on the Mediterranean Meteoric Water Line (MMWL) with average values of -4.82 ‰ for $\delta\ ^{18}O$, -21.6‰ for $\delta\ ^{2}H$ and 16.9 ‰ for d-excess, which means that the water of these springs and wells originated from the rain water.

Results of tritium concentrations in the water of groundwater are collected from study area in spite its only three samples, show that the ^{3}H concentrations within the range of old water before to 1950s.

الملخص

تلعب المياه دوراً هاماً وحاسماً في حياة الفلسطينيون وتعتبر من أكثر الموضوعات السياسية حساسية في المنطقة خاصة وأن معظم مصادر المياه في فلسطين هي مياه جوفية.

منطقة الدراسة التي تم اختيارها تقع في الجزء الشمالي من محافظة أريحا الواقعة ضمن خط العرض ′32°10 -′32°12 شمالاً وخط الطول ′35°32 -′35°27 شرقاً علماً أن محافظة أريحا تقع في الجزء الشرقي من الضفة الغربية في فلسطين.

هدفت الدراسة إلى التعرف على صفات وخصائص ونشأة المياه الجوفية في منطقة مرج نعجا ولتحقيق أهداف الدراسة تم جمع ثمانية وثلاثون عينة خلال الفترة ما بين شهر تموز ٢٠٠٣ وشهر أيار ٢٠٠٤ من الآبار والمياه الجوفية الواقعة ضمن حدود منطقة الدراسة وذلك نظراً لقلة الدراسات المتعلقة بخصائص وصفات المنطقة المائية.

أثناء سحب العينات في الموقع تم قياس درجة الحرارة ودرجة الحموضة ومقدار الإيصال الكهربائي بينما التحاليل الكيميائية للعناصر الرئيسية الموجبة والسالبة تم القيام بها في مختبرات جامعة القدس أما تحليل النظائر فقد تم في مختبرات UFZ في ألمانيا.

أظهرت النتائج تفاوتاً واسعاً في الصفات الفيزيائية والكيميائية للآبار والينابيع حيث تراوح تركيز الصوديوم ما بين ٦٥-٧٩٨,٨ ملغرام وتركيز الكلور ما بين ٩٩-١٧٦٥,٥ملغرام.

هذا وبالاعتماد على نموذج (Piper) وجد أن معظم عينات المياه الجوفية من ينابيع وآبار تقع في منطقة المياه القلوية مع زيادة في تركيز الكلور وظهرت بعض عينات المياه الجوفية في منطقة المياه القلوية الأرضية مع زيادة في تركيز القلويات ووجود الكلور. بينما ظهرت عينات مياه المالح البارد في منطقة القلويات الأرضية مع زيادة في تركيز البايكربونات.

هذا وقد دلت نتائج ربط العلاقات بين المتغيرات المدروسة علاقات تتراوح ما بين قوية جداً والتي كان معامل ارتباطها أعلى أو يساوي ٠,٩ إلى علاقات ضعيفة ما بين بعض المتغيرات وقد أشارت النتائج إلى أن العلاقة ما بين تركيز الصوديوم وتركيز الكلور عالية جداً.

كما وظهرت أربع مجموعات بالاعتماد على الخصائص المشتركة للعينات وقد تميزت أيضاً بوجود الصوديوم والكلور.

هذا وقد أظهرت نتائج الدراسة أن جميع عينات المياه التي تمت دراستها في المنطقة غير صالحة للاستخدامات المنزلية باستثناء عينات مياه المالح البارد وقد تراوحت درجة عسر المياه ما بين مياه عسرة إلى عسرة جداً. كما وأظهرت النتائج بناء على العلاقة ما بين اللإيصالية الكهربائية للمياه ومعدلات الصوديوم بأن غالبية المياه صالحة للاستخدامات الزراعية بمحددات باستثناء ينابيع المالح الحار الغير صالحة نهائياً للزراعة ونبع المالح البارد الصالح للزراعة بدون أية محددات.

معظم المياه الجوفية بالاعتماد على نموذج (Durov) تقع ضمن المنطقة التي تتميز بوجود الصوديوم كعنصر موجب رئيسي والكلور كعنصر سالب رئيسي والتي تشير إلى وجود تبادل أيوني عكسي في هذه المياه، كما وظهرت بعض العينات في المنطقة على خط التحلل.
نوعية المياه في المنطقة تتميز بأنها تحتوي على الصوديوم والكلور كعنصران رئيسيان إلا مياه نبع المالح البارد التي تتميز بوجودج الصوديوم والبايكربونات كعنصران رئيسيان.

كما وتشير النتائج أن نسبة المغنيسيوم/ الكالسيوم توضح سريان المياه الجوفية في المنطقة التي تتميز بوجود صخور كلسية وصخور تحتوي على الكالسيوم والمغنيسيوم. بينما تشير علاقة البايكربونات/الكلور إلى ذوبان للمواد الموجودة في الصخور المحيطة بينما في نبع المالح فقد أشارت هذه النسبة إلى احتكاك بسيط للمياه مع الصخور المحيطة.

أما علاقة الصوديوم/الكلور فقد أظهرت أن بعض العينات تحتوي على نسبة قريبة من تلك الناتجة عن مياه الأمطار أونسبة أقل من الموجودة في مياه الأمطار مما يشير إلى وجود تبادل أيوني.

وقد أظهرت النتائج المتعلقة بدراسة المحتوى النظائري لعينات المياه التي تم تحليلها أنه تقع على خط مياه البحر المتوسط بمعدل $\delta\ ^{18}O$ -4.82 ‰ و $\delta\ ^{2}H$ -21.6‰ مثبتاً أصلها الجوي. أما بالنسبة لعينات التريتوم (ثلاث عينات فقط) فتشير إلى عمر مياه يعود إلى بداية الخمسينات.

CHAPTER ONE

INTRODUCTION

1.1 Introduction

Water is essential to people, and the largest available source of fresh water in Palestine is groundwater. Increased demand for water has stimulated development of ground water resources.

There is little surface water in the West Bank and Gaza Strip, therefore groundwater is the main sources for drinking water in Palestine. Therefore, ample supplies of high quality water are essential for economic growth, quality of life, environmental sustainability, and when considered in the extreme for survival. In addition, water is one of our most precious resources, and polluted water is one of major hazards especially in the world's poorest countries.

The understanding of the water movement in the unsaturated and saturated zones is quite important. This knowledge is also vital for judging the quality of the underlying water resources.

Human activities often cause serious deteriorations in the groundwater quality. It is always extremely difficult and very costly to clean up a polluted aquifer, and in some cases, it is simply impossible. Water flows slowly in the underground, so it takes many years or decades for pollution to show up and even larger period to disappear.

Groundwater is generally considered the major water resources in arid and semiarid environments. Its protection and development is therefore important.

1.2 Significance of study

Water is a crucial and highly politically sensitive issue among Palestinians. At present, the West Bank is considered water stressed area. In addition, the West Bank governorates of Palestine are considered such arid to semiarid areas that face severe water shortages.

The infrastructure in the Palestinian built-up areas in the West Bank is weak resulting in water resources becoming vulnerable to pollution through various sources. Deterioration of water quality in the West Bank originates from four main sources; domestic wastewater, solid waste leachate, industrial effluents, and run-off from agricultural activities.

Water resources may be also contaminated by agrochemicals from agricultural activities. Fertilizers and pesticides accumulated in the soil, filter downwards and may reach the groundwater table.

Quality measurements of groundwater in the West Bank, conducted by ARIJ (1995), have shown that the nitrate level in some areas exceeds the permissible level (45 mg/l). This is particularly true in areas such as Nablus city and the Jericho area. A nitrate in groundwater is an indicator of pollution from fertilizers or wastewater.

Future estimates predict that groundwater quality will deteriorate with the expected population growth, if adequate measures will not take to prevent pollution.

A very limited number of studies concerning groundwater quality in the Marj Na'ja Area have been conducted and these were dependent on partial chemical analyses on Jericho District. This presents the need for a comprehensive study concerning the ground water quality in Marj Na'ja area of Jericho district in the West Bank /Palestine.

1.3 Aim and Objectives

The aim of this Research is to study the characteristics and genesis of the groundwater in Marj Na'ja Area in Jericho District

1.3.1 The study has the following objectives:

1- Study the water quality of the springs and wells in the Marj Na'ja area through determination of the concentration of the major ions to evaluate the suitability of the water for both drinking and irrigation purposes.

2- Evaluation of the different sources (natural as well as anthropogenic) of the dissolved substances.

3- Determination of the origin and genesis of groundwater in the study area.

4- Determination of the isotopic compositions to study the groundwater recharge and flow.

1.4 Location of the study area

The Marj Na'ja area was chosen for the present study, as there is a lack of available data concerning the hydrology, hydrogeology and hydrochemistry. The study area selected is situated in the northern part of Jericho district which represent the eastern part of the West Bank / Palestine between 32°10/ and 32°12/ latitude N and 35°27/ and 35°32/ E longitude (Figure1.1). The region is surrounded by Tubas in the north; Al Jiftlik in the south; Nablus in the west and Jordan River in the east. Catchments area for the study Area was presented in Figure (1.2).
Marj Na'ja Area in Jericho district includes different geographical locations (Marj Na'ja, Frush Bait Dajan, Al Himmah and Wadi Al Maleh. Table (1.1) presents the general characteristics of Marj Na'ja Location.

Table (1.1): Area and Population of Study Area (PCBS, 2005)

Locality name	Mid–Year population 2005	Area (m^2)
Marj Na'ja	743	116935.5
Az Zubiedat	1,299	199237.7
Marj al Ghazal	373	4891.3

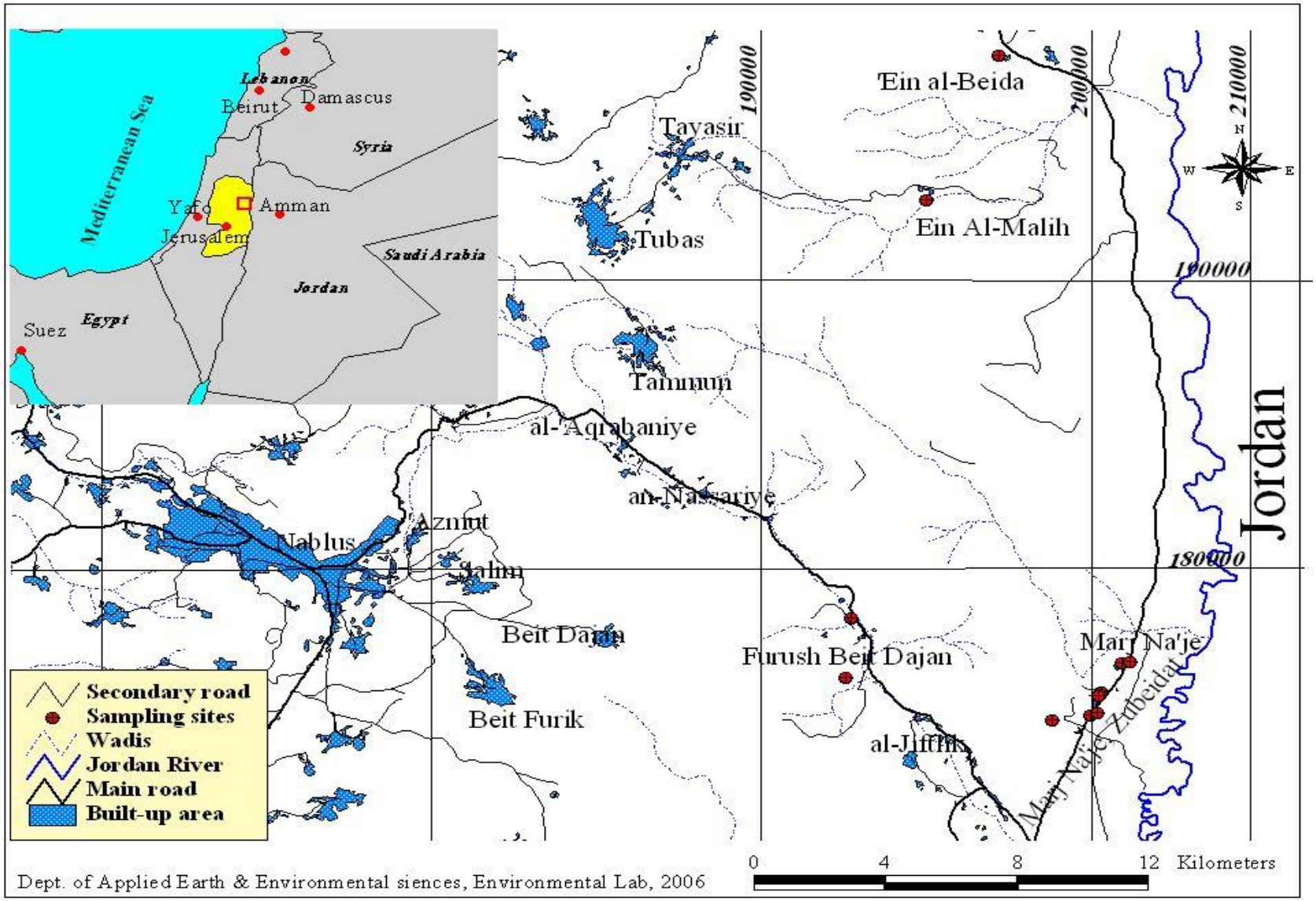

Figure (1.1): Location of Marj Na'ja Study Area (Environmental Research Laboratory of Al – Quds University, 2006)

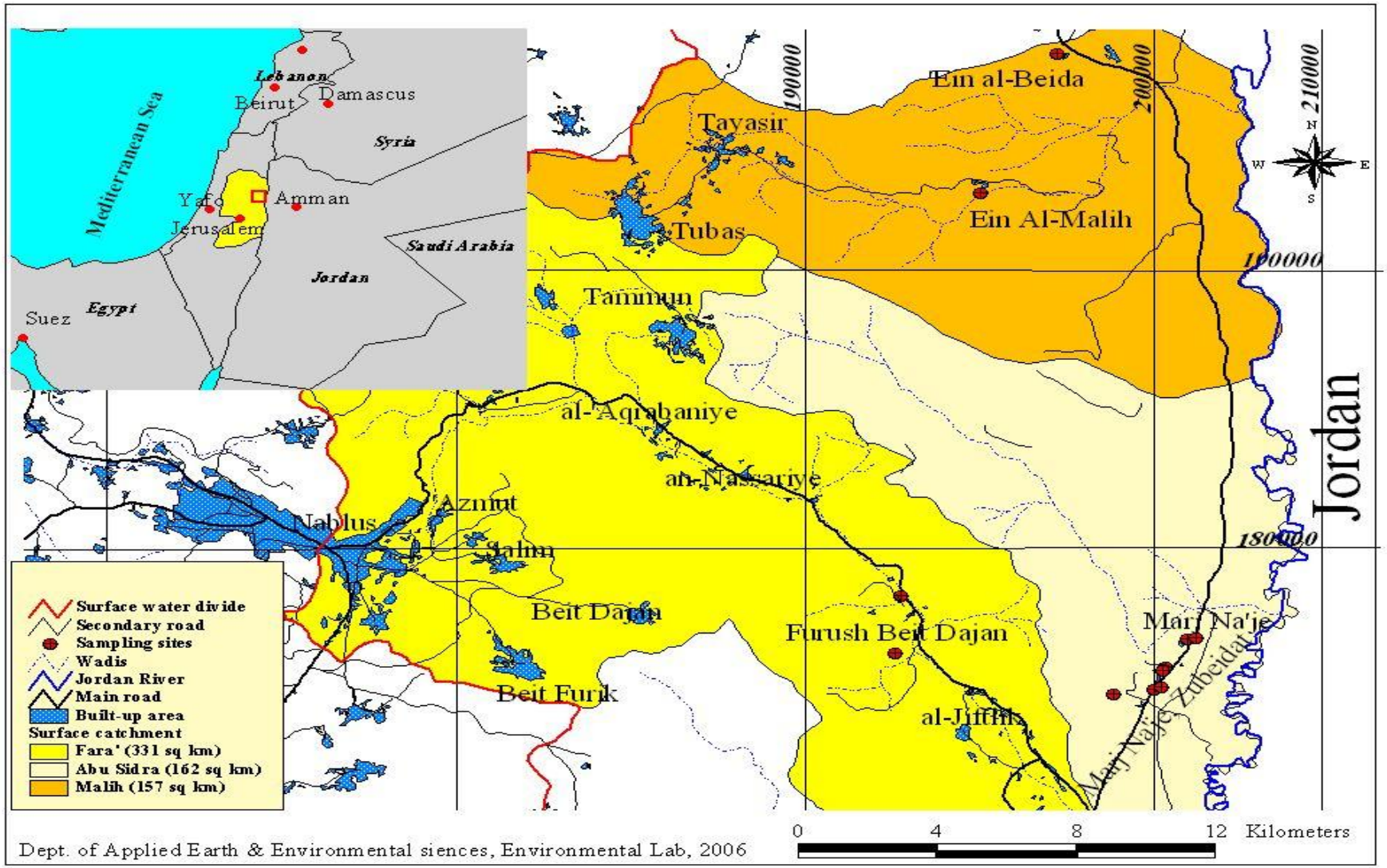

Figure (1.2): Surface Catchment of Marj Na'ja Study Area (Environmental Research Laboratory of Al – Quds University, 2006)

1.5 Previous Studies

Rising salinity levels is one of the significant signs of water-quality degradation in groundwater. The high levels of salinity limit the utilization of groundwater for both domestic and agricultural applications.

The alluvial Pleistocene wells in the Jericho area, Palestine show high salinity and a high susceptibility to contamination thus Khayat *et al*, 2006 deals in their paper with the source of salinity in the wells using hydrochemical tracers. The study revealed three main zones of different salinity by using different diagnostic hydrochemical fingerprinting as tracers for elucidating the sources of salinity.

They were concluded most three probable sources of salinity. The first possible source of salinity the geological formations of the region, which form inter-fingering layers of both the Samara and Lisan formations of Pleistocene age, where the eastern Arab Project aquifers show the highest amount of sulphate. The location and geological formation of these wells within the Lisan suggested that the source of high sulphate content is the dissociation of gypsum (Khayat et al, 2006).

The second possible source of salinity The NaCl water within the same area may also be upwelling from a deep brine aquifer or from a fresh-water aquifer, which contains salt-bearing rocks with particles becoming finer from west to east. This noticeable high TDS to the east affected by the rate of pumping from the upper shallow aquifer, especially in the wells of the Arab Project, which are in continuous pumping during the year(Khayat et al, 2006).

The third possible source of salinity is from anthropogenic influences. Influences that shown by the increment of nitrate, bromide and sulphate, depending on whether the location of the well is coincident with urban or agricultural areas. This reflects the addition of agricultural chemical effluents or sewer pollution from adjacent septic tanks which are mainly constructed in top gravel in the Samara layer (Khayat et al.2006).

Marie and Vengosh ,2001 evaluated the sources and mechanisms for salinization in the Jericho area by employing diagnostic geochemical fingerprinting methods to trace the potential sources of the salinity in the deep confined subaquifer system of Lower Cenomanian age, the upper subaquifer system of Upper Cenomanian and Turonian ages, and the shallow aquifer system of Plio-Pleistocene ages. The chemical composition of the saline groundwater from the two Cenomanian subaquifers point to a single saline source with Na^+/Cl^- approximately 0.5 and Br/Cl^- approximately 7×10^{-3}.

This composition is similar to that of thermal hypersaline springs that are found along the western shore of the Dead Sea. They suggest that the increasing salinity in both Lower and Upper Cenomanian subaquifers system is derived from the mixing with deep seated brines that flow through the Rift fault system. The salinization rate depends on the discharge volume of the fresh meteoric water in the Cenomanian Aquifer (Marie and Vengosh , 2001).

In the contrast, the chemical composition of groundwater from the Plio-Pleistocene Aquifers shows a wide range of Cl^- (100-2000 mg/L), Na^+/Cl^- (0.4–1.0), Br/Cl^- ($2\text{-}6\times10^{-3}$), and $SO4^{-2}/Cl^-$ (0.01-0.4) ratios. These variations together with the high SO_4^{-2}, K^+ and NO_3^- concentrations suggest that the salinity in the shallow aquifer is derived from the combination of the upcoming of deep brines as reflected by low Na^+/Cl^- and high Br/Cl^- ratios (Marie and Vengosh , 2001).

Leaching of salts from the Lisan formation within the Plio-Pleistocene Aquifer, as suggested by the high SO_4^{-2} concentrations, and anthropogenic contamination of agriculture return flow and sewage effluents with distinctive high K^+ (80mg/L) and NO_3^- (80mg/L) contents and low Br/Cl^- ratios 2×10^{-3} (Marie and Vengosh, 2001)

Abdul –Jaber, 1995 evaluated the chemistry of some springs and groundwater wells from the central and northern parts of the West bank. He showed that there are four water types represented in the West Bank. The most abundant type is the earth alkaline with prevailing bicarbonate, followed by the earth alkaline with increased portions of alkalis and prevailing bicarbonate, then the earth alkaline water with increased portions of alkalis and prevailing chloride and lastly the alkaline water with prevailing chloride.

Scarpa *et al,*1998 introduced the results of the chemical and biological study of the wells extracting water from the unconfined aquifer system in the northern West Bank. The excessive use of fertilizers, wide distribution of cesspits and uncontrolled disposal of wastewater were considered probable sources of the wide spread biological contamination and the alarming nitrate, chloride and potassium levels that were found in many of the wells studied.

The survey of the available water quality data in the West Bank conducted by the Ministry of Planning and International Cooperation, 1998 showed that the groundwater in local and regional aquifer systems is partially contaminated. Since the aquifers in the West bank are carbonate aquifer, it is expected that the water will be a Ca,Mg-HCO3 water which is true for unpolluted water resources. The polluted resources are Ca, Na-HCO_3 or Ca, Na, Cl^-, NO_3^- water and in some cases Na-Cl water.

This survey concludes that the sources of pollution in groundwater may be one of the following: wastewater, agricultural activities, salt deposits, and solid waste. The wells and some springs in the Jordan Valley area have a relatively high Na – Cl concentrations which might origin from the leaching of the salt deposits within the aquifer.

Abdul-Jaber *et al*, 1999 collected water samples between 1995 and 1997 from wells throughout the West Bank to provide an overall picture of the water quality of the wells.
The results indicated that the most abundant water type among the wells of the West Bank is the "earth alkaline water with prevailing bicarbonate", where Ca^{+2} is the major cation and HCO_3^- is the major anion. This water type is the original type found especially in uncontaminated carbonate aquifer in recharge areas.

Other important water types are the "earth alkaline water with increased portion of alkalis and prevailing bicarbonate" and "earth alkaline water with increased portion of alkalis and prevailing chloride" (Abdul-Jaber et al, 1999).

In these two types, the original water has been mixed with some untreated wastewater from cesspools and wastewater streams that has infiltrated the Karstic rocks and contaminated the unconfined local perched aquifer. A fourth water type represented by the Mukarker well in the Jordan Valley, is the “alkaline water with prevailing chloride” (Abdul-Jaber et al, 1999).

The water of the West Bank wells are chemically suitable for drinking purposes, although some wells show higher nitrate concentrations than recommended by WHO. The water of the wells of the West Bank is “hard” to “very hard” and may need softening to reduce excessive use of detergents and to prevent the formation of scales in facilities used for boiling water. Most of the West Bank wells are suitable for irrigation, having a low sodium adsorption ratio or “excellent” to “good” soluble sodium percentage values with a low to medium salinity hazard. A few wells cannot be used for irrigation without restrictions as they have a high sodium adsorption ratio or “permissible” soluble sodium percentage values with a high to very salinity hazard (Abdul-Jaber et al, 1999).

The variations in the water chemistry of the wells of the West Bank may be attributed to the differing chemical and mineralogical compositions of the aquifer, to agricultural activities or to the illegal disposal of raw wastewater in the recharge area and in the surroundings of the wells. These processes may modify the chemistry of the wells mainly by increasing the concentrations of some major ions such as chloride, sulphate, nitrate, sodium and potassium (Abdul-Jaber *et al*, 1999).

Another study conducted by Abed Rabbo et al, 1999 about water quality and chemistry of the springs in the West Bank. In this study, water samples were collected between 1995 and 1997 from springs throughout the West Bank. These springs discharge from the Eocene aquifer system in the Nablus and Jenin districts, and from the Albian – Turonian aquifer systems elsewhere. The study is of considerable important that these springs are the major source of water both domestic and agricultural purposes. In some Palestinian communities, a spring is the only source of water.

The results of the study indicated that the most abundant water type among the springs of the West Bank is the "earth alkaline water with prevailing bicarbonate", where Ca^{+2} is the major cation and HCO_3^- is the major anion. The water type is the original type found especially in uncontaminated carbonate aquifers in recharge areas. Other important water types are the “earth alkaline water with increased portions of alkalis and prevailing bicarbonate", and “earth alkaline water with increased portions of alkalis and prevailing chloride". In these two types, the original water has been mixed with some untreated wastewater from cesspools and waste wastewater streams, which has infiltrated the karastic rocks and contaminated the unconfined local perched aquifer(Abed Rabbo et al, 1999).

A fourth water type represented by some springs in the West Bank is the "Alkaline water with prevailing chloride" which is restricted to some springs in the Jordan Valley, such as the springs of Maleh and Feshkha. This type is characterized by its high total dissolved solids as well as chloride and sodium concentrations, a result of the leaching of the aquifer material and/or the mixing with deep brine water (Abed Rabbo et al, 1999).

The water of the West Bank springs is chemically suitable for drinking purposes, although some springs show higher nitrate concentrations than recommended by WHO.

The water of the springs of the West Bank is " hard to " very hard" and may need softening to reduce the effects of excessive use of detergents and to prevent the formation of scales in facilities used for boiling water (Abed Rabbo et al, 1999).

Most of the West Bank springs are suitable for irrigation, having a low sodium adsorption ratio, or “excellent to “good" soluble sodium percentage values with a low to medium salinity hazard. A few springs cannot be used for irrigation without restrictions as they have a high sodium adsorption ratio or "permissible” soluble sodium percentage values with a high to very high salinity hazard (Abed Rabbo et al, 1999).

The variations in the water chemistry of the springs of the West Bank may be attributed to the differing chemical and mineralogical compositions of the aquifer, to the agricultural activities or to the illegal disposal of raw wastewater in the recharge area and in the surroundings of the springs.

These processes may modify the chemistry of the sprigs, mainly by increasing the concentrations of some major ions such as chloride, sulphate, nitrate, sodium or potassium. It is important that steps be taken to protect and to improve the water quality of these vital water resources by appropriate legislation, mitigation measures and upgrading project as the various levels (Abed Rabbo et al, 1999).

Moller *et al*., 2006 evaluated the probable sources of salinization of the thermal groundwater of Jordan from major and some minor elements. In Jordan, mineralization of groundwater is largely controlled by dissolution of halite, carbonates, gypsum, and leaching diverse bearing minerals, caused by interaction with Neogene basalts, limestones are silicified and mineralogically altered. Salinization of sandstone–bound water along the rift escarpment is caused by a Na^{+}-K^{+}, SO_4^{-2}-HCO_3^{-} brine. However other wells are affected by the presence of a Ca^{+2} – Cl^{-} brine .

Moller et al., 2006 in their study evaluated the sources of geothermal water in Jordan using stable isotopes of H_2O revealed two trends by cross plots of $\delta^{18}O$ vs. $\delta^{2}H$. The main trend of the water from limestone aquifers define a mixing line of past to recent meteoric water with negligible contributions of Pleistocene water. Some water from Eocene aquifers plot on local Mediterranean meteoric water line, others plot together with water from sandstone aquifers at enhanced $\delta^{18}O$ values due to hydrothermal overprinting.

1.6 Climate

The West Bank is considered a semiarid to arid area. There are four climatic/geographical zones in the West Bank (ARIJ, 1997).Figure (1.3) represents the average annual rainfall over the West bank.

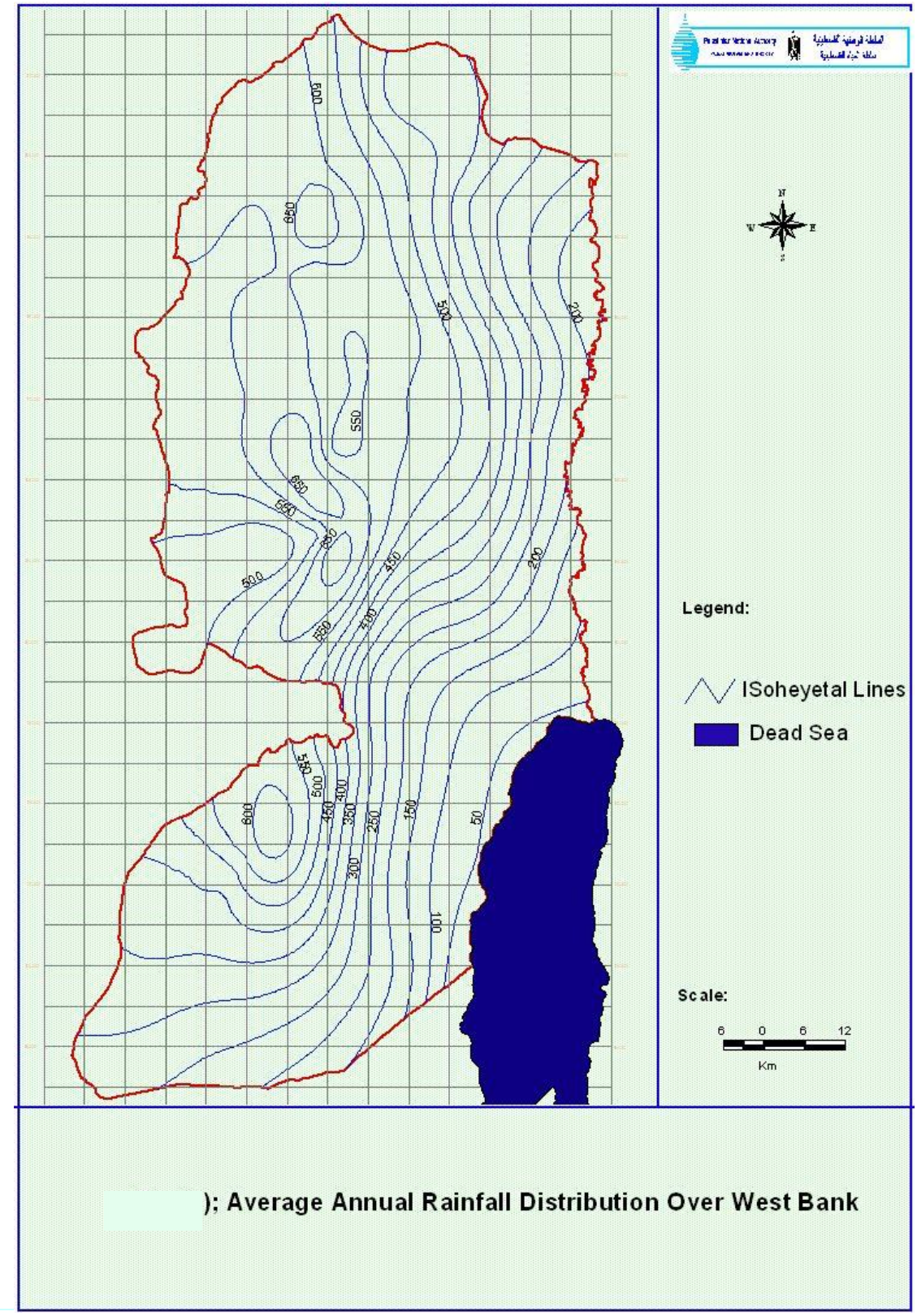

Figure (1.3): Average Annual Rainfall Distribution Over West Bank (PWA, 2005)

1.6.1 Climate of the Study Area:

The Marj Na'ja area is part of Jericho district, which is classified as arid that has hot summers and warm winters with very rare frosts incidents (ARIJ, 1995). Table (1.2) shows the mean monthly climatic averages 1997-2004.

1.6.1.1 Temperature:

The location of the study area to the east of the highlands prevents the benefits of the northwestern wind that cools the rest of the West Bank especially in the Summer time. January is the coldest month, and August the warmest (Figure1.4). The average maximum temperatures during January (coldest month) and August (hottest month) are around 19^0C and 38^0C respectively. The average minimum temperatures for the same months are around 7^0C and 22^0C respectively (Palestinian Metrological Department, 2004).

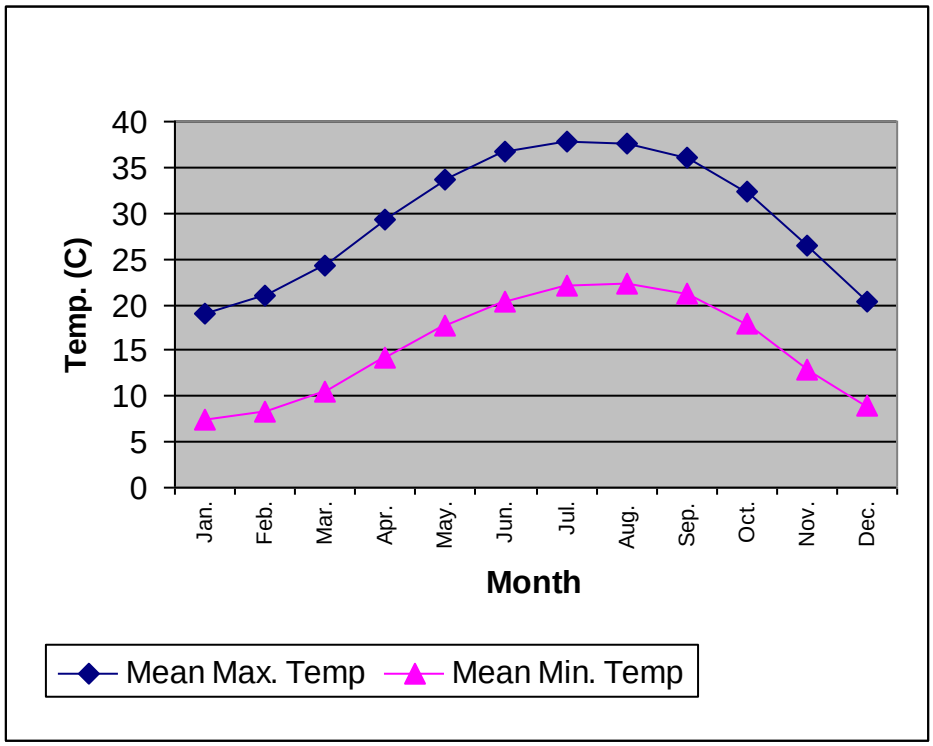

Figure (1.4): Variation of maximum and minimum temperature during the period 1997-2004 (Palestinian Metrological Department, 2004)

1. 6.1.2 Wind:

The average daily wind speed in the district is around 3.27m/sec. During Spring, the maximum wind speed is measured at 15m/sec, often reaching to 20 m/sec from west to northwest (Figure1.5). The maximum wind speed through the rest of the year reaches to 12 m/sec. The effect of the *Khamaseen* (hot, dry and sandy wind blowing from the Saudi Arabia) on agriculture is limited because it comes after the end of the growing season (Palestinian Metrological Department, 2004).

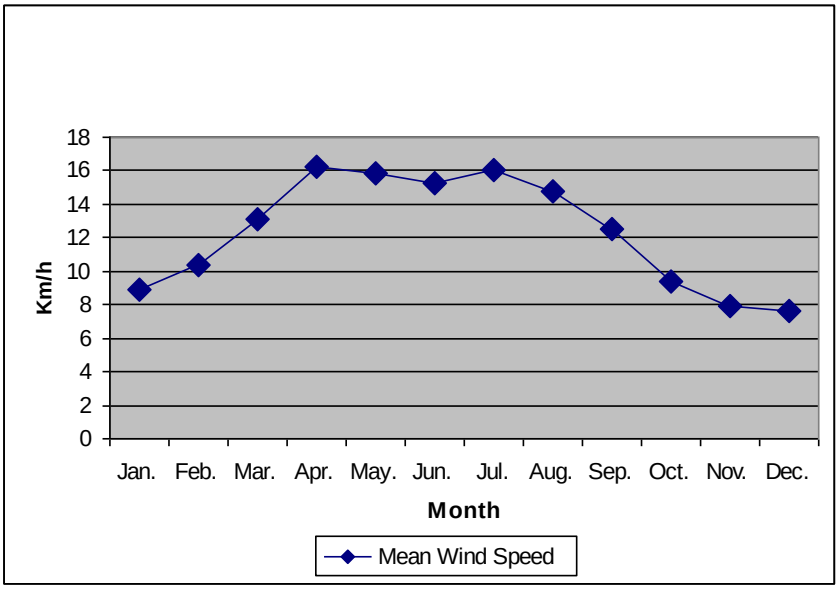

Figure (1.5): Long term average Wind Speed (Km/h) 1997 -2004 (Palestinian Metrological Department, 2004)

1. 6.1.3 Radiation:

The solar radiation reaches its peak during July. The total annual solar radiation measured for the period between June 1994 and May 1995 amounts to 62,520 watt/m^2 (ARJI, 1995).

The total incoming radiation at the district to thus high, which bring great benefits to agriculture and greenhouse cultivation.

1. 6.1.4 Rainfall:

The rainy season in the area district starts in the middle of October and continues to the end of April (Figure1.6). Rainfall showers are particularly violent and short in duration. Both rainfall and dewfall decrease from the northern to southern part of the Jericho district, contrary to temperature and evaporation. According to the Palestinian Metrological Services (2004), mean annual rainfall at the Jericho city for the period 1997-2004 was 166 mm (Figure1.7). Snow and hail are uncommon in the district.

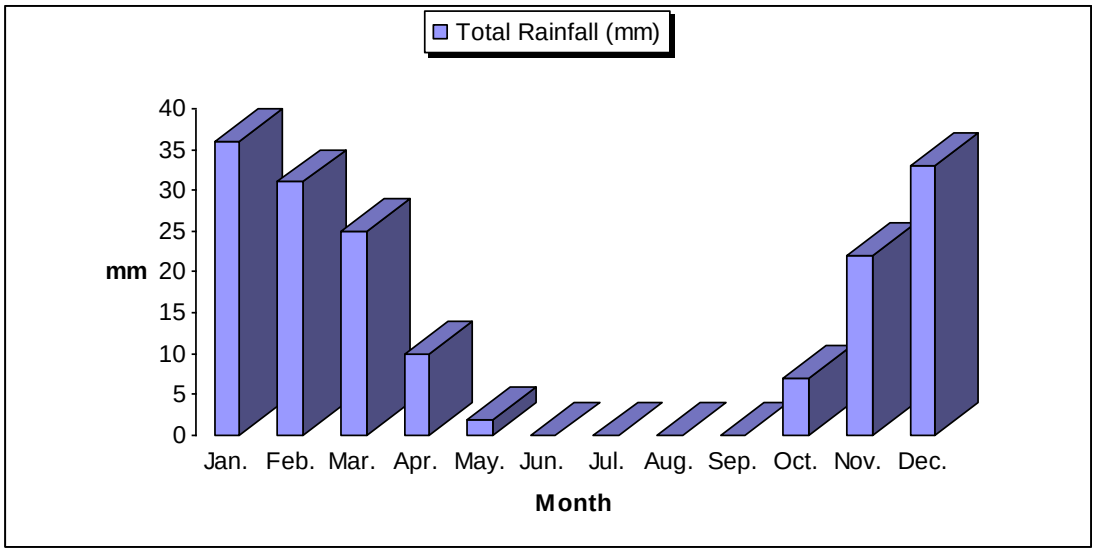

Figure (1.6): Long term average monthly rainfall for 1997–2004 (Palestinian Metrological Department, 2004).

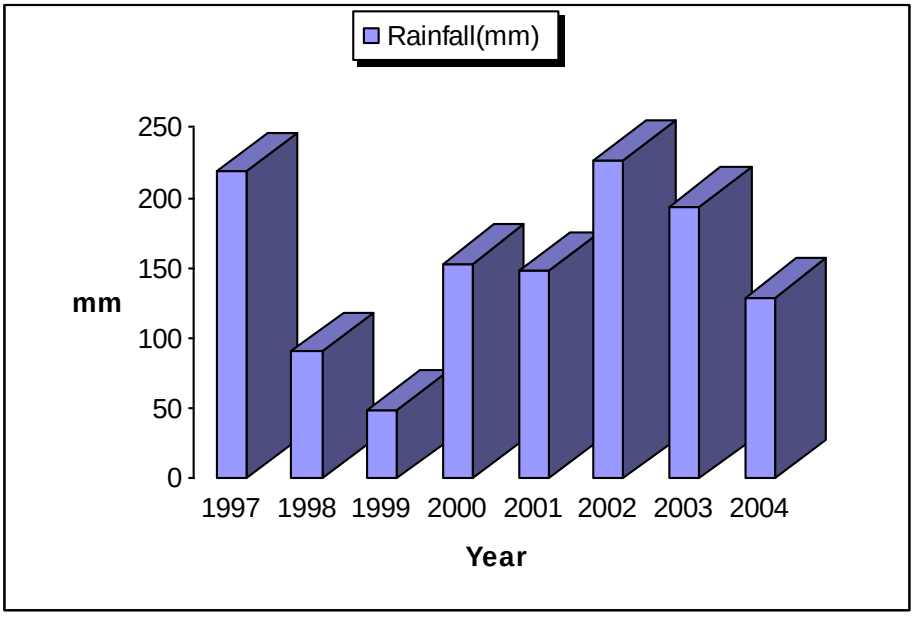

Figure (1.7): Annual rainfall in mm for 1997 – 2004 (Palestinian Metrological Department, 2004).

1. 6.1.5 Relative Humidity:

The mean annual relative humidity in Jericho district is about 50%. It reaches its highest rates in winter, amounting 70% during the day time and approximately 85% during the night.

During summer the relative humidity ranges between 45 – 60%, dropping to as low as 5% when the temperature is very high.

In spring, the relative humidity reaches around 60% with a mid – day average of 30% despite the presence of southern wind which is common during season (Palestinian Metrological Department, 2004). (Figure 1.8).

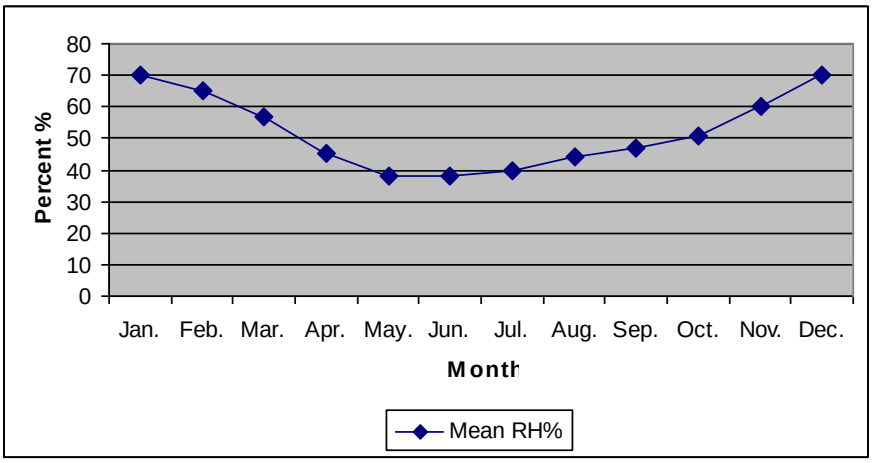

Figure (1.8): Long term average monthly Relative Humidity for 1997–2004 (Palestinian Metrological Department, 2004).

1. 6.1.6 Evaporation:

Potential Evaporation rate is very high varying between 59 mm/month when solar radiation is lowest and 298.5 mm/month in July when solar radiation is at its highest (Figure1.9).

During the spring and autumn, the total amount of evaporation reaches 200–250 mm/month. The variation in evaporation is affected by the changes in solar radiation (Figure1.10). Evaporation exceeds precipitation during the year in Jericho district, giving an indication that irrigated agriculture is necessary (Palestinian Metrological Department, 2004).

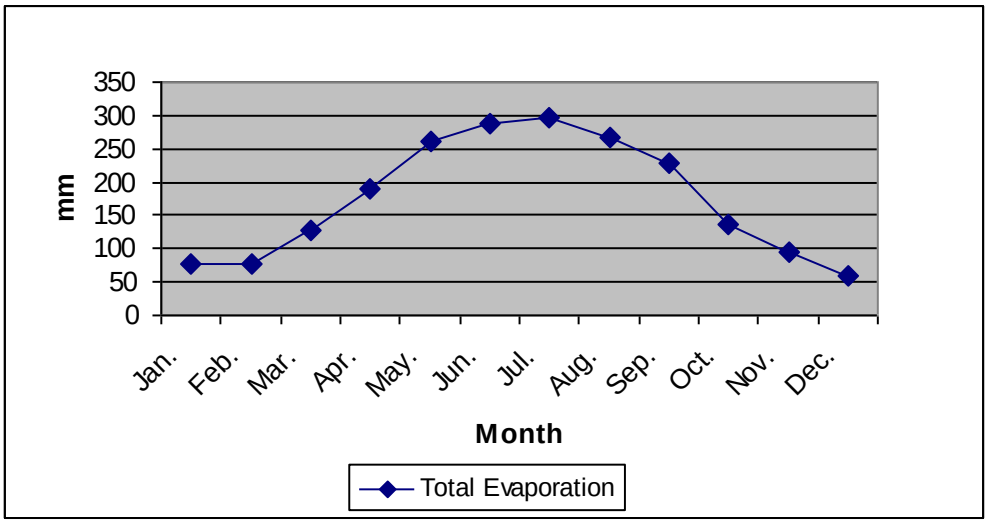

Figure (1.9): Long term average monthly Total Evaporation for 1997-2004 (Palestinian Metrological Department, 2004)

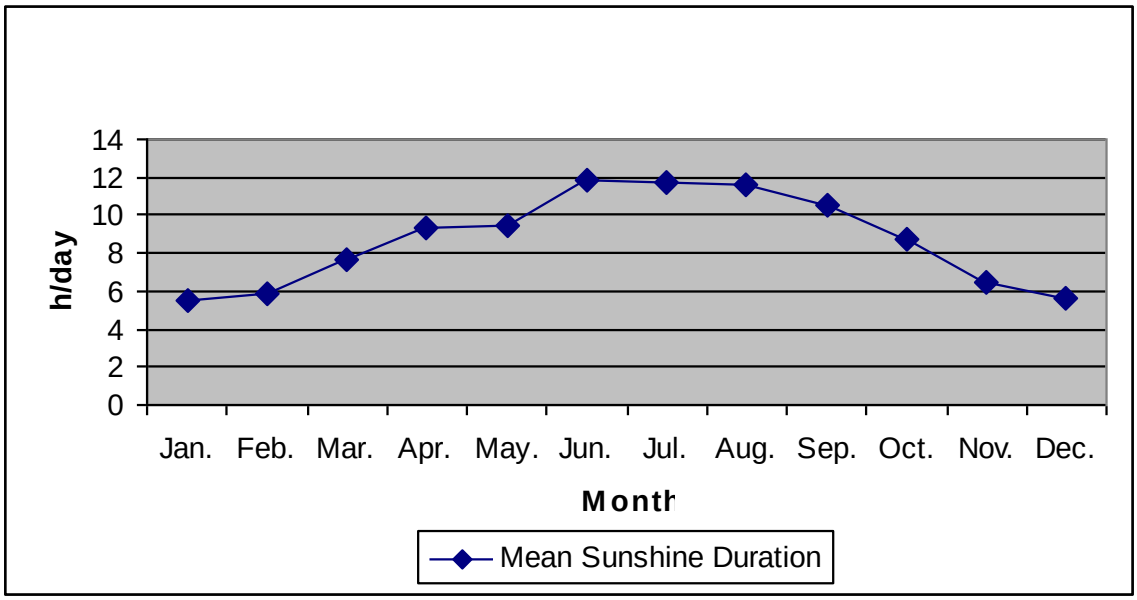

Figure (1.10): Long term average monthly Sunshine duration for 1997 – 2004 (Palestinian Metrological Department, 2004)

Table (1.2): Mean Monthly Climatic Averages 1997 –2004 from Jericho weather station (Palestinian Metrological Services, 2004)

Element	Month											
	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Mean Max. Temp (^{0}C)	19.1	20.9	24.3	29.3	33.7	36.7	37.8	37.6	36.1	32.3	26.4	20.4
Mean Min. Temp (^{0}C)	7.4	8.3	10.5	14.2	17.6	20.4	22.1	22.4	21.2	17.9	12.9	9.0
Mean. Temp (^{0}C)	13.2	14.6	17.4	21.7	25.6	28.5	29.9	30	28.6	25.1	19.6	14.7
Mean Wind Speed (Km/h)	8.9	10.4	13.1	16.2	15.8	15.3	16	14.8	12.5	9.4	7.9	7.6
Pressure (mbar)	1048	1046	1044	1041	1040	1037	1034	1035	1039	1042	1046	1048
Mean Sunshine Duration (h/day)	5.5	5.9	7.7	9.3	9.4	11.8	11.7	11.6	10.5	8.7	6.5	5.6
Mean RH (%)	70	65	57	45	38	38	40	44	47	51	60	70
Total Rainfall (mm)	36	31	25	10	2	0	0	0	0	7	22	33
Total Evaporation (mm)	78	76	128	189	261	289	298	267	227	135	94	59
Max Monthly Rainfall (mm)	62	112	41	20	22	7	0	0	7	71	81	104

Source: Data collected from the (Palestinian Metrological Department, 2004).
Table Notes: Max: Maximum. Min: Minimum Evap.: Evaporation
W. Wind R.H: Relative Humidity

1.7 Geohydrology

1.7.1 Geology of the West Bank:

The stratigraph and lithology in the West Bank consists of several formations, which were formed during the different geological ages (Rofe and Raffety 1963, 1965). The detailed geology of the West Bank was outlined in the Appendix (1.1). The exposed rock formations (Figure1.11) of the West Bank are:

1- Albian-Lower Cretaceous formations comprising the regional West Bank groundwater system (Beit Kahil, Yatta formations). These formations are composed mainly of limestone, dolomite, marl, chalk and clay. The thickness of the groundwater system in this area ranges from 500-970 meters.

2- Upper Cretaceous formations comprising the regional West Bank groundwater system (Hebron, Bethlehem and Jerusalem formations). These formations are composed mainly of hard limestone, dolomite, marl, and conglomerate. The thickness of the groundwater system in this area ranges from 190-490 meters.

3- Senonian age rocks are composed mainly of chalks and marls. The thickness range is 0-45 meters.

4- Pleistocene to Eocene age rocks overlay the Senonian age rocks in the Northern and Northeastrean area of the West Bank, the rocks are composed mainly of limestone, chalky limestone, chalks, marls and siltstone, which are of limited extent and thickness.

5- Unconsolidated, Quaternary alluvial sediments overlie the major rock formations. (Rofe and Raffety 1963, 1965;Awadallah and Owaiwi,2005)

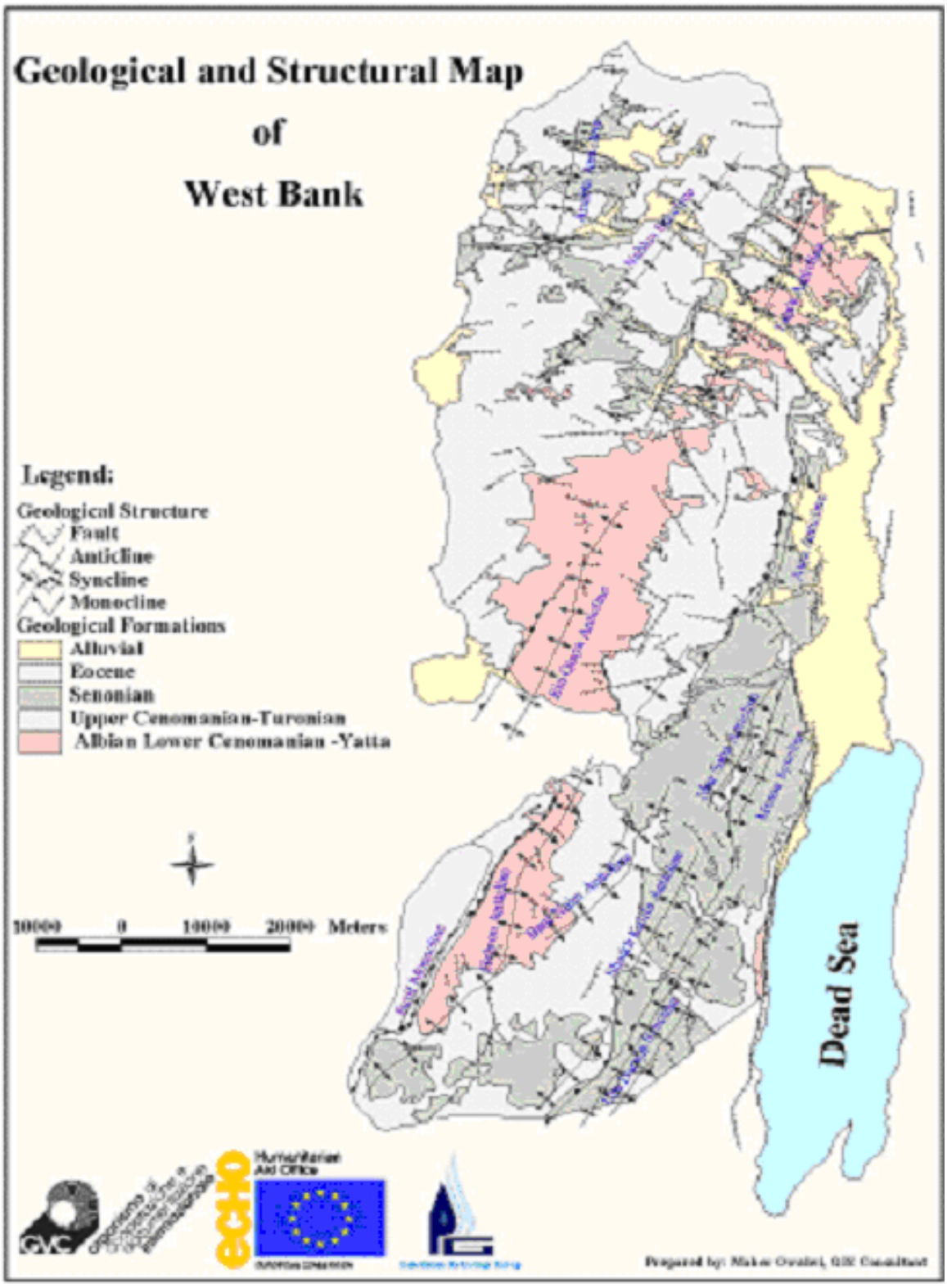

Figure (1.11): Geological and Structural Map of the West Bank (modified after P.H.G, 2005; Arij, 1998 and Rofe and Raffety, 1963, 1965)

1.7.2 Geology and Stratigraphy of Study Area:

The following paragraphs give an introduction to the general lithostratigraphy of the Marj Na'ja area that build up the aquifers in the study area (Figure 1.12). The lithology, thickness and other features relevant to the aquifer characteristics are presented briefly (Rofe and Raffety 1963, 1965):

1.7.2.1 Quaternary Rocks:

This system is composed of the Lisan Formation, Alluvial and gravel fans and the Nari Blanket. They are presented in the study are in the following formations:

1.7.2.1.1 Lisan Formation (Pleistocene Aquifer):

This formation is exposed in some wells of Marj Na'ja and Az Zubiedat in the study area. It is of the Pleistocene to Recent age, and includes three local faults of up to three Km long. The Lisan Formation is exposed along the Rift valley and extends from Lake Tiberias in the north to about 40 Km south of the Dead Sea.

Lithologically it is composed of laminated marl that consists of thin layers of gypsum and limestone, forming alternating light and dark bands. Fine laminations indicate annual clam deposition. Total thickness is about 200 meter.

Alternation of dark and light colors indicates seasonal sedimentation. The formation is of variable thickness and becomes more gravely at the margins, while it becomes more calcareous and thick away from the margins.

1.7.2.1.2. Alluvium Formation (Holocene Aquifer):

This formation is exposed in other wells of Marj Na'ja and Az Zubiedat and some wells in F.B.D. It is of the Pleistocene to Recent in age. It is bounded structurally by the Jordan rift regional fault in the east and another fault of 12 km long in the west. The alluvium is, generally, unconsolidated in the Rift Valley, where it is formed of laminated marls with occasional sands.

However, the nature of the alluvial deposits is affected by the nature of the rock from which they are derived. Alluvial deposits derived from limestone have red color and those derived from sandstone are sandy. Alluvium is important in agriculture and they play an important role in transferring groundwater from limestone aquifers.

1.7.2.2 Tertiary Rocks:

The tertiary rocks are represented by two lithological units: the Jenin Subseries and the Beida Fomation.

1.7.2.2 .1 Beida Formation (Neogene Aquifer):

The formation is exposed in Al-Himmah Spring. The Beida Formation (Neogene Aquifer) is composed of variable thicknesses of conglomerate lenses, limestone, marl and clay

with Lower Tertiary age. The area of Baida was subjected to folding, faulting and uplifting. Recent erosion has cut down the solid rocks leaving capping on the interfluves.

Geomorphologically, the Beida Formation can be easily recognized by its soft rounded features, light colors and encrusted surface. Conglomerates of the formation include boulders of various lithologies such as nummulitic limestone, chert, dolomite and sandstone. They are well cemented by calcite. Away from the margins, the formation consists of thin–bedded and laminated marl of a variety of colors with intercalations of hard white fossiliferous limestone. The lenses of conglometartes and the margins of the formation has good aquiferous characteristics. Intercalated marls act as a confining aquiclude.

1.7.2.2 .2 Jenin Subseries (Eocene Aquifer):

It consists of Eocene aged rocks that are most of the wells in Marj Na'ja and Az Zubiedat Studied occupied by this formation.

In this formation five different limestone and chalk faces are recognized within the Jenin Subseries: chalk with minor chert, chalk with minor interbedded chalk, bedded massive nummulitic limestone and highly karstified reef limestone faces. The total thickness of this formation is about 500 m. Rocks of the Jenin subseries are caved and have joints, therefore they are considered as a major aquifer.

1.7.2.3 Cretaceous Rocks:

The main important formation in cretaceous rocks which are related to the study area Jerusalem formation that covers other wells in F.B.D and Ramali formation that is presented in Wadi Al Malleh

1.7.2.3.1 Jerusalem Formation:

This formation belongs to the Turonian period. It is exposed in the west along the axial area of the Anabta anticline and in narrow strips flanking the Far'a anticline. It consists mainly of massive limestone, dolomite and, sometimes chalk. The formation varies in thickness and lithology and has a thickness of about 50-100 m.

Hydrogeologically this formation can be considered to be good aquifer. The presence of chalk faces in the western part reduces its hydraulic potential in these areas.

1.7.2.3.2 Ramali Formation:

The Ramali Formation consists of sandstone series occurring between the base of the Beit Kahil and the Malleh formations. The Ramali formation is exposed in the core of the Judean anticline in three distinct areas. The three exposures of the formation resulted from fault scarps. The most extensive outcrop is in wadi Malleh area where the sandstone is the main component. The two other exposures of this formation are in wadi Far'a and Luhuf Jadir and are composed mainly of a prominent craggy limestone.

The thickness of the formation reaches 290 metes in Wadi Malleh where it consists mainly of sandstone. The lower 60 meters of the formation in Wadi Malleh consist of

agglomerates and basalts. Ramali formation is an excellent aquifer, the cemented sandstone is well jointed and the bulk of the sand is porous. In Wadi Malih the rocks at the base are possibly of lowest Neocomian age and could extend down in to the Upper Jurassic Owing to the contact being obscured it must remain a matter for speculation as to whether a stratigraphical.

1.7.2.4 Jurassic Rocks:

The oldest rocks on the west Bank are exposed in Wadi Malleh, and composed mainly of limestone. Jurassic rocks are divided into the following formations:

1.7.2.4.1 Upper Malleh Formation:

The lower part of this formation is marked with marl and chalky limestone, while chalk and chalky limestone mark the upper part. The limestone of the lower formation is suddenly transformed from massive to a sharp topographic feature.

the formation is mostly an a quiclude containing chalk and chalky limestone distributed regularly throughout its sequence Narrower bands of grey weathered coarse limestone are however generally karstified and could act as minor aquifers

1.7.2.4.2 Lower Malleh Formation:

It consists mainly of limestone, which is affected by instrustive basalt. The limestone is massive and it has a light-brown color which is due to limonate. The formation is marked with vertical joints.

1.7.3 Groundwater Basins:

The general groundwater flow direction in this system is to the east and southeast towards the Jordan Valley and the Dead Sea. The Study Area overlies sub-basin of the Eastern Aquifer System, which is Auja-Fasayel Sub-basin that drains the Neogene/Pleistocene and Upper Cenomanian aquifers and flows towards the southeast direction (Figure1.13).

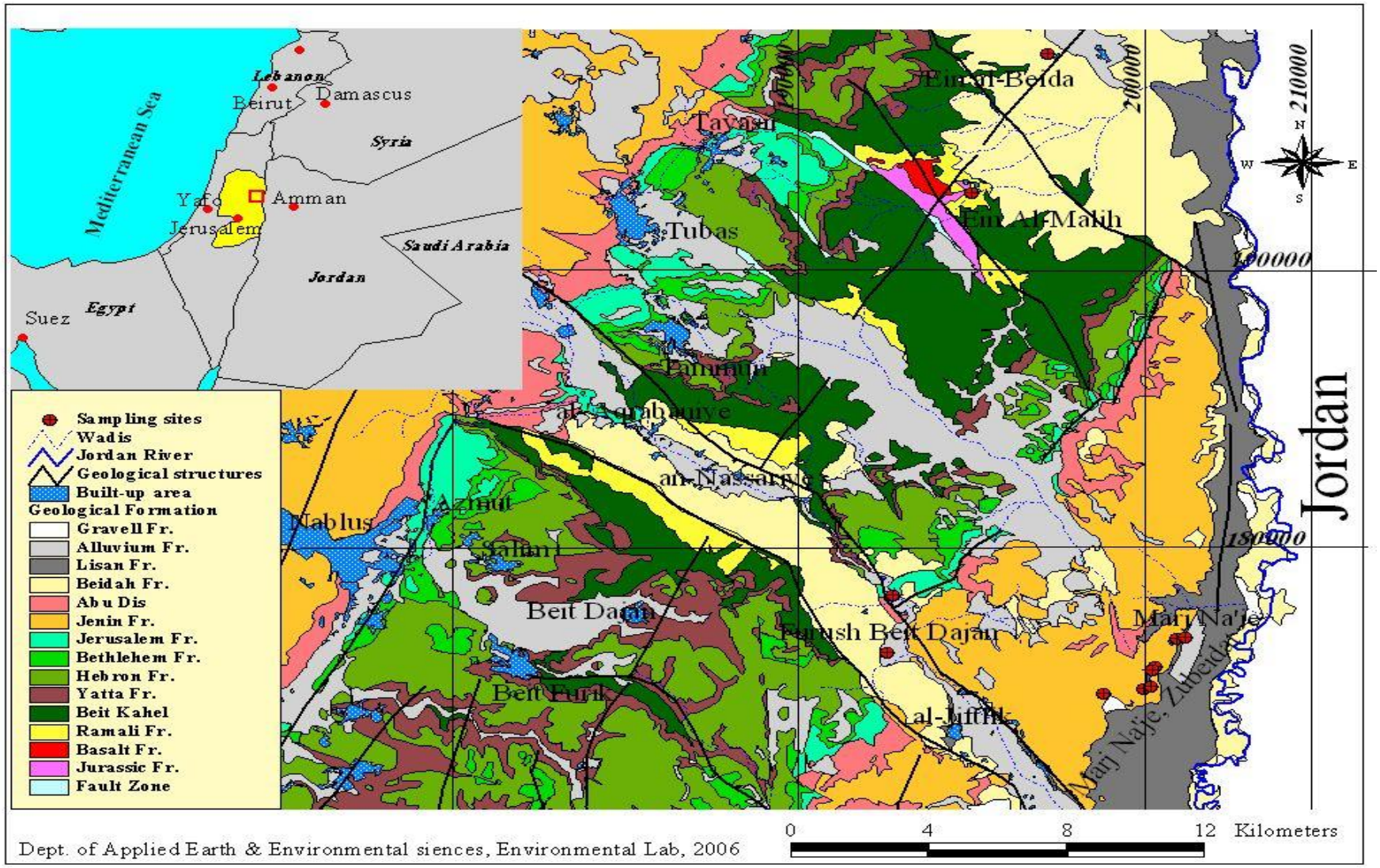

Figure (1.12): Geology of Marj Na'ja Study Area (Environmental Research Laboratory of Al – Quds University, 2006)

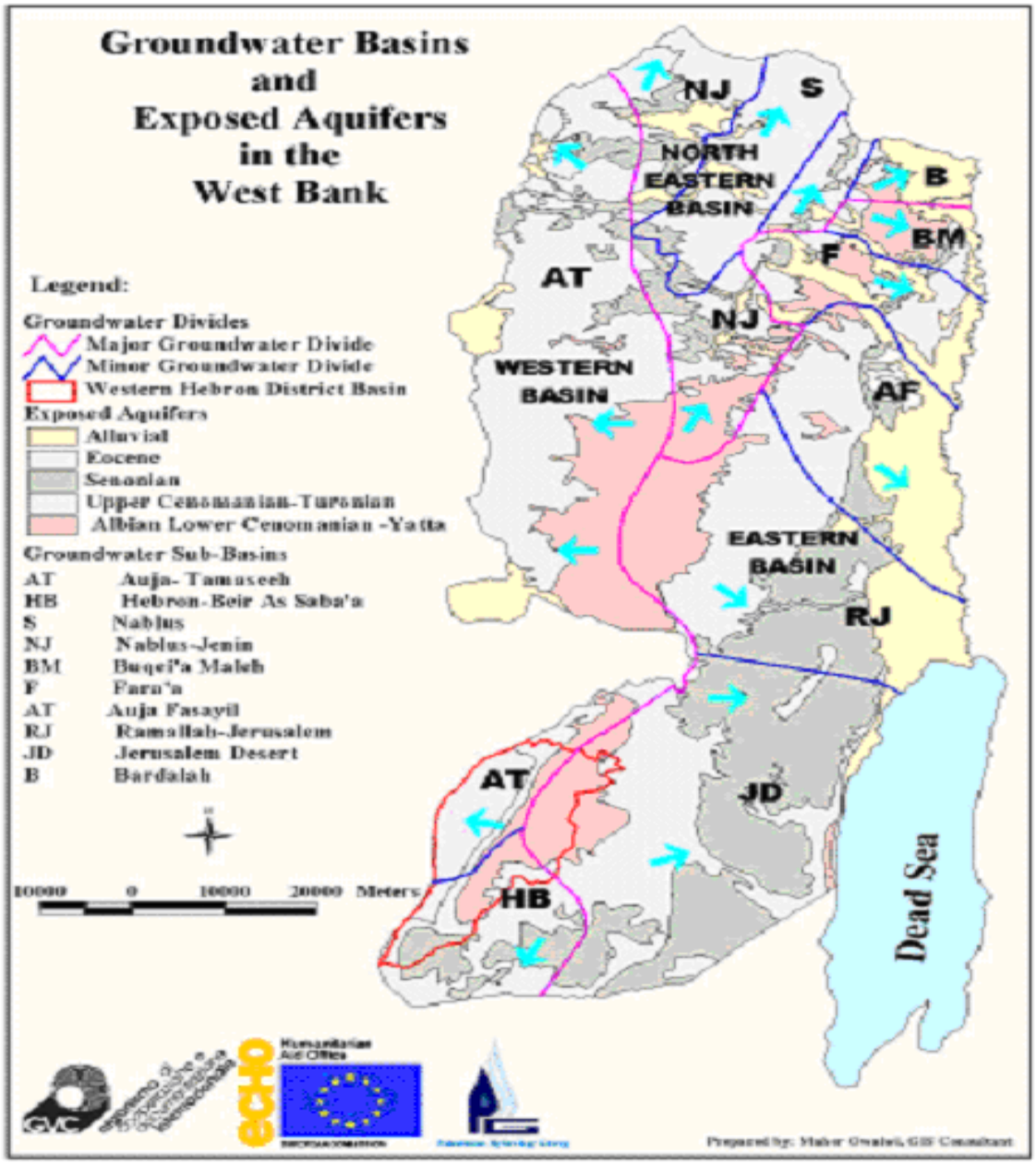

Figure (1.13): Groundwater Basins and Exposed aquifers in the West Bank/Palestine (modified after P.H.G, 2005; Arij, 1998 and Rofe and Raffety, 1963, 1965)

CHAPTER TWO

METHODOLOGY

2.1 Setting and Time of Sample collection

Eleven wells and springs were chosen along the study area. These locations are Marj Na'ja, Az Zubiedat, Frush Bait Dajan (F.B.D), Al –Himmah, Wadi Maleh Cold and Wadi Al Maleh Warm (East and West).

To achieve the objectives of study and cover all study area the wells and springs of the Marj Na'ja Area in Jericho district were divided into four groups according to their geographical location as follows:

Group 1 = Marj Na'ja and Az Zubiedat)
Group 2 = Frush Bait Dajan (F.B.D)
Group 3 = Al Himmah (AC/030A)
Group 4 = Al Maleh Warm (East and West) and Al Maleh Cold (AC/041)

Water samples were collected in two years intervals, the first period started near the end of dry season (July 2003), while the second period started at wet seasons (January 2004).

2.2 Field Work

2.2.1 Preparation of Sampling Bottles:

Two clean bottles of one-liter isopropalene were used for collecting samples for chemical analysis.

2.2.2 Sampling:

The bottles of samples were filled by direct flow of the spring water into the bottle. The wells were sampled with the help of the installed pumps. Before sampling the wells and the water was allowed to flow for few minutes before the samples were taken.

All the bottles were first rinsed with the water intended for sampling and then filled completely and placed in an ice box until arrival at the laboratory.

2.2.3 Field Measurements:

Direct measurements were made at each site with a Mettler Toledo field set of probes, giving readings for temperature, electrical conductivity (EC) and pH**.**

2.3 Laboratory Analysis

In the laboratories Biological and Chemical analysis center and the laboratories of the Department of Earth and Environmental Sciences of Al–Quds University, the samples

were analyzed according to the standard methods for the examination of water and waste water (American Public Health Association 1995) for the major ions Calcium (Ca^{2+}), Magnesium (Mg^{2+}), Sodium (Na^{+}), Potassium (K^{+}), Bicarbonate (HCO_3^{-}), Chloride (Cl^{-}), Sulphate (SO_4^{2-}) and Nitrate (NO_3^{-}). A list of the analytical methods used for determining the various parameters is shown in Table (2.1)

Table (2.1): Analytical Methods used in the Determination of the Various Parameters Analysis

Parameter	Method of Analysis
Temperature, DO, EC and pH–value	Field multi – electrode metre (Mettler Toledo)
Ca^{+2}	Titration with Na_2 – EDTA using Murexide indicator
Total hardness (Ca^{+2} and Mg^{+2})	Titration with Na_2 – EDTA using Eriochrome back – T indicator
Na+ and K+	Flame Photometre
Alkalinity (CO_3^{-2}/HCO_3^{-})	Titration with HCl using phenolphthalein and bromocresol – green indicators
SO_4^{-2}	Turbidmiteric method, Spectrophotpometre (λ=220nm)
Cl^{-}	Titration with $AgNO_3$ using potassium chromote indicator
$NO3^{-}$	UV – Spectrophotometric method (λ=220nm)

2.4 Correctness of the analyses

The correctness of the analysis was tested based on electrical balance, which was calculated as:

Ionic Balance % =[(total cations-total anions)/(total cations+total anions)]*100%

Applying this equation on the results leads to difference of less than 5 %, which is considered to be acceptable.

2.5 Data Presentation

Graphical and statistical methodologies were used to present water samples as explained below.

2.5.1 Graphic presentations:

Graphic representations are useful for interpret the results especially where more than few analysis are involved, for comparing analyses, and for emphasizing similarities and differences. Graphs can also aid in detecting the mixing of water of different compositions and in identifying chemical processes occurring as groundwater moves.
Graphical presentation of samples includes the diagrams of Piper, Durov, Schoeller, and Wilcox

2.5.1.1 Piper diagram:

Based on the four main cations (calcium, magnesium, and sodium+ potassium) and the four main anions (bicarbonate, sulfate, chloride and nitrate), Piper (1944) proposed a trilinear diagram that permits the interpretation of hydrochemical processes. Langguth (1966) used the Piper diagram and suggests a classification of water according to its chemistry into seven types as shown in Figure2.1. Samples were plotted on the diagram using GWW and Aquachem 3.70 software

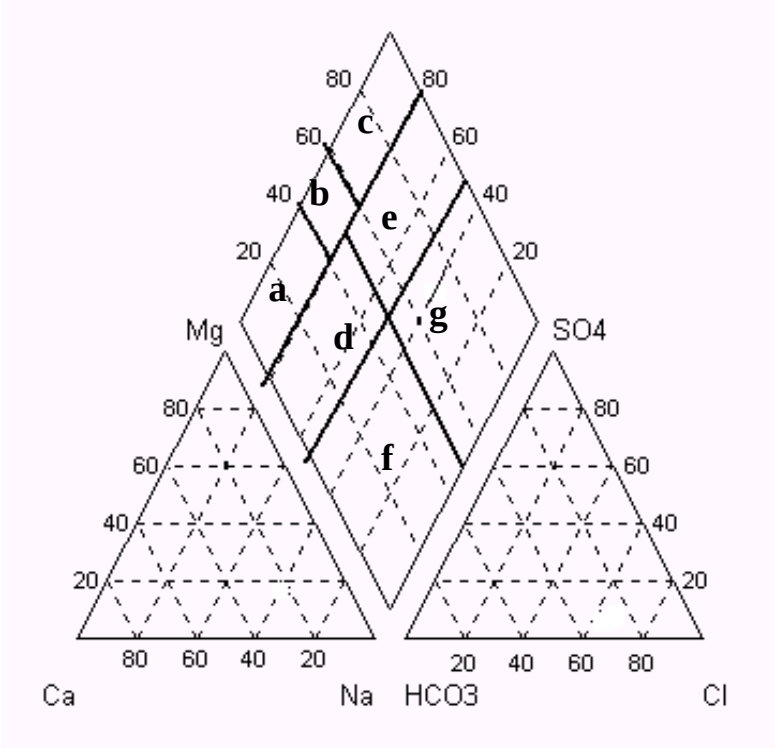

Figure (2.1): Piper Trilinear Diagram

Water Types:

Normal earth alkaline water

a: with prevailing bicarbonate
b: with prevailing bicarbonate and sulfate or chloride
c: with prevailing sulfate or chloride

Earth alkaline water with increased portions of alkalis

d: with prevailing bicarbonate
e: with prevailing sulfate and chloride

Alkaline water

f: with prevailing bicarbonate
g: with prevailing sulfate-chloride

2.5.1.2 Durov diagram:

Durov diagram (Figure 2.2) is based on the percentage of the major ions' in meq/L. Both the positive and the negative ion percentages total 100 %. The values of the cations and the anions are plotted in the appropriate triangular and projected into the square of the main field (Durove, 1948). The advantage of this diagram over that of Piper diagram displays some possible geochemical processes that could affect the water genesis (Qannam, 2003).

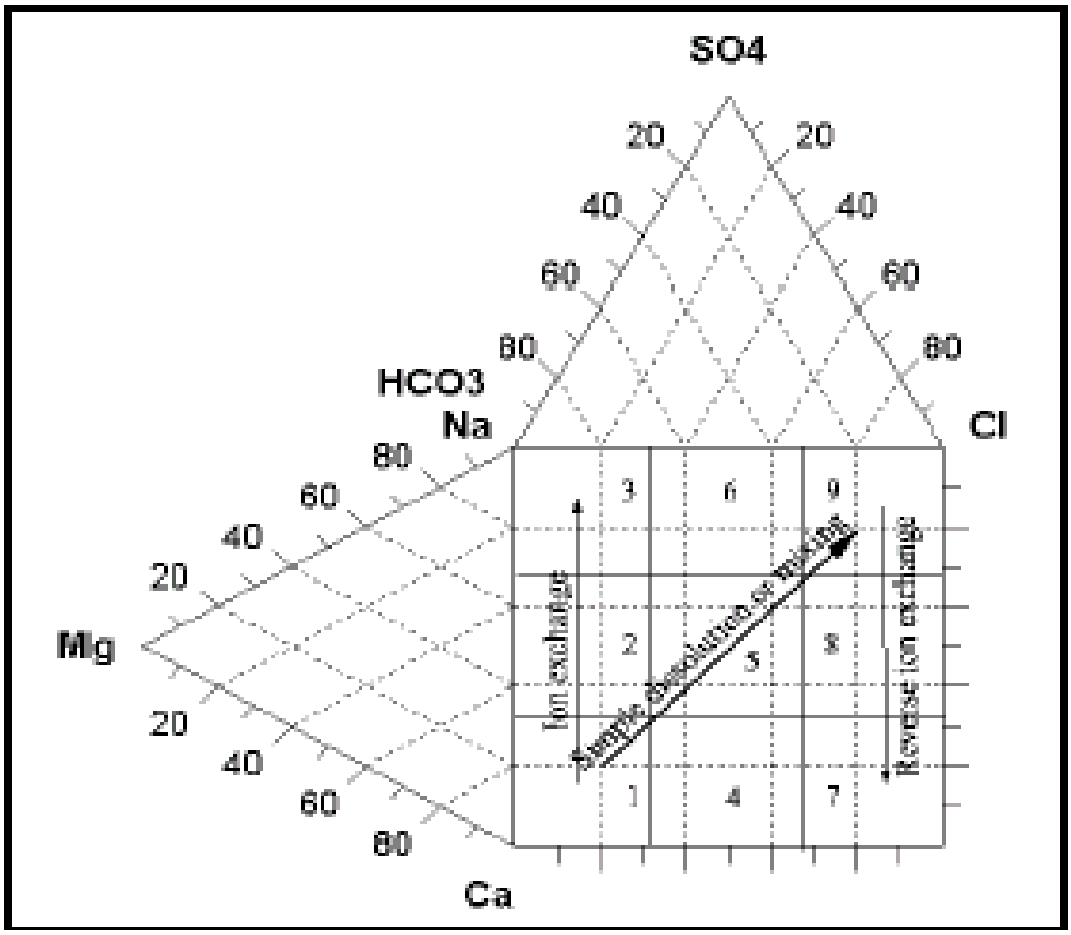

Figure (2.2): Durov diagram for the major cations and anions

Below a summary about the theory behind the divisions in the diagram is given (Lloyd and Heathcoat, 1985):

Field (1): HCO_3 and Ca dominant, frequently indicates recharging waters in limestone, sandstone, and many other aquifers.

Field (2): This water type is dominated by Ca and HCO_3 ions. Association with dolomite is presumed if Mg is significant. However, those samples in which Na is significant, an important ion exchange is presumed.

Field (3): HCO_3 and Na are dominant, indicates ion exchanged water, although the generation of CO_2 at depth can produce HCO_3 where Na is dominant under certain circumstances.

Field(4): SO_4 dominates, or anion discriminant and Ca dominant, Ca and SO_4 dominant, frequently indicates a recharge water in lava and gypsiferous deposits, otherwise a mixed water or water exhibiting simple dissolution may be indicated.

Field (5): No dominant anion or cation, indicates water exhibiting simple dissolution or mixing.

Field (6): SO_4 dominant or anion discriminant and Na dominant; is a water type that is not frequently encountered and indicates probable mixing influences.

Field (7): Cl and Na dominant is frequently encountered unless cement pollution is present. Otherwise the water may result from reverse ion exchange of Na-Cl waters.

Field (8): Cl dominant anion and Na dominant cation, indicate that the ground waters be related to reverse ion exchange of Na-Cl waters.

Field (9): Cl and Na dominant frequently indicate end-point waters.

2.5.1.3 Schoellar diagram:

Semi-logarithmic diagrams were developed by Schoellar (1962) to present major ion analysis in milliequivalent per liter and to demonstrate different hydrochemical water types on the same diagram (Figure2.3). The diagram has one advantage over the more universally used trilinear diagram in that actual parameter concentrations are given.

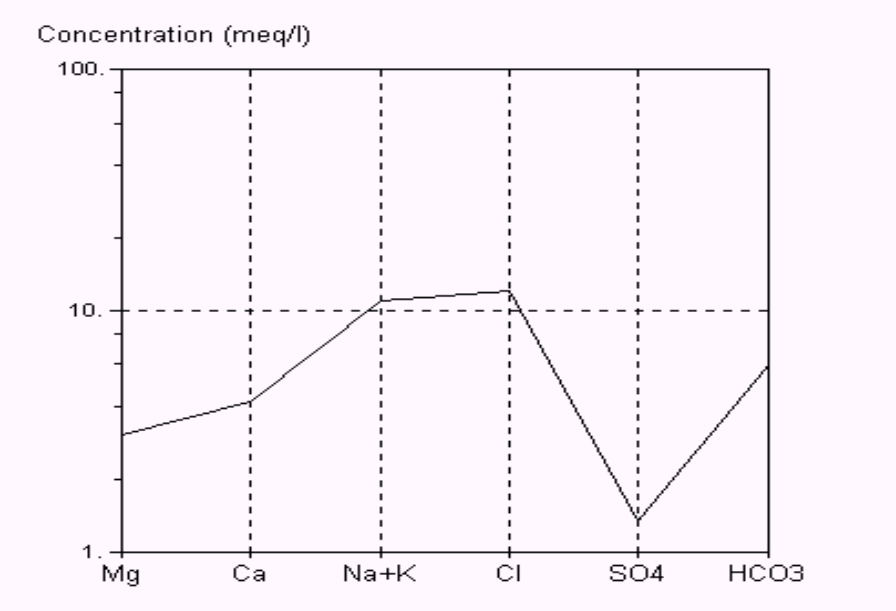

Figure (2.3): Schoellar diagram

2.5.2 Software used in this study:

The data analyses was carried out using various software packages:

Statistical calculations were conducted using the statistical software packages SPSS 11 for Windows (2000).

Aquchem3.7 (1997) for Windows -1999 (Calmbach, 1995) and Groundwater Software for Windows GWW (United Nations, 1995) for graphical presentation of data.

The saturation indices (SI) of the sampled collected in this study were calculated for the major mineral phases using the software package (PHREEQC for windows version 1.5.08) (Rollins, 1988).

CHAPTER THREE

RESULTS AND DISCUSSIONS

3.1 SAMPLE DISTRIBUTION

To achieve the aims of the study, three field trips of water sampling of groundwater sources were done. These sampling episodes were conducted during three different seasons to achieve specific objectives of the study as follows: First during summer seasons at July and August 2003, when groundwater recharge is low and pumping from wells for various purposes is at its peak. Second during winter seasons at January 2004, when groundwater recharge is existent, a long drought period has passed and so large amounts of water had been pumped from wells. Third during spring seasons at May 2004, when groundwater recharge from rainfall is at peak and water pumping from wells is low.

Table (3.1) shows the number of samples collected during different three periods. While Table (3.2 A & B) shows the number of samples collected from different sites of study area.

Table (3.1): Distribution of Sample Collected by Date

N	Date	NO. of samples collected
1-	10/07/2003	7
2-	04/08/2003	4
3-	09/01/2004	11
4-	11/01/2004	2
5-	14/05/2004	14
	TOTAL	**38**

Table (3.2 A): Distribution of Sample Collected by Location from the Wells

Groups	Well -ID	No. of Samples	Location	No. of Samples from each group
Group 1	19-17/011	3	Az Zubeidat	20
	19-17/020	3	Az Zubeidat	
	20-17/010	3	Marj Na'ja	
	20-17/011	2	Marj Na'ja	
	20-17/016	3	Marj Na'ja	
	20-17/018	3	Marj Na'ja	
	20-17/019	3	Marj Na'ja	
Group2	19-17/034	2	Frush Bait Dajan	5
	19-17/046	3	Frush Bait Dajan	
	Total sample	**25**		

Table (3.2 B): Distribution of Sample Collected by Location from the Springs

Groups	Spring-ID	No. of Samples	Name	Location	No. of Samples from each group
Group3 AC/030A	AC/030A	3	Al Himmah	Bardalah	3
Group 4 AC/041	AC/041-E	3	Al Maleh Warm	Bardalah	10
	AC/041-W	3	Al Maleh Warm	Bardalah	
	AC/041-C	4	Al Maleh Cold	Bardalah	
	Total sample	**13**			

3.2 GENERAL CHARACTERISTICS OF SAMPLES

In order to interpret the chemical parameters descriptive statistics including minimum, maximum, and average of different physical water quality parameters for the water samples were used.

3.2.1 All samples (General):

Thirty-eight samples from the nine wells and four springs of the Marj Na'ja Area (Marj Na'ja and Az Zubiedat wells, Al Himmah and Al Maleh Springs) were collected and analyzed for this study. These wells and springs are distributed throughout the study area.
The results show a great diversity in the chemical and physical characteristics of the wells and springs. The EC ranges between 663 µS/cm and 7580 µS/cm, which reflect significant variations in the concentrations of most of the major ions, also TDS ranges between 435.6 mg/L and 3488.2 mg/L.
Calcium ranges between 68.1 mg/L and 365.5 mg/L, while sodium ranges between 65 mg/L and 798.8 mg/L. The anions show the same trend of variation as the bicarbonate and chloride ranges, between 244 and 463.7 mg/L and 99 and 1765.5 mg/L, respectively (Table 3.3).

Table (3.3): Descriptive statistics of physical and chemical parameters of All Samples of Marj Na'ja Area

Variable	Minimum	Maximum	Average	Std. Deviation
Temp (^{0}C)	17.8	35.3	28.32	3.69
EC (µS/cm)	663	7580	3392.34	1937.4
TDS (mg/L)	435.6	3488.2	1870.2	936.9
pH	6.65	7.49	7.12	0.19
Ca^{2+} (mg/L)	68.1	365.5	156.0	85.0
Mg^{+2} (mg/L)	20.9	175	88.2	41.5
Na^{+} (mg/L)	65	798.8	403.7	211.5
K^{+} (mg/L)	0.61	209.9	31.9	40.7
HCO_3^{-} (mg/L)	244	463.7	315.3	44.9
SO_4^{2-} (mg/L)	27.3	520	187.7	131.9
Cl^{-} (mg/L)	99	1765.5	819.3	482.9
NO_3^{-} (mg/L)	5.2	114.9	26.0	20.7

On piper diagram, the most abundant water type of the study is the "Alkaline water with prevailing sulfate – chloride". Other samples of wells and springs plot on a piper diagram in area of "Earth alkaline water with increased portions of alkalis with prevailing sulfate and chloride" and other few samples have "Earth alkaline water with increased portions of alkalis with prevailing bicarbonate" (Figure 3.1)

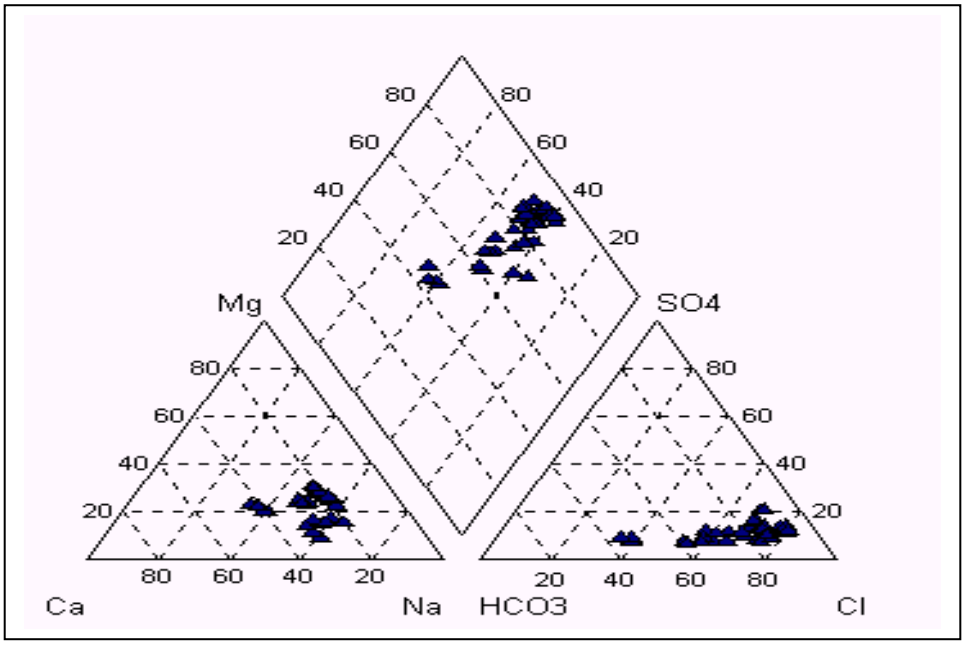

Figure (3.1): Piper Diagram showing the Springs and Wells of the Study Area

3.2.2 The Wells of Marj Na'ja and Az Zubiedat:

Twenty samples representing seven wells used for agricultural purposes were considered in this study. Most of the wells of this group extract water from the Eocene aquifer system. Other wells of this group extract their water from either the Pleistocene aquifer or the Holocene aquifer.

The wells of Marj Na'ja and Az Zubiedat range widely in their EC values between 2230 µS/cm and 5550 µS/cm, TDS from 1290.1 mg/L to 3182.6 mg/L. The wells in this area range in their Calcium from 95 mg/L to 210.2 mg/L and sodium from 300.5 mg/L to 619 mg/L.

However, the anions show a trend of variation as the bicarbonate and chloride ranges, between 280.6 and 353.9 mg/L and 498 and 1304.6 mg/L, respectively. Nitrate values ranges between 5.2 and 45 mg/L (Table 3.4). Detailed physical and chemical characteristics of Marj Na;ja and Az Zubiedat wells are shown in Appendix (3.1)

Table (3.4): Descriptive Statistics of Physical and Chemical Parameters of Marj Na'ja and Az Zubiedat Wells

Variable	Minimum	Maximum	Average	Std. Deviation
Temp (^{0}C)	26.5	29.9	28.6	1.0
EC (µS/cm)	2230	5550	3709.5	921.1
TDS (mg/L)	1290.1	3182.6	2016.3	506.7
pH	6.96	7.48	7.14	0.13
Ca^{2+} (mg/L)	95	210.2	143.71	33.3
Mg^{+2} (mg/L)	70.9	175	115.7	28.2
Na^{+} (mg/L)	300.5	619	434.7	95.3
K^{+} (mg/L)	17.4	209.9	44.1	50.5
HCO_3^{-} (mg/L)	280.6	353.9	317.7	21.1
SO_4^{2-} (mg/L)	98.7	520	212.7	115.1
Cl^{-} (mg/L)	498	1304.6	883.5	213.7
NO_3^{-} (mg/L)	5.2	45	23.2	8.6

This group is presented by the wells of Marj Na'ja and Az Zubiedat. On Piper diagram, the most abundant water type of the wells of this is "Alkaline water with prevailing chloride". However, few sample of wells of this group plot on piper diagram in the area of "Earth alkaline water with increased portions of alkalis with prevailing chloride" (Figure 3.2)

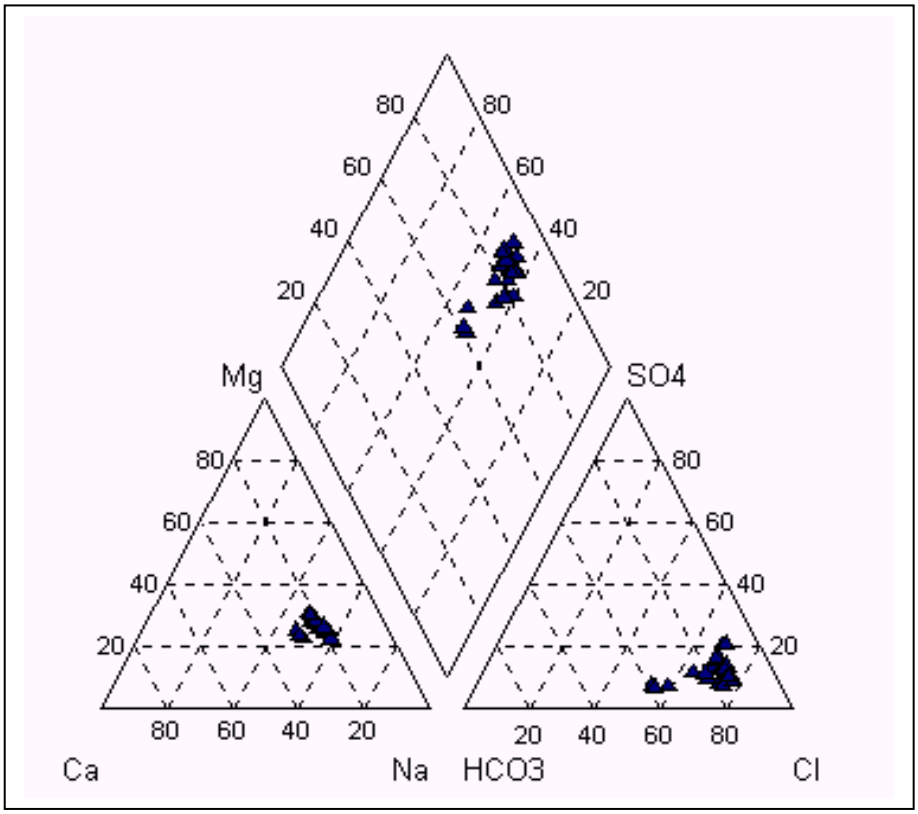

Figure (3.2): Piper Diagram showing the wells of Marj Na'ja and Az Zubiedat

3.2.3 The Wells of Frush Bait Dajan (F.B.D):

Five samples representing two wells used for agricultural purposes were considered in this study. These wells extract water from the Upper Cenomania Turonian aquifer system and the Holocene Aquifer system.

The wells of the Frush Bait Dajan vary widely in their EC values, from 788 to 2430 µS/cm, TDS from 1098.5 to 1512.3 mg/L, Calcium ranges between 84.1 and 141 mg/L, sodium ranges between 232.8 and 305.6 mg/L.

Also, the anions show the same trend of variation as the bicarbonate and chloride ranges, between 341 and 463.7 mg/L and 430 and 503 mg/L, respectively. However, nitrate values ranges between 41.8 and 114.9 mg/L (Table 3.5). Detailed physical and chemical characteristics of F.B.D wells are shown in Appendix (3.2).

Table (3.5): Descriptive statistics of physical and chemical parameters of Frush Bait Dajan (F.B.D)

Variable	Minimum	Maximum	Average	Std. Deviation
Temp (^{0}C)	20.6	25.9	23.74	2.27
EC (µS/cm)	788	2430	1732.8	846.7
TDS (mg/L)	1098.5	1512.3	1259.0	154.5
pH	6.83	7.39	7.13	0.20
Ca^{2+} (mg/L)	84.1	141	112.6	26.7
Mg^{+2} (mg/L)	37	75.3	55.01	17.1
Na^{+} (mg/L)	232.8	305.6	269.0	32.2
K^{+} (mg/L)	3.2	12.9	7.4	3.7
HCO_3^{-} (mg/L)	341	463.7	387.9	50.6
SO_4^{2-} (mg/L)	65	135.9	93.8	29.1
Cl^{-} (mg/L)	430	503	459.9	31.4
NO_3^{-} (mg/L)	41.8	114.9	67.5	29.5

The water of the wells studied in this group was of two types. The "Earth alkaline water with increased portions of alkalis with prevailing chloride" was presented by the water samples of well code (19-17/046). While the samples of well code (19-17/034) shows "Alkaline water with prevailing chloride" (Figure 3.3 & 3.4)

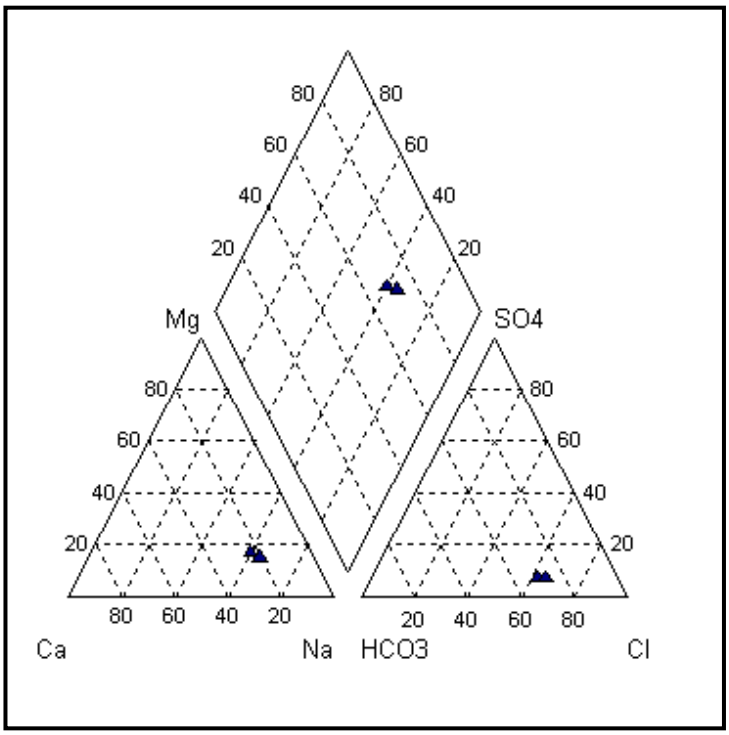

Figure (3.3): Piper Diagram showing the wells of F.B.D (19-17/034)

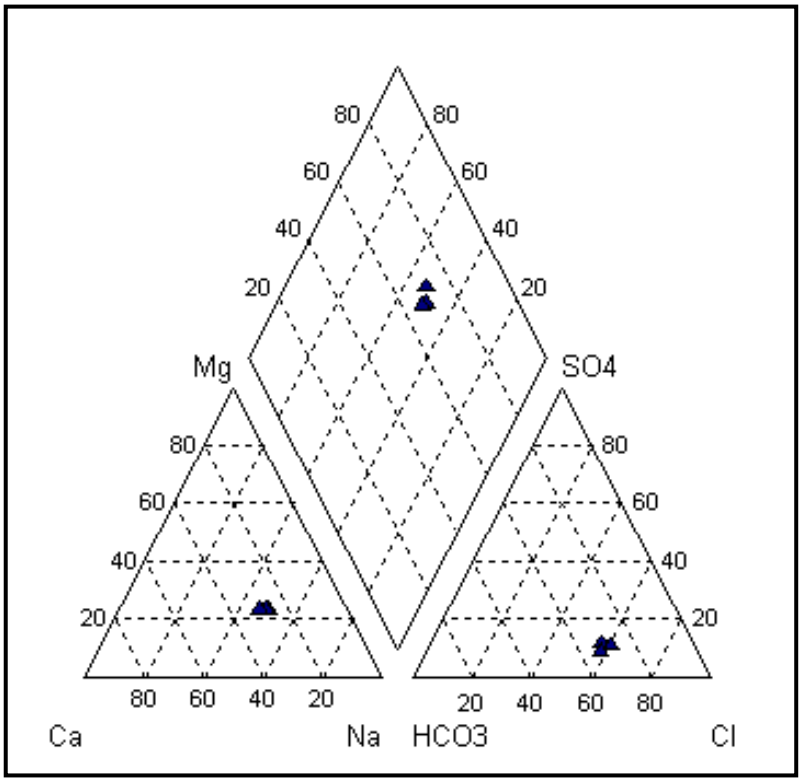

Figure (3.4): Piper Diagram showing the wells of F.B.D (19-17/046)

3.2.4 Spring of Al Himmah:

Three samples of different dates representing Al Himmeh spring in Bardala were collected. This spring discharges water from Neogene Aquifer. The samples of this spring show little variation in the various parameters, EC ranges between 1225 and 1505 µS/cm, while TDS ranges between 763.2 and 828.4 mg/L.

Calcium, sodium, chloride, bicarbonate and nitrate ranges between 76.3 to 80.2 mg/L, 145.7 to 169 mg/L, 283.6 to 294.4 mg/L, 292.9 to 360 mg/L and 6.72 to 13.2 mg/L, respectively (Table 3.6) Detailed physical and chemical characteristics of Al Himmah Spring is shown in Appendix (3.3)

Table (3.6): Descriptive statistics of physical and chemical parameters of Al Himmah Spring

Variable	Minimum	Maximum	Average	Std. Deviation
Temp (^{0}C)	27.2	31.7	29.93	2.40
EC (µS/cm)	1225	1505	1399	151.9
TDS (mg/L)	763.2	828.4	795.8	32.6
pH	7.21	7.31	7.3	0.05
Ca^{2+} (mg/L)	76.3	80.2	78.6	2.04
Mg^{+2} (mg/L)	39.9	41.1	40.3	0.72
Na^{+} (mg/L)	145.7	169.0	157.2	11.7
K^{+} (mg/L)	4.7	6.9	5.7	1.11
HCO_3^{-} (mg/L)	292.9	360.0	331.5	34.7
SO_4^{2-} (mg/L)	45	55.0	49.0	5.3
Cl^{-} (mg/L)	283.6	294.4	289.1	5.4
NO_3^{-} (mg/L)	6.72	13.2	10.1	3.3

On piper diagram the water of this spring is "Earth alkaline water with increased portions of alkalis with prevailing chloride" (Figure 3.5)

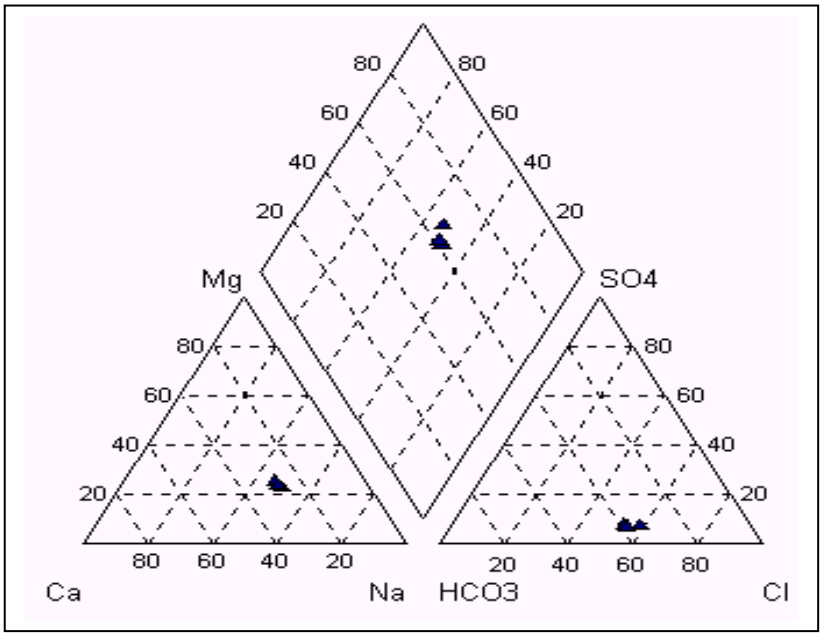

Figure (3.5): Piper Diagram showing the spring of Al Himmah

3.2.5 Springs of Al Maleh:

Ten samples representing three different locations of Wadi Al Maleh springs (East, West, and Cold) were collected for this study. The samples of this groups show a great diversity of physical and chemical parameters especially in Temp. The average temperature. of Al Maleh West and East was 33.8 ^{0}C while the average temperature of Al Maleh cold was 23.53 ^{0}C.

According to the great variation in average temperature, samples of Al Maleh were divided into two subgroups which are Al Maleh Cold and Al Maleh Warm (East and West).

3.2.5.1 Al Maleh Warm:

The springs of Al Maleh Warm are characterized by high EC values (5180 – 7580 µS/cm) and high concentration of calcium, magnesium, sodium, potassium, and chloride.

Chloride and sodium ranges between 1512 to 1765.5 mg/L and 709.5 to 798.8 mg/L, respectively (Table 3.7).

Calcium, bicarbonate and nitrate ranges between 298.1 to 365.5mg/L, 244.1 to 311.2 mg/L and 6.3 to 20.7 mg/L, respectively (Table 3.7) Detailed physical and chemical characteristics of Al Maleh springs are shown in Appendix (3.4)

Table (3.7): Descriptive statistics of physical and chemical parameters of Al Maleh Warm

Variable	Minimum	Maximum	Average	Std. Deviation
Temp (^{0}C)	30.0	35.3	33.8	2.01
EC (µS/cm)	5180.0	7580.0	6505.0	1015.9
TDS (mg/L)	3236.0	3488.2	3377.5	83.8
pH	6.7	7.0	6.9	0.14
Ca^{2+} (mg/L)	298.1	365.5	329.3	23.0
Mg^{+2} (mg/L)	60.8	109.4	92.1	19.9
Na^{+} (mg/L)	709.5	798.8	755.8	38.7
K^{+} (mg/L)	32.3	50.4	44.5	7.0
HCO_3^{-} (mg/L)	244.1	311.2	278.7	24.6
SO_4^{2-} (mg/L)	321.7	390.0	356.9	22.9
Cl^{-}(mg/L)	1512.0	1765.5	1646.5	85.3
NO_3^{-}(mg/L)	6.3	20.7	12.9	6.2

On piper diagram, the water samples of Al Maleh Warm plot on piper diagram in the area "Alkaline water with prevailing – chloride" (Figure 3.6)

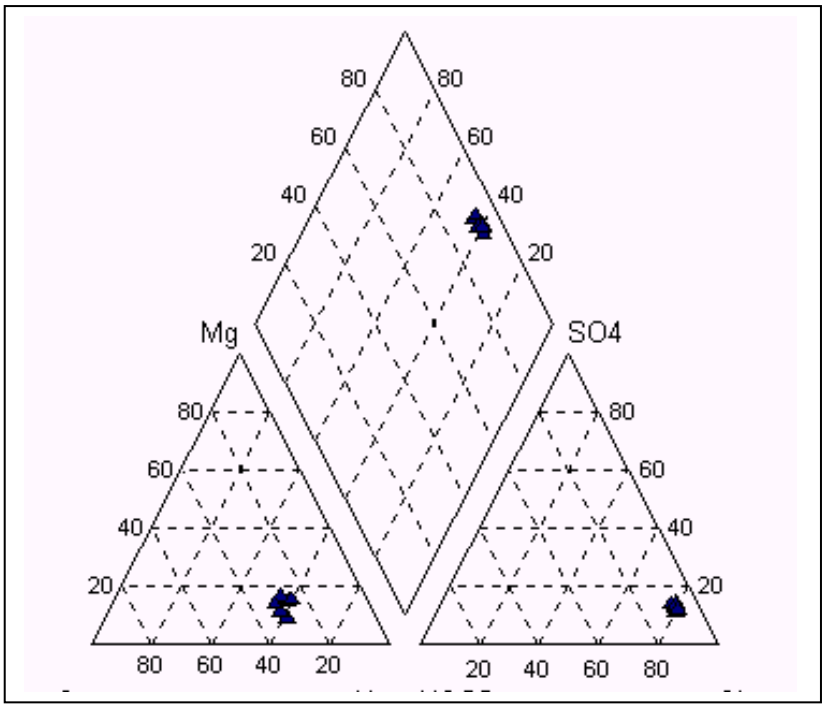

Figure (3.6): Piper Diagram showing the spring of Al Maleh Warm

3.2.5.2 Al Maleh Cold:

The samples of the cold spring of Al Maleh are characterized by medium EC values (663 – 743 µS/cm) and relatively high concentrations of sulfate and nitrate.

Chloride and sodium ranges between 99 to 11.2 mg/L and 65 to 81.8 mg/L, respectively. Calcium, bicarbonate and nitrate ranges between 68.1 to 70.5 mg/L, 244 to 268.9 mg/L and 17.2 to 25.2 mg/L, respectively (Table 3.8). Detailed physical and chemical characteristics of Al Maleh cold are shown in Appendix (3.5)

Table (3.8): Descriptive statistics of physical and chemical parameters of Al Maleh Cold

Variable	Minimum	Maximum	Average	Std. Deviation
Temp (^{0}C)	17.8	26.6	23.5	4.1
EC (µS/cm)	663	743	707.0	33.2
TDS (mg/L)	435.6	461.2	448.9	11.9
pH	7.19	7.49	7.37	0.13
Ca^{2+} (mg/L)	68.1	70.5	69.1	1.20
Mg^{+2} (mg/L)	20.9	23.0	21.8	1.1
Na^{+} (mg/L)	65.0	81.8	74.1	7.8
K^{+} (mg/L)	0.61	3.8	2.5	1.5
HCO_3^{-} (mg/L)	244	268.9	255.0	12.6
SO_4^{2-} (mg/L)	27.3	33	29.9	2.6
Cl^{-}(mg/L)	99.0	111.2	104.4	5.1
NO_3^{-}(mg/L)	17.2	25.2	19.7	3.8

On piper diagram, the water samples of Al Maleh cold plot on piper diagram in the area "Earth alkaline water with increased portions of alkalis with prevailing bicarbonate". (Figure 3.7)

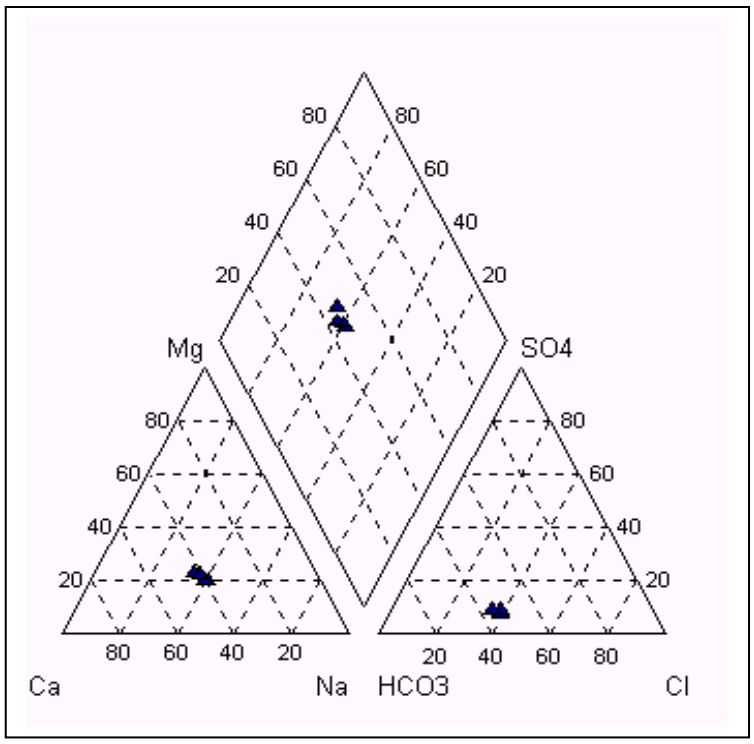

Figure (3.7): Piper Diagram showing the spring of Al Maleh Cold

3. 3 STATISTICAL ANALYSES (CORRELATION)

3.3.1 The water parameters interrelationships (Classes):

To distinguish the interrelationships among the different analyzed parameters of the water samples a linear correlation was performed (nonparametric Spearman's rank correlation coefficient was used for testing the correlation between the different variables). These interrelationships between different parameters were represented by the correlation matrix that is shown in Appendix (3.6). Based on the data appears in the correlation matrix, the interrelationships between the variables could be classified into the following classes**:**

Class (I) (very high significant relationship): This class includes all the variables that have correlation coefficient ≥0.9

Most of the variables studied in show very high significant relation. The most important relationships are as following. However, detailed variables interrelationships between different variables are presented in Appendix (3.7)

Variables	Correlation coefficient
EC µS/cm versus each of: Ca^{+2}, Na^{+}, K^{+}, Cl^{-}, SO_4^{-2}, and TDS mg/L.	0.96, 0.949, 0.914, 0.961, 0.94, and 0.967, respectively
Ca^{+2} mg/L versus each of: Na^{+}, K^{+}, Cl^{-}, SO_4^{-2}, and TDS mg/L.	0.957, 0.907, 0.964, 0.949, and 0.981, respectively
Na^{+} mg/L versus each of: K^{+}, Cl^{-}, SO_4^{-2}, and TDS mg/L.	0.939, 0.977, 0.937, and 0.985, respectively
K^{+} mg/L versus each of: Cl^{-}, SO_4^{-2}, and TDS mg/L.	0.942, 0.921, and 0.935, Respectively
Cl^{-} mg/L versus each of: SO_4^{-2} and TDS mg/L	0.933 and 0.986
SO_4^{-2}mg/L versus TDS mg/L.	0.957

Appendix (3.8) shows the high correlation between TDS and Cl^{-} with R-square of 0.98 which indicate the main salinity–controlling ions (TDS) are Cl^{-}.

The EC of the water samples were found to correlate directly with Cl^{-}, Na^{+} and Ca^{+2} with high correlation (0.91, 0.87 and 0.86 respectively) and with SO_4^{-2} with good correlation coefficient (0.76). This indicates the direct contribution of these ions in the salinity of the groundwater. The relationship between those ions and the EC were found to fit the equations in Appendix (3.8).

The correlation between Cl^{-} and Na^{+} appears in class (I) with R-square of 0.96 and this give clear picture about the origin of the majority of these ions. The halite minerals play a major rule here (Figure 3.8).

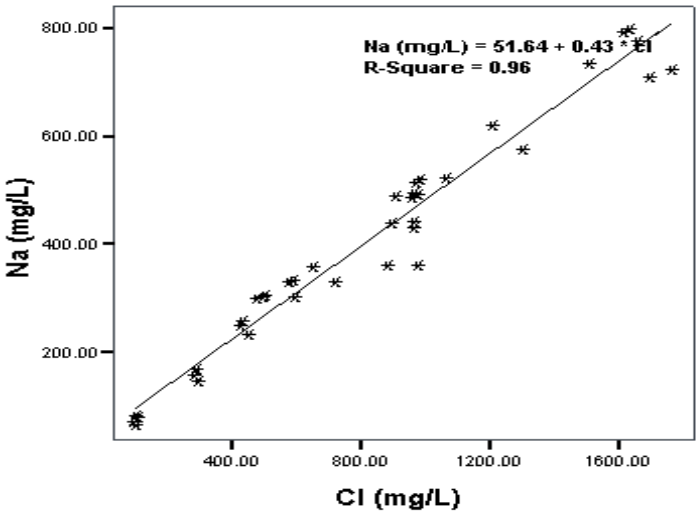

Figure (3.8): Relationship between Cl^{-} and Na^{+} in class (I) of very high significant relationship.

Class (II) (High significant relationship): This class includes all the variables that have correlation between 0.90 and 0.80

Variables	Correlation coefficient
EC (µS/cm) versus SAR	0.854
Ca^{+2} mg/L versus SAR	0.879
K^{+} mg/L versus SAR	0.862
K^{+} mg/L versus SI-gypsum and SI-anhydrite	0.897
SO_4^{-2} mg/L versus SAR	0.867
SAR versus SI-gypsum and SI-anhydrite	0.866
SAR versus Ca^{+2}/HCO_3^{-}	0.834

The relationship between different variables were found to fit the following equations (Table 3.9)

Table (3.9): The mathematical expressions of the relation between different parameters in class (II)

Mathematical expressions	R- square
EC=739.49*SAR-1143.23	0.72
Ca^{+2}=31.91*SAR-39.82	0.69
SO_4^{-2} =47.52*SAR-103.80	0.64
SAR=4.85*SI-gypsum+13.34	0.80

Class (III) (good relationship): This class includes all the variables that have correlation coefficient between 0.80 and 0.70

Variables	Correlation coefficient
EC µS/cm versus Mg^{+2} mg/L	0.745
pH versus SI-aragonite	0.703
Ca^{+2} mg/L versus Mg^{+2} mg/L	0.719
Mg^{+2} mg/L versus Na^{+} mg/L	0.722
Mg^{+2} mg/L versus K^{+} mg/L	0.765
Mg^{+2} mg/L versus Cl^{-} mg/L	0.734
Mg^{+2} mg/L versus SO_4^{-2} mg/L	0.766
TDS mg/L versus Mg^{+2} mg/L	0.746
Mg^{+2} mg/L versus Total hardness	0.779
Mg^{+2} mg/L versus SI-gypsum and SI-anhydrite	0.711
SI-gypsum versus Ca^{+2}/SO_4^{-2}	0.703

The relationship between different variables in class (III) were found to fit the following equations (Table 3.10)

Table (3.10): The mathematical expressions of the relation between different parameters in class (III) are

Mathematical expressions	R- square
EC=31.22* Mg^{+2} +640.02	0.45
Mg^{+2} =0.23* SO_4^{-2} +45.13	0.53
Mg^{+2} =0.03*TDS+29.20	0.51

Table (3.10) show that Mg^{+2} play a medium rule in the value of the TDS which appear from the distribution of the samples around the line, R-square is 0.51 (Figure 3.9)

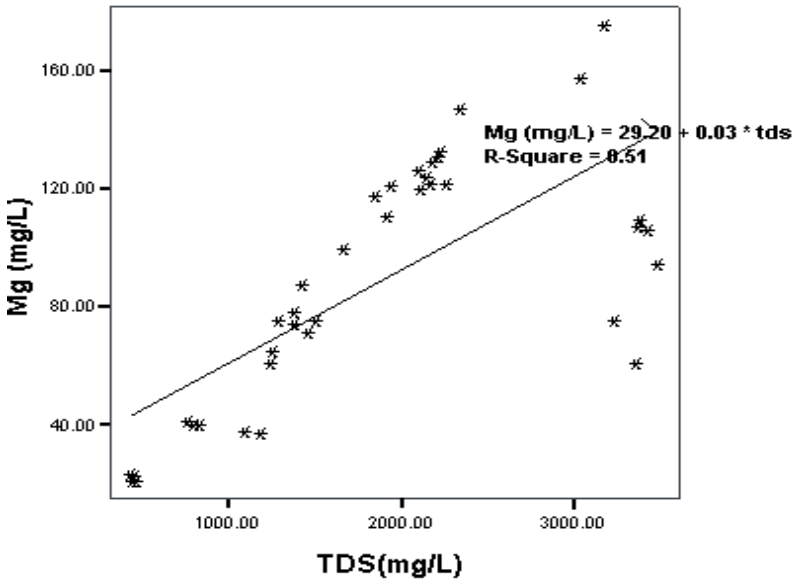

Figure (3.9): Relationship between Mg^{+2} and TDS in class (III) of good relationship

Class (IV) (Medium to poor relationships): This class includes all the variables that have correlation coefficient between <0.7, the variables which not in any of the above classes

Appendices (3.9) shows the Correlation between Na^{+}, Cl^{-}, Ca^{+2}, Mg^{+2} and SO_4^{-2} vs. TDS and EC

3.3.2 Cluster Analyses:

Cluster analysis is an exploratory data analysis tool for solving classification problems. A cluster analysis allows the grouping of groundwater samples based on their similarities in chemical composition. Its object is to sort cases into groups, or clusters, so that the degree of association is strong between members of the same cluster and weak between the members of different clusters. Each cluster thus describes, in terms of the data collected, the class to which its members belong; and this description may be abstracted through use from the particular to the general class or type. The program SPSS 11.0 for windows 2000 is used here to classify the samples in this research into clusters and here are the clusters found with the main and major correlations between the parameters of the different clusters. This method is used to group the samples of this study depending on the common characteristics between the samples using the major chemical parameters (cations and anions).

In this method the consequences of the concentration of the ions used as the similarity measures to group the higher the similarity in one group, depending on the correlations between the samples of the same group (Helena et al, 1998).

To apply this analytical methods both the excel program and SPSS 11.0 were used and four clusters appeared.

Cluster analyses presenting the grouping of the wells and springs in the study area shows that the sampled springs and wells in the study area are mainly divided into the following cluster:

3.3.2.1 Cluster (I):

This cluster includes springs that are located in Himmah and Al-Maleh Cold. This cluster includes 18.4% of the study samples with average EC of 1003.8 µS/cm. It is dominated by Sodium cation (46% of the total cation) and the Chloride anion (59% of the total anion). Detailed descriptive statistics of the hydrochemical parameters are shown in Appendix (3.10)

The main characteristics of this cluster are

$$Na^{+} > Ca^{+2} > Mg^{+2} > K^{+}$$
$$Cl^{-} > HCO_3^{-} > SO_4^{-2}$$
$$Na^{+}/Cl^{-} \leq 1$$

Where all concentrations are in (meq/L)

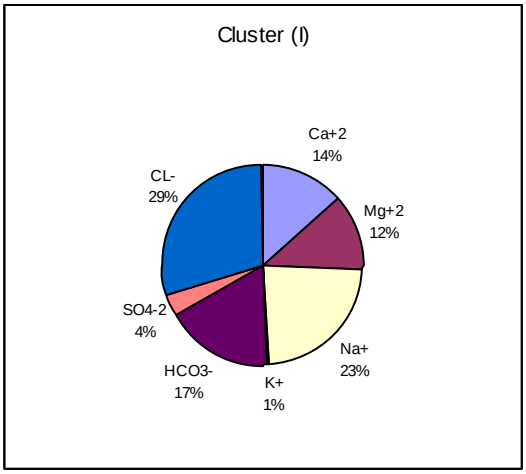

Figure (3.10): The presentation percentage graph of the Cluster (I)

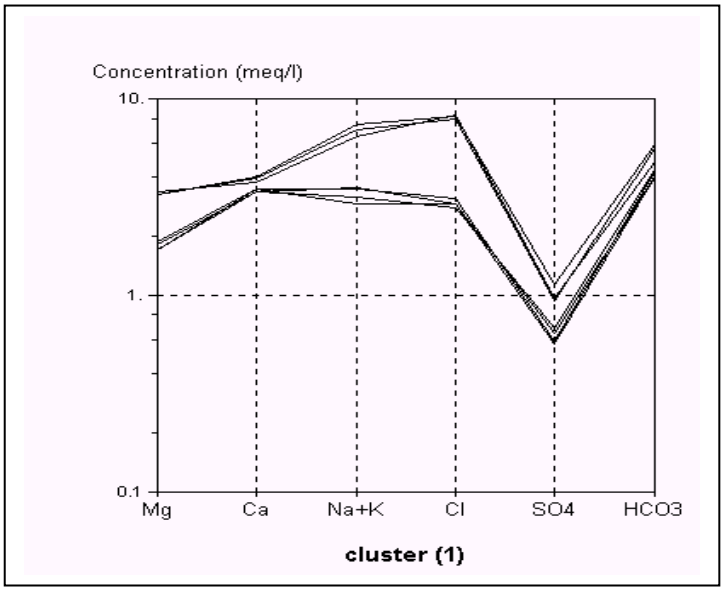

Figure (3.11): Schoeller diagram plot for the samples of cluster (I)

3.3.2.2 Cluster (II):

This cluster includes samples of wells that are located in Marj Na'ja and F.B.D. It is dominated by Sodium cation (56 % of the total cation) and the Chloride anion (70 % of the total anion). This cluster includes 28.9 % of the research samples with average EC of 2243.09 µS/cm. Appendix (3.11) show a detailed descriptive statistics of the hydrochemical parameters of this group

The main characteristics of this cluster are:

$$Na^{+} > Mg^{+2} \approx Ca^{+2} > K^{+}$$
$$Cl^{-} > SO_4^{-2} > HCO_3^{-}$$
$$Na^{+}/Cl^{-} < 1$$

Where all concentrations are in (meq/L)

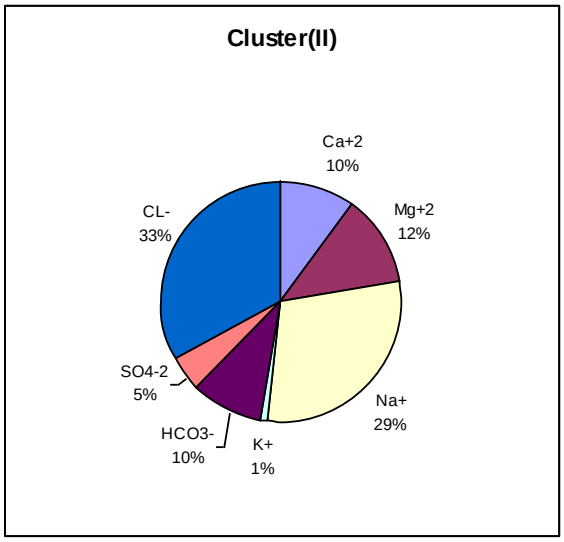

Figure (3.12): The presentation percentage graph of the Cluster (II)

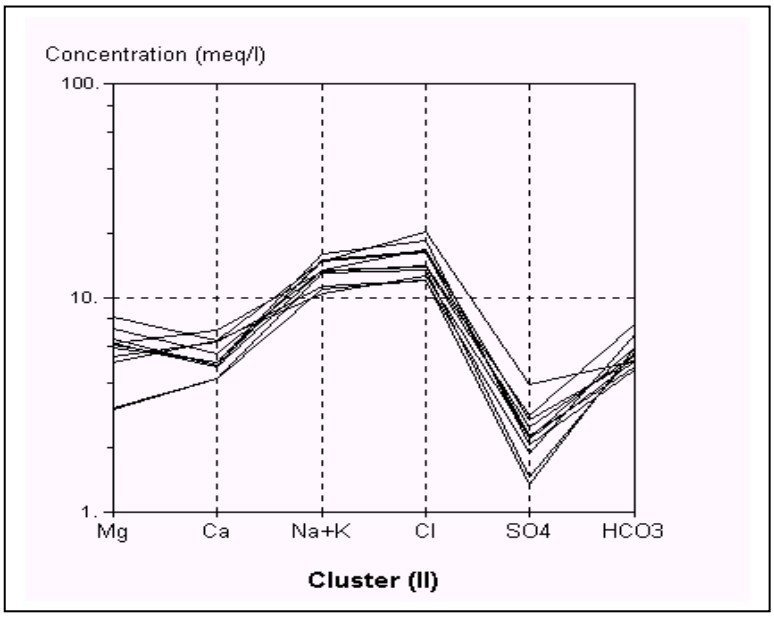

Figure (3.13): Schoeller diagram plot for the samples of cluster (II)

3.3.2.3 Cluster (III):

This cluster includes samples of springs that are located in Wadi Al Maleh West and East. It is dominated by Sodium cation (58 % of the total cation) and the Chloride anion (79 % of the total anion). This cluster includes 15.8 % of the research samples with average EC of 6505.0 µS/cm. Appendix (3.12) show a detailed descriptive statistics of the hydrochemical parameters of this group

The main characteristics of this cluster are:

$$Na^{+} > Ca^{+2} > Mg^{+2} > K^{+}$$
$$Cl^{-} > SO_4^{-2} > HCO_3^{-}$$
$$Na^{+}/Cl^{-} < 1$$

Where all concentrations are in (meq/L)

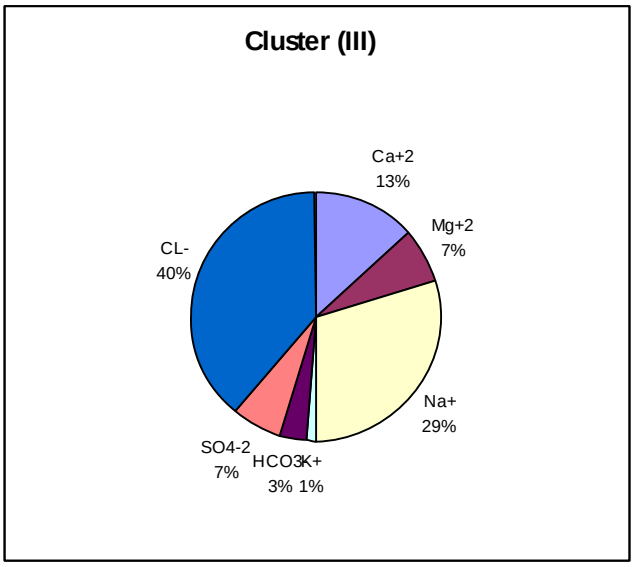

Figure (3.14): The presentation percentage graph of the Cluster (III)

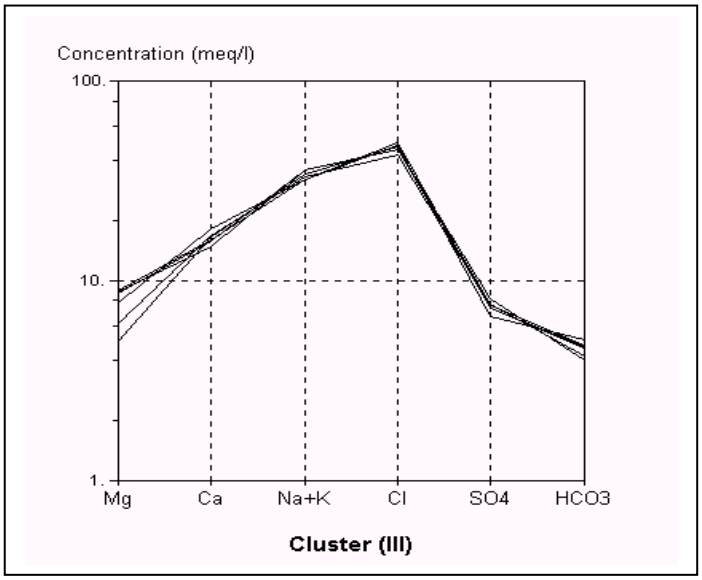

Figure (3.15): Schoeller diagram plot for the samples of cluster (III)

3.3.2.4 Cluster (IV):

This cluster includes samples of wells that are located in Marj Na'ja. It is dominated by Sodium cation (53 % of the total cation) and the Chloride anion (74 % of the total anion). This cluster includes 36.8 % of the research samples with average EC of 4155.71µS/cm. Detailed descriptive statistics of the hydrochemical parameters are shown in Appendix (3.13)

The main characteristics of this cluster are:

$$Na^{+} > Mg^{+2} \geq Ca^{+2} > K^{+}$$
$$Cl^{-} > SO_4^{-2} > HCO_3^{-}$$
$$Na^{+}/Cl^{-} < 1$$

Where all concentrations are in (meq/L)

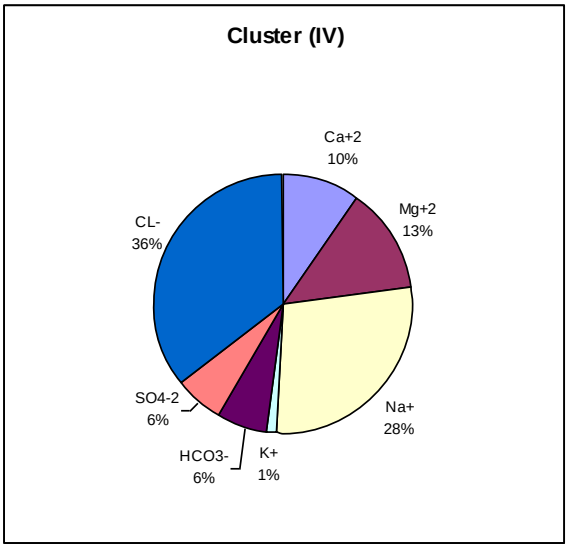

Figure (3.16): The presentation percentage graph of the Cluster (IV)

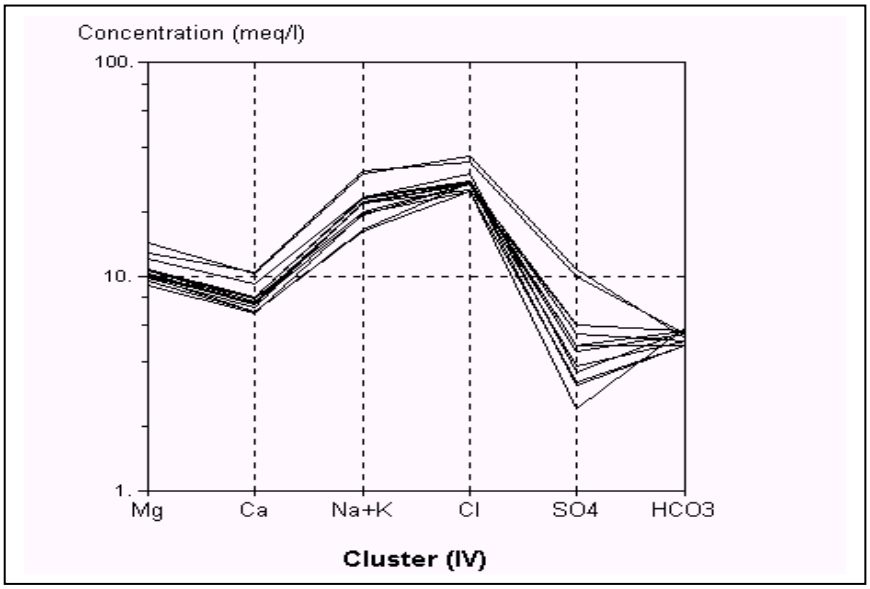

Figure (3.17): Schoeller diagram plot for the samples of cluster (IV)

3.4 WATER QUALITY

3.4.1 Introduction:

Water quality refers to the water chemical, biological and physical characteristics. It is now generally recognized that the quantity of groundwater is just as its quality. All groundwater contains salts in solution that are derived from the location and past movement of the water. The quality of groundwater required for drinking water, industrial water, and irrigation purposes vary widely. (Todd, 1980)

Water is said to be good or acceptable for a special use, if its characteristics meet the standards for that use. A standard is the concentration of the constituent that does not result in significant risks (negative impact) to the health (balance) of the consumer (consuming system) over the lifetime of consumption. Short-term exceeding of deviations above the standards values does not necessarily mean that the water is unusable for consumption. The amount by which and the period for which any standard value can be exceeded without affecting public health depends upon the specific substance involved (WHO,2004).

In this chapter, the water quality of the wells and springs of the study area will be evaluated for both domestic and agricultural purposes. Although, the wells and springs studied were mainly used for agricultural purposes.

3.4.1.1 Water Quality for Domestic Purposes:

Domestic water is defined as the water used for drinking, cooking, bathing, cleaning and in residential, institutional and public. The suitability of its quality as domestic water is judged on physical, microbiological and chemical characteristics (WHO, 2004).

In specifying the quality characteristics of groundwater, chemical and physical analyses were done. Properties of groundwater evaluated in a physical analysis include temperature, color, turbidity, odor, and taste which they are first concern the evaluation process, as they are the easiest to detect (Todd, 1980).

Waterborne – chemical diseases are less well – known by the public as waterborne – microbiological diseases. However, though it is no less important, the need for the identification and evaluation of the chemical characteristics. Also, the testing and treatment for the chemical parameters are difficult and require expensive high technology (Abdul-Jaber et al., 1999).

Potable water that can be used safely for domestic purposes must be free of pathogens, its turbidity, color, odor and taste must be within acceptable and permissible limits. In addition, its content of hazardous chemicals must be within permissible limits. It must be neither corrosive nor contain dyeing substances (Abdul-Jaber et al., 1999).

3.4.1.1.1 Chemical Quality Evaluation:

The chemical characteristics which decided the suitability of water for domestics use are the concentrations of the various ions which can be health hazards if they exceed a certain threshold or can change the aesthetic quality of the water by causing an undesirable color, taste or odor or water hardness.

The 2004 Palestinian Water Authority Standards (PWA, 2004) and the WHO (2004) guidelines that are shown in table will be used as guides for the water quality evaluation of using the water of the studied resources for domestic purposes (Table 3.11).

Table (3.11): Palestinian Standards and World Health Organization (WHO) Guidelines for Drinking Water (PWA, 2004; WHO, 2004)

Parameters	Palestinian Standards (2004)		WHO (2004)
	Basic	Conditional	
Temp C^0	8–25		12–25
pH	6.5–8.5	9.5	6.5–8.5
Na^{+2} (mg/L)	200	400	200
Ca^{+2} (mg/L)	100	200	75
Mg^{+2} (mg/L)	100	120	<125
K^{+} (mg/L)	10	12	12
HCO_3^{-} (mg/L)	125–350	125–350	125–350
Cl^{-} (mg/L)	250	600	250
SO_4^{2-} (mg/L)	200	400	250
NO_3^{-} (mg/L)	50	70	50
TDS (mg/L)	1000	1500	500–1000
Hardness(mg/L)	500	500	500

3.4.1.1.2 Hardness:

The hardness of the water is defined as its content of divelant metallic ions of which calcium and magnesium are the most abundant in groundwater react with sodium soaps to produce solid soaps or scummy residue and which react with negative ions when the water is heated in boilers to produce solid boiler scales (De Zuane, 1990). Because of their adverse action with soap, hard waters are unsatisfactory for household cleansing purposes; hence, water – softening processes for removal of hardness are needed (Todd, 1980).

Total hardness is expressed as $CaCO_3$ in mg/L, which is calculated according to the following equation (Todd, 1980):

$$\text{Total hardness } (CaCO_3) = 2.497\ Ca^{+2} + 4.115\ Mg^{+2}$$

Where the Ca^{+2} and Mg^{+2} concentrations are in mg/L.

The Sawyer and McCarty (1967) classification of water according to total hardness is given in Table (3.12).This classification is helpful in the evaluation of water for domestic purposes.

Table (3.12): Sawyer and McCarty (1967) Classification of Water Based on Hardness

Hardness as ($CaCO_3$) mg/L	Water Type
0 – 75	Soft
75 – 150	Moderately hard
150 – 300	Hard
>300	Very Hard

3.4.1.2 Water Quality for Irrigation Purposes:

The suitability of water for irrigation is determined the type and concentration of dissolved spices and soil type, as well as the type of crops to be irrigated. Salts in the irrigation water would negatively affect the growth of plants by changing the osmotic conditions in the root zone, which would decrease or limit the water uptake (a physical effect). Salts may also affect the soil by changing the soil structure, permeability and aeration, which would indirectly affect the growth of plants (Todd, 1980). The evaluation of the soluble sodium percentage, sodium adsorption ratio and the total dissolved solids/ electrical conductivity plays a major role in the evaluation of the suitability of water for irrigation.

3.4.1.2.1 Sodium hazard:

3.4.1.2.1.1 Sodium Adsorption Ratio (SAR):

The main problem with high sodium concentration is its effect on soil permeability and water infiltration. Sodium also contributes directly to the total salinity of the water and may be toxic to sensitive crops.

The sodium hazard of irrigation water is estimated by the sodium adsorption ratio (SAR), The expression SAR was recommended by the United States Salinity Laboratory (USSL) of the Department of Agriculture (Richard, 1954).

SAR is considered to be in direct relationship with the water adsorption by the soil. It is calculated according to the formula:

$$SAR = Na^{+} / ((Ca^{+2} + Mg^{+2}) / 2)^{0.5}$$

Where the cations are expressed in meq/L.

Continued use of water having a high SAR leads to a breakdown in the physical structure of the soil. The sodium replaces calcium and magnesium sorbet on clay minerals and causes dispersion of soil particles. This dispersion results in breakdown of soil aggregates and causes a cementation of the soil under drying conditions as well as preventing

infiltration of rain water (Qannam, 2003). Classification of irrigation water based on SAR values is shown in Table (3.13).

Table (3.13): Irrigation Water Classification, Based on SAR Values (Wilcox, 1995)

SAR Range	Water Class	Comments
<10	S1	Low sodium hazards: can be used for irrigation on almost all soils with little danger
10 – 18	S2	Medium sodium hazards: can cause an appreciable sodium hazard, fine–textured soils having high cation exchange capacity under low loading conditions. It can be used on coarse – textured soil with good permeability.
18 – 26	S3	High sodium hazards: may produce harmful levels of exchangeable sodium in most soils.
>26	S4	Very high sodium hazards: unsatisfactory for purposes, except for waters with low and medium salinity.

The Wilcox classification is a modification of Richard (1954), which has the same ranges of SAR and divides water into four groups: excellent, good, fair and poor.

3.4.1.2.1.2 Soluble Sodium Percentage (SSP):

Sodium concentration is an important index in the evaluation of irrigation water as it has an influence on soil permeability. Using water with high sodium concentration and high sodium ratio increases the concentration of sodium in the soil and allows the sodium to exchange other ions in the soil particles.

Soluble sodium percentage (SSP) is an estimation of the sodium hazard of irrigation water like SAR. But it expresses the percentage of sodium out of the total cations and not as SAR correlating the sodium with the Ca and Mg only. SSP is calculated by the following formula

The sodium content is expressed in terms of the SSP, which is defined as:

$$SSP = ((Na^{+} + K^{+}) / (Ca^{+2} + Mg^{+2} + Na^{+} + K^{+}))*100$$

Where all concentrations are in meq/L.

Based on Todd (1980) classification of the irrigation water according to the soluble sodium percentage (Table 3.14)

Table (3.14): Classification of Irrigation Water Based on SSP (Todd, 1980).

Water Class	SSP Percentage	EC (µS/cm)
Excellent	<20	<250
Good	20 – 40	250 – 750
Permissible	40 – 60	750 – 2000
Doubtful	60 – 80	2000 – 3000
Unsuitable	>80	>3000

3.4.1.2.2 Total dissolved Solids/ Electrical Conductivity:

Excess salt increases the osmotic pressure of the soil water and produces conditions that keep the roots from absorbing water. This results in a physiological drought condition. Even though the soil appears to have plenty of moisture, the plants may wilt because the roots do not absorb enough water to replace water lost from transpiration.

The USSL (Richard, 1954) places irrigation water in groups according to EC and total dissolved solids and TDS (Table 3.15)

Table (3.15): Grouping of irrigation water, based on EC (Richard, 1954)

TDS (mg/L)	EC (µS/cm)	Water Class	Remarks
<200	<250	C1	Low salinity hazards: can be used for irrigation with most crops on most soils.
200–500	250 – 750	C2	Medium salinity hazards: can be used to irrigate plants with moderate salt tolerance if moderate amount of leaching occurs.
500–1500	750–2250	C3	High salinity hazards: can not be used on soils with restricted drainage. Can be used to irrigate plants with high salt tolerance.
1500–3000	2250–5000	C4	Very high salinity hazards: not suitable for irrigation under ordinary conditions. It can be used for irrigation occasionally under very special circumstances.

Wilcox diagram (Wilcox, 1955) presented with the help of the GWW software (United Nations, 1995), of the EC and SAR water types recorded in the study

3.4.2 Suitability of Water for Domestic and Irrigation Purposes:

The water of the ground water wells and springs in this study are used fully or partially for irrigation (for agricultural purposes).

When contamination reaches the water resources there are negative chemical and biological effects, especially in concentrations of nitrate, chloride, potassium, sodium, sulphate and coliform bacteria. Generally, the contamination can be accounted for by the mixing of municipal wastewater, industrial wastewater or agricultural effluents with the well water. In the urban areas, mixing could be a result of the infiltration of raw sewage conduits.

Agricultural effluent originates from the heavy use of animal manure, or the various chemical fertilizers, which are always rich in nitrate, potassium and sulphate, with excessive irrigation. This, together with irrigation with raw wastewater, could be main source of contamination in agricultural areas.

3.4.2.1 Quality Evaluation:

The factors that will be considered in evaluating the suitability of well water for drinking purposes are the concentration of some ions such as Cl^{-}, affecting the aesthetic water quality and concentrations of NO_3^- that is causing health hazards. The factors which will be considered in evaluating the suitability of well and springs water for irrigation purposes are the values of EC, SSP and SAR.

3.4.2.1.1 The Wells of Marj Na'ja and Az Zubiedat:

The chemical characteristics of water quality of the samples of Marj Na'ja and Az Zubiedat wells are shown in Table (3.16).

Table (3.16): Major chemical characteristics of water quality of the wells studied in Marj Na'ja and Az Zubiedat

No.	Well Code	Date	EC µS/cm	SAR	SSP	Hardness mg/L	Na^+ mg/L	K^+ mg/L	SO_4^{-2} mg/L	Cl^- mg/L	NO_3^- mg/L
1-	19-17/011	10/7/03	2230	6.1	57.3	555.9	329.5	23.2	110	580	17.8
2-	19-17/011	09/1/04	2620	5.6	55.4	545.8	301.0	17.4	120	498	19.2
3-	19-17/011	14/5/04	3240	5.3	50.7	726.5	330.3	22.6	188.5	723	24.4
4-	19-17/020	04/8/03	3360	7.1	55.5	879.9	486.8	31.3	230	956	24.3
5-	19-17/020	09/1/04	4840	7.1	54.9	912.9	492.0	31.6	214	978	22.4
6-	19-17/020	14/5/04	4170	6.3	51.8	930.5	441.2	32.3	285	964	37.8
7-	20-17/010	04/8/03	2350	6.7	59.9	544.0	357.0	26.6	98.7	655	17.4
8-	20-17/010	09/1/04	2670	6.1	34.8	562.4	333.0	25.1	105.3	590.0	5.2
9-	20-17/10	14/5/04	2900	5.2	51.9	632.2	300.5	22.6	130	595.6	25.4
10-	20-17/011	09/1/04	5110	7.9	57.2	1171.0	619.0	170	483.8	1211.6	19.9
11-	20-17/011	14/5/04	5550	7.1	55.0	1240.5	574.0	209.9	520	1304.6	32
12-	20-17/016	10/7/03	3560	7.5	56.5	900.2	519.2	32.0	260	986	28.4
13-	20-17/016	09/1/04	4190	7.3	55.0	944.2	514.0	28.4	229	970	24.6
14-	20-17/016	14/5/04	4700	7.0	52.5	1066.5	523.5	30.7	172.5	1067	45
15-	20-17/018	04/8/03	3310	7.4	56.8	850.5	494.3	32.7	184.5	963	24.5
16-	20-17/018	09/1/04	3750	6.8	55.6	792.3	438.6	28.4	115.5	894.8	20.7
17-	20-17/019	14/5/04	4160	6.2	52.0	898.4	430.0	30.7	215.0	964	24.9
18-	20-17/019	10/7/03	3430	5.4	49.5	844.0	361.8	32.0	150.0	977	16.4
19-	20-17/019	09/1/04	4250	7.2	55.6	878.3	488.9	28.4	287.6	907	12.2
20-	20-17/019	14/5/04	3800	5.5	49.7	826.5	360.0	26.0	155	886	20.8

The results show that all samples of wells studied are exceed the WHO (2004) guidelines for Na^+, K^+ and Cl^-, but not for NO_3^-. The concentration of Cl^- gives the water a very unacceptable salty taste, thus making it unsuitable for drinking, but the highest concentrations were recorded in well code 20-17/011 of sample collected in 09/01/200 (1211.6mg/L) and sample collected in 14/05/2004 (1304.6 mg/L) in well code (20-17/011).

In addition, the highest concentration of Na^+ (574 mg/L) and K^+ (209.9 mg/L) were recorded in 14/05/2004 in well code (20-17/011).

The WHO (2004) guidelines for SO_4^{-2} were exceeded only in samples collected in 14/05/2004 (285 mg/L) of Well Code 19-17/020, 09/01/2004 (287.6 mg/L) of Well Code (20-17/019) and samples collected in 09/01/2004 and 14/05/2004 of Well Code (20-

17/011) that had highest concentration of SO_4^{-2} (483.8 and 520 mg/l), respectively. (Table 3.16)

The Sawyer and McCarty (1967) classification of water, based on total hardness shows that the water of all samples of wells studied in Marj Na'ja and Az Zubiedat is "very hard ". The highest value of hardness (1240.5 mg/L) was recorded in sample of well code (20-17/011) that collected in 14/05/2004 (Table 3.16)

The majority of samples studied in this group are of permissible for irrigation purposes, based on SSP. Sample collected in 09/01/2004 from well 20-17/010 is the only sample that has only good SSP (Table 3.16).

According to the EC–SAR relationship, the majority of the samples studied of this group can be classified as medium sodium – very high salinity hazards (S2 – C4) ((Figure 3.18 A & B). The water of these samples is not suitable for irrigation under ordinary conditions. It can be used for irrigation occasionally under very special circumstances.

It can cause an appreciable sodium hazard, fine textured soils having high cation exchange capacity under low loading conditions. It can be used on coarse –textured soil with good permeability.

In addition, the well code 19-17/011 in 10/07/2003 has Medium sodium – high salinity hazards (S2 – C3) that means the water of this wells is suitable for irrigation purposes with limitations , while samples of well code 19-17/020 in 09/01/2004 and of well code 20-17/016 in 14/05/2004 have high sodium – very high salinity hazards (S3 – C4), the water of these two sample is unsuitable for irrigation purposes based on SSP and EC – SAR (Figure 3.18 A & B).

Sample of well code 20-17/010 in 09/01/2004 was the only sample of this group can be classified as low sodium –very high salinity hazards (S1 – C4) (Figure 3.18 A & B).

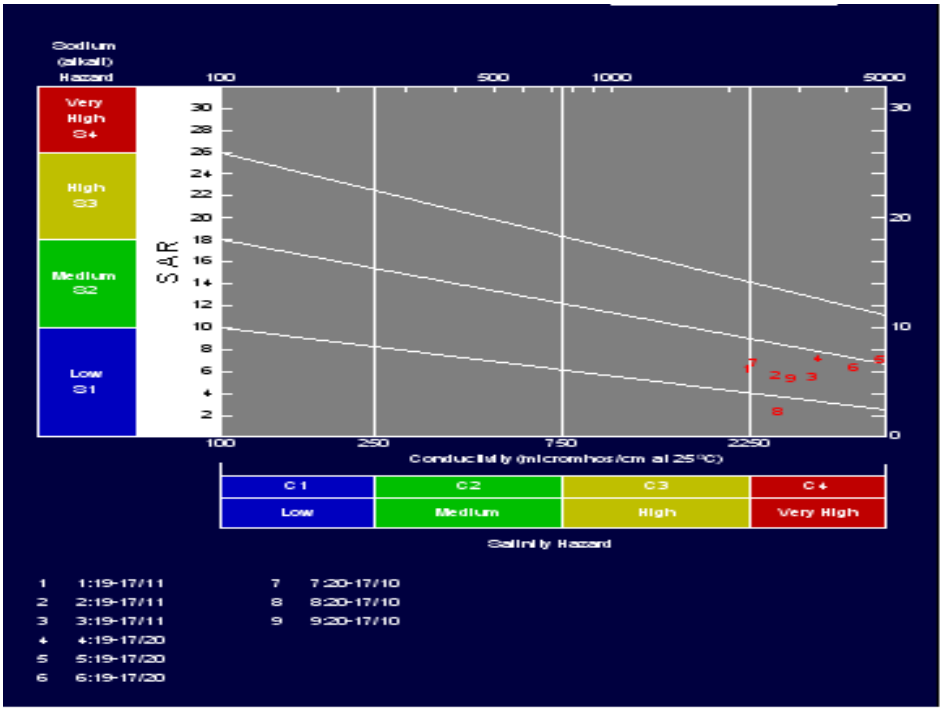

Figure (3.18 A): EC-SAR Classification of the wells studied in Marj Na'ja and Az Zubiedat (1st tenth samples)

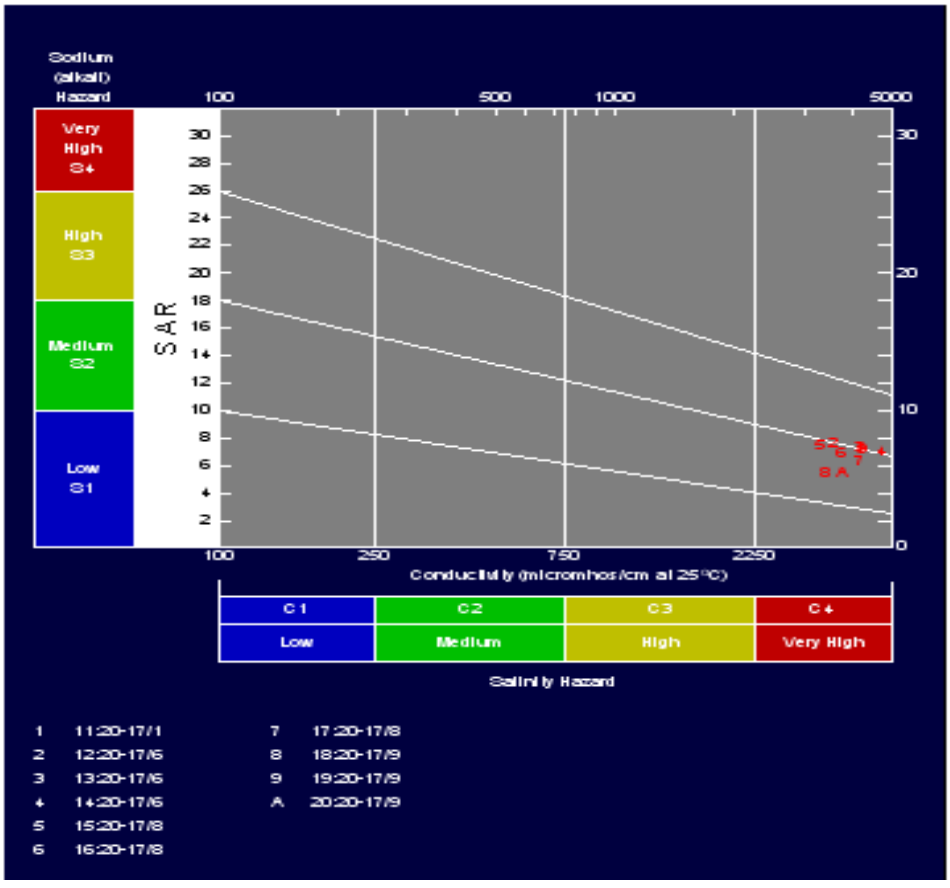

Figure (3.18B): EC-SAR Classification of the wells studied in Marj Na'ja and Az Zubiedat (2nd tenth samples)

3.4.2.1.2 The Wells of Frush Bait Dajan (F.B.D):

The chemical characteristics of water quality of the samples of F.B.D wells are shown in Table (3.17)

Table (3.17): Major chemical characteristics of water quality of the wells studied in F.B.D

No.	Well Code	Date	EC µS/cm	SAR	SSP	Hardness mg/L	Na^+ mg/L	K^+ mg/L	SO_4^{-2} mg/L	Cl^- mg/L	NO_3^- mg/L
1-	19-17/034	11/1/04	788	5.7	60.4	363.9	250	8	65	430	44
2-	19-17/034	14/5/04	826	6.86	64.5	362.3	300	3.2	70	480	41.8
3-	19-17/046	11/1/04	2430	5.17	50.3	662.0	305.6	4.7	135.9	503	114.9
4-	19-17/046a	14/5/04	2310	4.63	49.5	580.0	256.3	8.1	90	432.5	71.2
5-	19-17/046b	14/5/04	2310	4.24	47.9	570.0	232.8	12.9	108	453.8	65.4

The results show that all samples of wells studied exceed the WHO (2004) guidelines for Na^+ and Cl^-, but not for SO_4^{-2}. The concentration of Cl^- gives the water a very unacceptable salty taste, thus making it unsuitable for drinking, but the highest concentrations of Na^+ (305.6 mg/L) and Cl^- (503 mg/L) were recorded in well code 19-17/046 (11/01/2004).

The well code 19-17/046 (14/05/2004) exceeds the WHO (2004) guidelines for potassium (12.9 mg/L). The wells in this group of well (19-17/046) exceed the WHO (2004) guidelines for NO_3^-, but the highest concentrations were recorded in sample collected in 11/1/2004 (114.9 mg/L). Thus, the wells in which the nitrate permissible limits were exceeded are not suitable for drinking (Table 3.17).

Well code (19-17/034) also has relatively high nitrate concentrations (44 and 41.8 mg/L) but within the WHO recommended limits (Table 3.17).

The Sawyer and McCarty (1967) classification of water, based on total hardness shows that the water of all samples of wells studied in F.B.D is "very hard ". The highest value of hardness (662.0 mg/L) was recorded in well code 19-17/046 (11/01/2004) Table (3.17)

The water from the wells of this group range from "permissible" to "doubtful" for irrigation purposes, based on SSP. The water of samples of well 19-17/034 is "doubtful", while the water of the samples of well code 19-17/046 is " permissible" (Table 3.17).

All samples studied of the well (19-17/046) can be classified as with medium sodium – very high salinity hazards (S2 – C4), according to the EC – SAR relationship (Figure 3.19). The water of these samples is unsuitable for irrigation purposes, based on SSP and EC-SAR classification.

In addition, according to the EC–SAR relationship, the sample of well 19-17/034 (11/01/2004) can be classified as low sodium – high salinity hazards (S1 – C3). Thus, the water of this sample is suitable for irrigation purposes. While, the sample collected in 14/05/2004 of well 19-17/034 is of medium sodium – high salinity hazards (S2 – C3) that is suitable for irrigation with limitation (Figure 3.19).

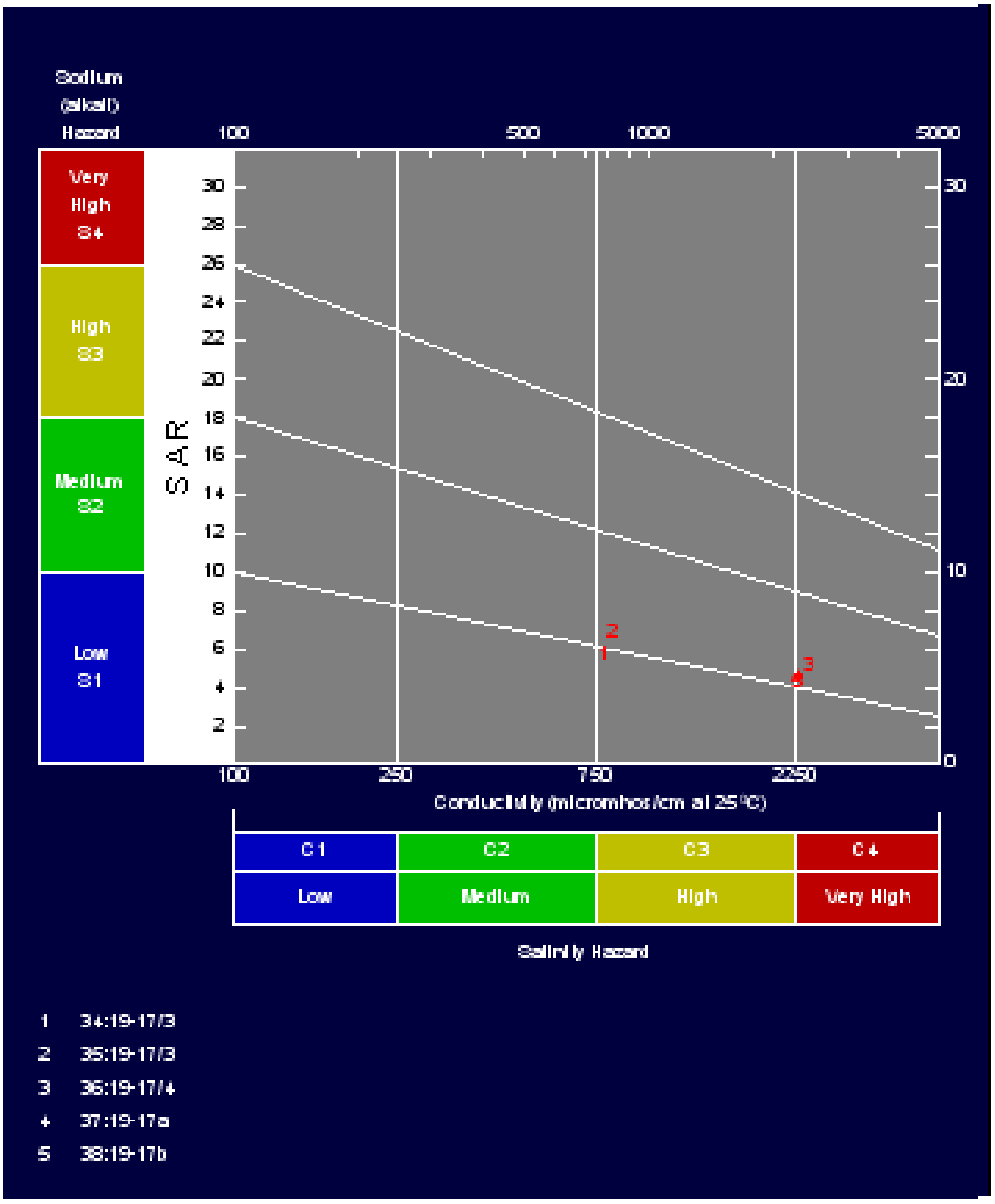

Figure (3.19): EC-SAR Classification of the wells studied in Frush Bait Dajan

3.4.2.1.3 Spring of Al Himmah:

The chemical characteristics of water quality of the samples of Al Himmah spring are shown in Table (3.18)

Table (3.18): Major chemical characteristics of water quality of the Al Himmah Springs

No.	Spring Code	Date	EC µS/cm	SAR	SSP	Hardness mg/L	Na^+ mg/L	K^+ mg/L	SO_4^{-2} mg/L	Cl^- mg/L	NO_3^- mg/L
1-	AC/030A	10/7/03	1225	3.3	47.4	359.7	145.7	5.5	47	294.4	6.8
2-	AC/030A	09/1/04	1467	3.9	50.7	364.2	169.0	4.7	55	289.3	10.4
3-	AC/030A	14/5/04	1505	3.6	49.2	362.2	157.0	6.9	45	283.6	13.2

None of the samples of Al Himmah spring studied exceed the WHO (2004) guidelines for Na^+, K^+, SO_4^{-2} and NO_3^-, but not for Cl^-. The concentration of Cl^- gives the water a very unacceptable salty taste, thus making it unsuitable for drinking. However, the highest concentrations of Cl^- was recorded in sample No. twenty–two (289.3 mg/L vs 250 mg/L recomended). Table (3.18)

The Sawyer and McCarty (1967) classification of water, based on total hardness shows that the water of all samples of Al Himmah spring studied is "very hard ". The highest value of hardness (364.14 mg/L) was recorded also in sample No. twenty–two. (Table 3.18)

The water of all samples of Al –Himmah spring is "permissible" for irrigation, based on the SSP classification.

All samples studied of Al-Himmah spring can be classified as low sodium – high salinity (S1 – C3) Figure (3.20) Based on the SSP and EC-SAR classifications, the water from this spring is suitable for irrigation purposes with limitation that can be used to irrigate plants with high salts tolerance.

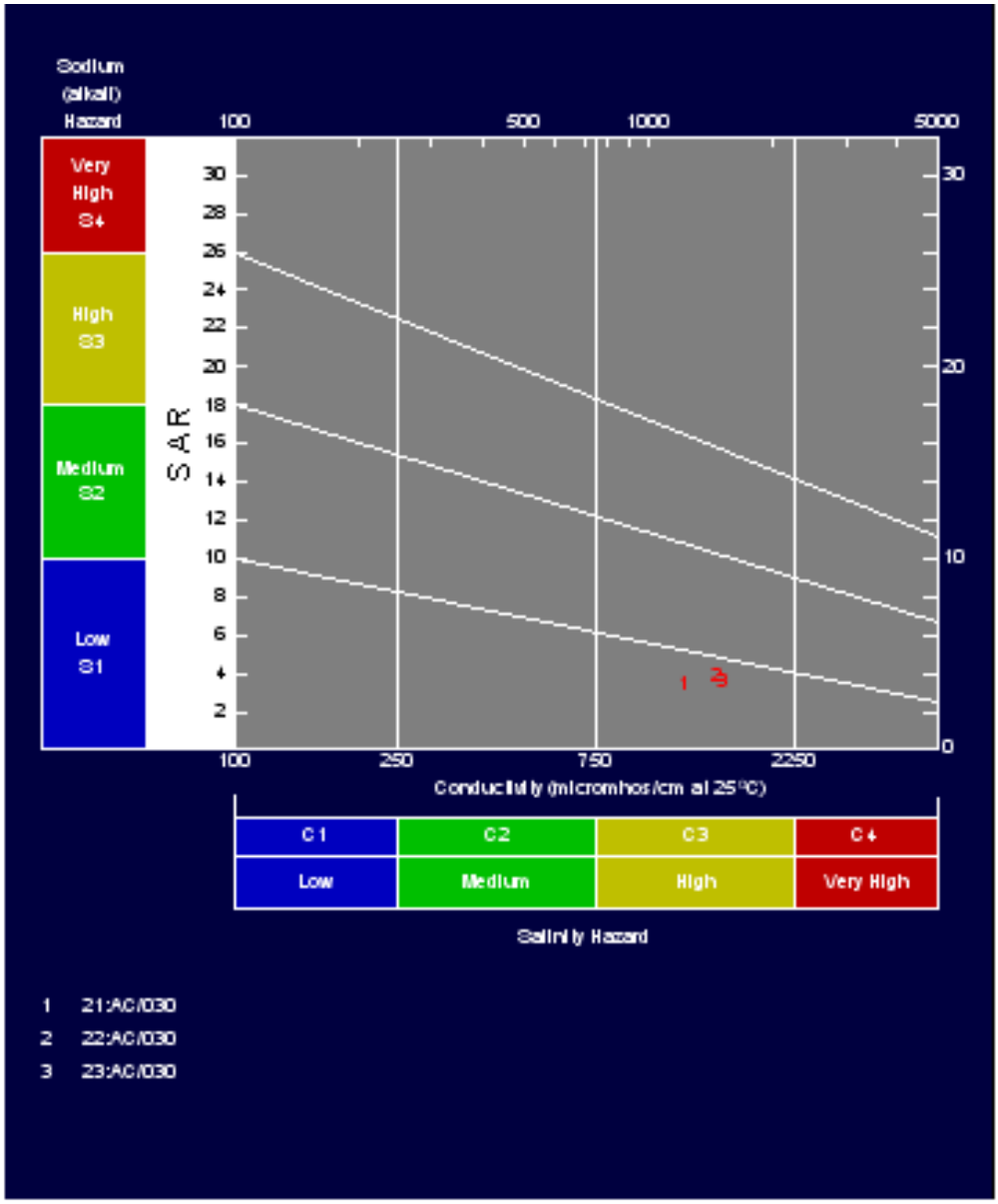

Figure (3.20): EC-SAR Classification of the Al-Himmah Spring

3.4.2.1.4 Springs of Al Maleh:

The samples of Al Maleh springs studied can be divided into two sub groups according to their major chemical characteristics of water quality:

3.4.2.1.4.1 Al Maleh Warm (East and West):

The chemical characteristics of water quality of the samples of Al Maleh Warm springs are shown in Table (3.19)

Table (3.19): Major Chemical characteristics of water quality of the Al Maleh Warm springs

No.	Name	Date	EC µS/cm	SAR	SSP	Hardness mg/L	Na^+ mg/L	K^+ mg/L	SO_4^{-2} mg/L	Cl^- mg/L	NO_3^- mg/L
1-	AC/041-E	10/7/03	5180	9.93	59.5	1226.3	798.8	49.7	390.0	1632.0	11.4
2-	AC/041-E	09/1/04	6500	8.72	56.1	1254.8	709.5	45.8	321.7	1697.6	20.7
3-	AC/041-E	14/5/04	6880	10.28	61.6	1080.6	777.0	32.3	350.0	1659.0	6.6
4-	AC/041W	09/1/04	7470	9.36	58.8	1160.6	733	48.6	360.0	1512.0	19.9
5-	AC/041W	10/7/03	5420	10.04	60.2	1184.3	793.8	50.4	370.0	1613.0	12.8
6-	AC/041W	14/5/04	7580	8.72	55.5	1300.7	722.8	40.4	350.0	1765.5	6.3

The results show that all samples of Al Maleh East and West exceed the WHO (2004) guidelines for Na^+, K^+, SO_4^{-2} and Cl^-, but not for NO_3^-. The concentration of Cl^- gives the water a very unacceptable salty taste, thus making it unsuitable for drinking, but the highest concentrations was recorded in spring code AC/041W collected in 14/05/2004 (1765.5 mg/L).Table (3.19)

In addition, the highest concentration of Na^+ (798.8 mg/L) and SO_4^{-2} (390 mg/L) were recorded in spring code AC/041-E collected in 10/07/2003, while the highest concentrations of K^+ was recorded in spring code AC/041W (10/7/2003). Table (3.19)

The Sawyer and McCarty (1967) classification of water, based on total hardness shows that the water of all samples of springs studied of East and West Al Maleh is "very hard ". The highest value of hardness (1300.7mg/L) was recorded in spring code AC/041W (14/05/2004). Table (3.19)

The water of all samples studied of this springs is "permissible" for irrigation purposes, based on the SSP classification (Table 3.19).

All samples studied of Al Maleh East and West can be classified as with high sodium – very high salinity hazards (S3 – C4) water, according to the EC –SAR relationship (Figure 3.21):The water of all samples of Al Maleh Warm are not suitable for irrigation purposes.

3.4.2.1.4.2 Al Maleh Cold:

The chemical characteristics of water quality of the samples of Al Maleh Cold spring is shown in Table (3.20)

Table (3.20): Major Chemical characteristics of water quality of the Al Maleh Cold spring

No.	Name	Date	EC µS/cm	SAR	SSP	Hardness mg/L	Na^+ mg/L	K^+ mg/L	SO_4^{-2} mg/L	Cl^- mg/L	NO_3^- mg/L
1-	AC/041C	04/8/03	706	2.22	41.12	256.1	81.8	0.6	27.3	103.9	17.5
2-	AC/041C	09/1/04	663	2.13	40.19	260.0	79.1	2.1	28.3	111.2	18.8
3-	AC/041C	10/7/03	716	1.72	35.01	270.7	65.0	3.4	31	103.5	17.2
4-	AC/041C	14/5/04	743	1.89	37.62	262.1	70.4	3.8	33	99.0	25.2

The results show that none of the samples of Al Maleh Cold exceeds the WHO (2004) guidelines for chemical content, and all are suitable for drinking in this respect (Table 3.20).

The Sawyer and McCarty (1967) classification of water, based on total hardness shows that the water of all samples of springs Al Maleh Cold is "hard ". The highest value of hardness (270.68mg/L) was recorded in spring code AC/041C (10/7/2003). Table (3.20)

The water of all samples studied of this springs is "good" for irrigation purposes, based on the SSP classification. Thus, the water of all samples of Al Maleh Cold could be used for irrigation without any limitations (Table 3.20).

All the samples of Al Maleh Cold spring can be classified as low sodium – medium salinity hazard (S1 – C2) water, according to the EC –SAR relationship (Figure 3.22). The water of all samples of Al Maleh Cold is suitable for irrigation purposes without any limitation.

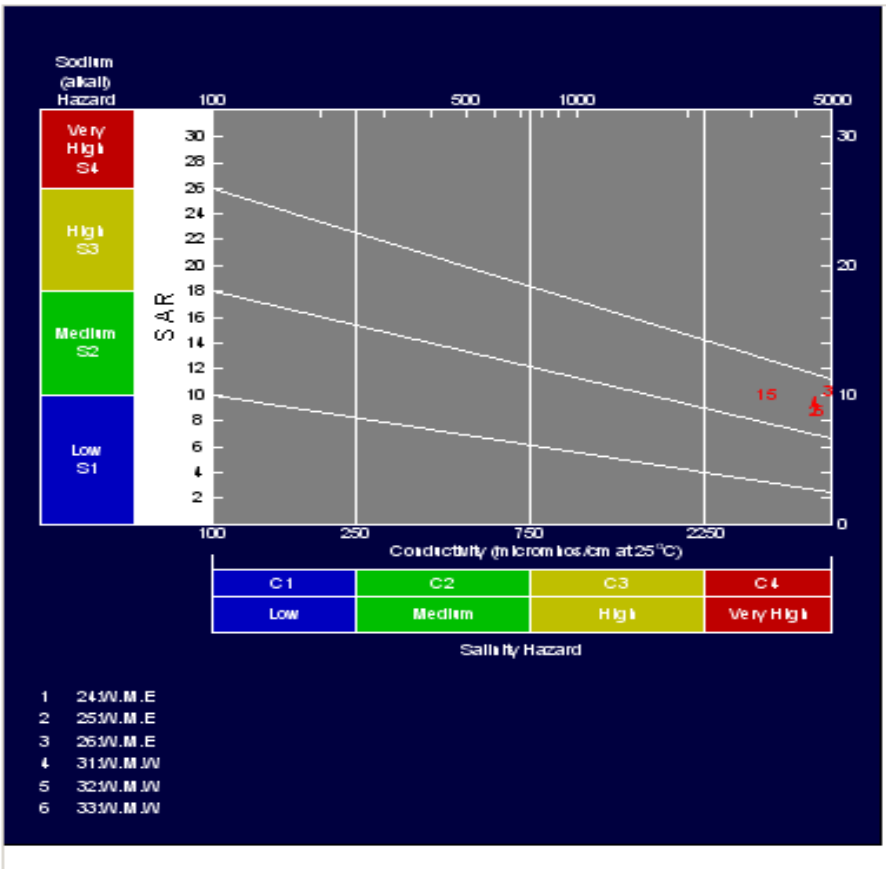

Figure (3.21): EC-SAR Classification of the Al-Maleh Warm Springs

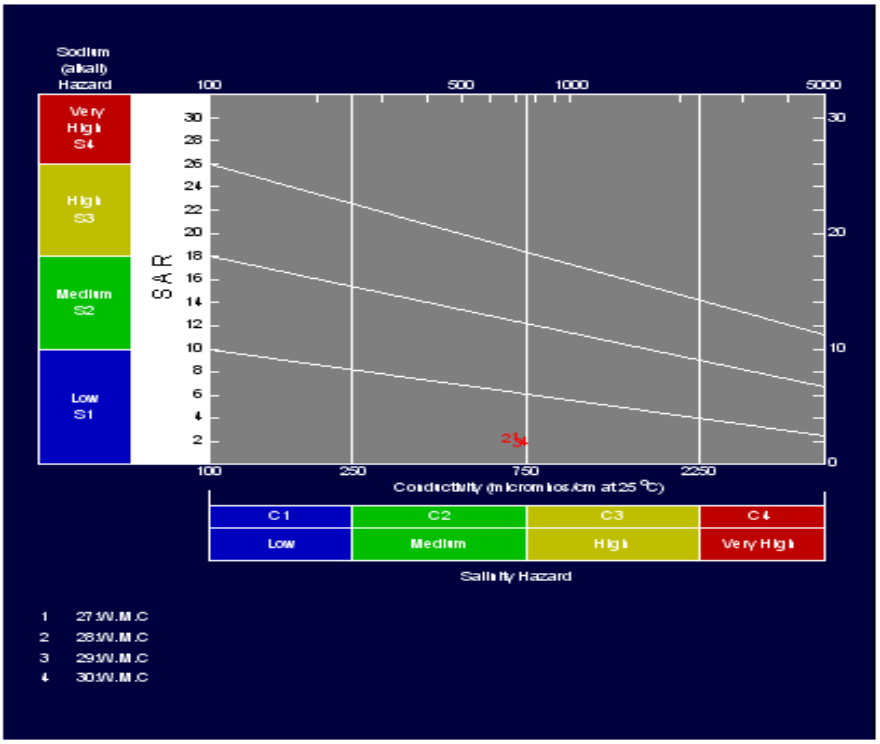

Figure (3.22): EC-SAR Classification of Al-Maleh Cold Spring

3.5 WATER GENISIS

3.5.1 Introduction:

The chemical composition of groundwater results from the interaction of meteoric water with soil and rocks. The major dissolved chemical species are controlled by leaching the most soluble minerals of the environment and their alternation products (Moller et al., 2006).

Groundwater flowing through different aquifer systems may be identified and differentiated by their salinity levels and ionic ratios.

The most abundant water type of the study is the "Alkaline water with prevailing sulfate – chloride".

Water- rock interaction and mixing with wastewater and agricultural effluents are the most important factors affecting the water genesis of the groundwater wells of the West Bank.

The effect of water – rock interaction and mixing with wastewater and agricultural effluents on the water genesis of the wells and springs of Marj Na'ja area is evaluated through determination of the ionic ratios of parameter of different variables, saturation indices of the water with respect to various mineral phases, and by plotting the results of the chemical analysis on Durov and Schoellar diagram.

3.5.1.1 Ion Exchange:

As groundwater moves underground it tends to develop a chemical equilibrium by chemical reactions with its environment. Ion exchange involves the replacement of ions adsorbed on the surface of fine-grained materials in aquifers by ions in solution. Because the exchange involves principally cations (sodium, calcium, and magnesium), the process is known as base, or cation exchange. The direction of the exchange is toward an equilibrium of bases present in the water and on the finer materials of the aquifer base exchange is known to soften groundwater naturally (Todd, 1980).

Base exchange causes changes in the physical properties of soils. When high – sodium water is applied to a soil, the number of sodium ions combined with the soil increases, while an equivalent quantity of calcium, or other, ions is displaced. These reactions cause deflocculation and reduction permeability. In the opposite case where calcium is dominant cation, the exchange occurs in the reverse direction, creating a flocculated and more permeable soil (Todd, 1980)

3.5.1.2 Saturation indices:

When a mineral is dissolved in water the cations and anions of which it is composed will attain a specific concentration. A method for expressing the extent of the chemical equilibrium between the water and the mineral phases of the aquifer materials is by making use of the saturation indices (Hounslow, 1995).

The equation that represents the degree of the water saturation with respect to a certain mineral phase is:

$$SI=\log (K_{IAP}/K_{sp})$$

Where:
SI: is the saturation index of the particular mineral,
K_{IAP}: is the ion activity product and
K_{sp} is the solubility product.

The equilibrium constant for a slightly soluble salt is termed the solubility product K_{sp}. The chemical activity of an ion is equal to the molal concentrations times a factor known as the activity coefficient. In order to compute the activity coefficient of an individual ion, the ionic strength of the solution must be determined. Once the ionic strength of the electrolytes is known, the activity coefficient of the individual ion can be determined from the Debye-Hukel equation (Fetter, 1994). The PHREEQC software was used to perform the calculations of SI (Parkhurst and Appelo, 2001).

The importance of the saturation indices is to show the possible dissolution/ precipitation process during the water – rock interaction.

The value of the saturation index is interpreted below:

- SI value = 0: The water is in equilibrium with respect to the particular mineral.
- SI value > 0 or ($K_{IAP} > K_{sp}$): The water is oversaturated with respect to that mineral, and thus tends towards its precipitation.
- SI value < 0 or ($K_{IAP} < K_{sp}$): The water is undersaturated with respect to that mineral and tends toward its dissolution.

The minerals considered in the calculation, with their essential thermodynamic data, are illustrated in Table (3.21)

Table (3.21): The mineral phases considered in the thermodynamic calculations of SI.

Mineral	Dissolved Species	Ksp
Aragonite	$CaCO_3=Ca^{+2}_{(aq)}+CO_3^{-2}{}_{(aq)}$	$4.94*10^{-9}$
Calcite	$CaCO_3=Ca^{+2}_{(aq)}+CO_3^{-2}{}_{(aq)}$	$3.52*10^{-9}$
Dolomite	$CaMg(CO_4)_2=Ca^{+2}_{(aq)}+Mg^{+2}_{(aq)}+2CO_3^{-2}{}_{(aq)}$	$1.07*10^{-17}$
Gypsum	$CaSO_4.H_2O=Ca^{+2}_{(aq)}+SO_4^{-2}{}_{(aq)}+H_2O$	$2.49*10^{-5}$
Anhydrite	$CaSO_4=Ca^{+2}_{(aq)}+SO_4^{-2}{}_{(aq)}$	$4.68*10^{-5}$

3.5.1.3 Deduction of rock source:

The initial composition of groundwater originates from rainfall, which may be considered to be diluted seawater. During its return path to the ocean, rock weathering, evaporation, and aeration alter the water composition. During rock weathering Ca^{+2}, Mg^{+2}, SO_4^{-2} and HCO_3^- are added to the water. The amount of each is depended on the rock mineralogy (Hounslow, 1995) .The ratios and parameters used to determine source rock are tabulated in Table (3.22)

In sedimentary rocks, the solute inventory of infiltrating water is also altered by mixing with enclosed saline formation and by water/rock interaction (Moller et al, 2006)

Table (3.22): Source – Rock Deduction Summary of Reasoning (Hounslow, 1995)

Parameter	Value	Conclusion
$Na^+ / Na^+ + Cl^-$	> 0.5	Sodium source other than halite-albite, ion exchange
	= 0	Halite solution
	<0.5 TDS >500 mg/L	Reverse softening
	<0.5 TDS <500 mg/L >50 mg/L	Analysis error
	<0.5 TDS<50 mg/L	Rainwater
$Mg^{+2} / (Ca^{+2} + Mg^{+2})$	= 0.5	Dolomite weathering
	< 0.5	Limestone – dolomite weathering
	>0.5	Dolomite dissolution, calcite precipitation, or seawater
$Ca^{+2} / (Ca^{+2} + SO_4^{-2})$	= 0.5	Gypsum dissolution
	< 0.5 pH<5.5	Pyrite oxidation
	< 0.5 neutral	Calcium removal–ion exchange or calcite precipitation
	> 0.5	Calcium source other than gypsum-carbonates or silicates
Cl^- /sum anions	>0.8 TDS> 500 mg/L	Seawater, or brine, or evaporates
	>0.8 TDS<100 mg/L	Rainwater
	< 0.8	Rock weathering of halite
HCO_3^-/ sum anions	> 0.8	Silicate or carbonate weathering
	< 0.8 sulfate high	Gypsum dissolution
	< 0.8 sulfate low	Seawater

TDS comprise inorganic salts, principally calcium, magnesium, potassium, sodium, bicarbonate, chlorides, sulphtes, and some small amounts of organic matter that are dissolved in water. A general classification of groundwater according to TDS is shown in Table (3.23)

Table (3.23): General Classification of groundwater according to TDS (Carroll, 1962)

Category of water	TDS (mg/L)
Fresh	0 – 1000
Brackish	1000 – 10000
Saline	10000 – 100000
Brine	> 100000

3.5.2 Water Genesis of Study Area:

3.5.2.1 The Wells of Marj Na'ja and Az Zubiedat:

3.5.2.1.1 Saturation Index and Durov Diagram:

In general, the water of the wells of Marj Na'ja and Az Zubiedat is undersaturated with respect to anhydrite, gypsum and aragonite, and oversaturated with respect to calcite and dolomite mineral phases except the sample of well 20-17/019 collected in 10/7/2003, which is in equilibrium with respect to the aragonite phase (Table 3.24). However, the water of samples collected in 9/1/2004 and 14/5/2004 of well (19-17/020), and sample collected in 4/8/2003 of well (20-17/010) are oversaturated with respect of aragonite mineral phases. The sample of well 19-17/011(9/1/2004) and sample of well 20-17/018 (4/8/2003) are undersaturated with respect to calcite mineral phase.

In Fact, this indicates that the calcite and dolomite are the main dominate mineral phases affecting the water composition through its transformation from the rainwater to groundwater in the recharge area of this watershed.

The sample of the well 19-17/020 (14/05/2004) is the most oversaturated with respect to calcite and dolomite. However, this sample was also the most oversaturated with respect to aragonite mineral phase.

Table (3.24): Saturation indices of the water of Marj Na'ja and Az Zubiedat wells with respect to some mineral phases.

No.	Well Code	Date	Saturation Indices				
			Anhydrite	Gypsum	Aragonite	Calcite	Dolomite
			– 1.89	– 1.67	– 0.03	0.11	0.44
2-	19-17/011	09/01/2004	– 1.87	– 1.65	– 0.20	– 0.06	0.13
3-	19-17/011	14/05/2004	– 1.62	– 1.40	– 0.09	0.05	0.35
4-	19-17/020	04/08/2003	– 1.54	– 1.32	– 0.13	0.02	0.31
5-	19-17/020	09/01/2004	– 1.56	– 1.34	0.04	0.19	0.66
6-	19-17/020	14/05/2004	– 1.43	– 1.21	0.27	0.42	1.10
7-	20-17/010	04/08/2003	–1.94	–1.72	0.16	0.30	0.80
8-	20-17/010	09/01/2004	–1.93	-1.71	-0.25	0.10	0.05
9-	20-17/010	14/05/2004	-1.81	-1.59	-0.08	0.06	0.38
10-	20-17/011	09/01/2004	-1.17	-0.95	-1.10	0.04	0.31
11-	20-17/011	14/05/2004	-1.15	-0.94	-0.09	0.06	0.38
12-	20-17/016	10/07/2003	-1.46	-1.24	-0.03	0.11	0.45
13-	20-17/016	09/01/2004	-1.52	-1.30	-0.10	0.04	0.35
14-	20-17/016	14/05/2004	-1.60	-1.38	0.15	0.30	0.85
15-	20-17/018	04/08/2003	-1.64	-1.42	-0.23	-0.09	0.09
16-	20-17/018	09/01/2004	-1.84	-1.62	-0.08	0.07	0.40
17-	20-17/019	14/05/2004	-1.55	-1.33	-0.05	0.09	0.45
18-	20-17/019	10/07/2003	-1.72	-1.50	0.00	0.14	0.57
19-	20-17/019	09/01/2004	-1.44	-1.22	-0.03	0.11	0.48
20-	20-17/019	14/05/2004	-1.70	-1.48	-0.09	0.05	0.39

The water from the wells of Marj Na'ja and Az Zubiedat plots in the Field (8) on Durov diagram "Cl dominant anion and Na dominant cation, indicating that the groundwaters be related to reverse ion exchange of Na-Cl waters" (Figure 3.23).

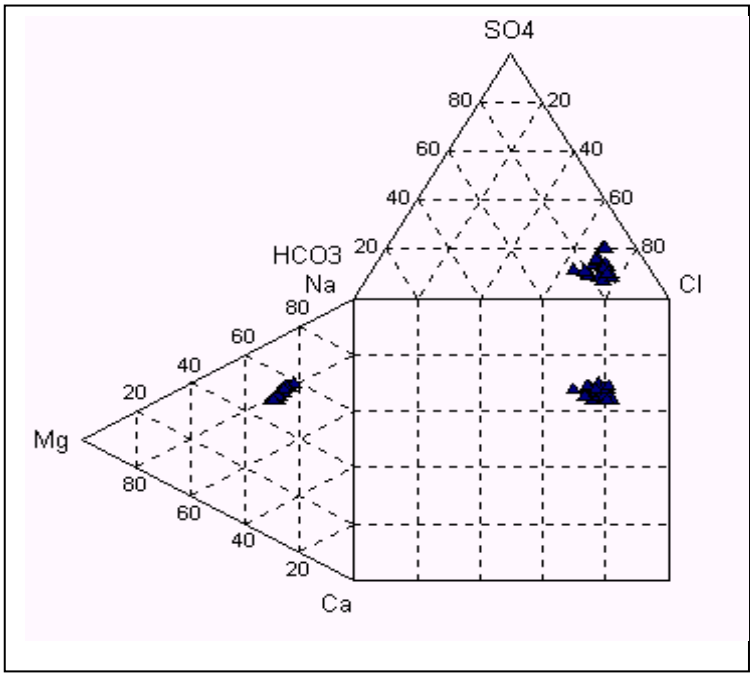

Figure (3.23): Durov Diagram showing the Wells of the Marj Na'ja and Az Zubiedat

3.5.2.1.2 Ionic Ratios and Water Type:

The groundwater of this group is characterized by sodium – chloride water type with the following ionic sequences: $Na^{+} > Mg^{+2} \geq Ca^{+2} > K^{+}$ and $Cl^{-} > HCO_3^{-} > SO_4^{-2} > NO_3^{-}$ (Appendix 3.14 A). The calculation of ionic ratios (expressed in meq/L) and water types are tabulated in Appendix (3.15)

This group is characterized by a relative high Mg^{+2}/Ca^{+2} ratios (1.22) which reflect water movement through limestone and dolomitic limestone (Kattan, 2001). These wells had surplus Mg which originates from dolomite dissolution of the Lisam formation since some wells of this area are characterized by Lisan formation (Khayat et al, 2006).

The Na^{+}/Cl^{-} ratio (0.77) is lower than that of water in the hydrological cycle (0.86 to 1), this may be probably because of a cationic exchange between sodium and both calcium and magnesium (Kattan, 2001).

Moreover, this group is characterized by low SO_4^{-2}/HCO_3^{-} ratio (0.85) accompanied by low HCO_3/Cl ratio (0.22) and low $Ca^{+2} + Mg^{+2}/Na^{+} + K^{+}$ ratio (0.84).

The ratio of HCO_3^{-}/Cl^{-} is commonly far less than 1 being the result of NaCl dissolution from the evaporites in the rocks (Moller et al., 2006).

3.5.2.1.3 Deduction of rock source:

Results indicate the following (Appendix 3.16):

- $Na^+ /Na^+ + Cl^-$ average value 0.43 indicates reserve softening. A $Na^+/Na^+ + Cl^-$ ratio less than 0.5 in combination with a high TDS suggest a reverse softening and upwelling from a fresh –water aquifer which contains salt-bearing rocks particles (Hounslow, 1995)

- $Mg^{+2}/Ca^{+2} + Mg^{+2}$ average value 0.57 indicate calcite precipitation which overlaps with Lisan formation and. $Ca^{+2}/Ca^{+2} + SO_4^{-2}$ ratio (0.64) indicate that in addition to calcite precipitation there is gypsum dissolution of Lisan Formation. The results show the main evaporitic effect, the effect of Lisan Formation and its gypsum and calcite (Khayat et al, 2006)
- TDS average value 2016.3 indicates brackish water (Todd, 1980).

- Cl^- /sum anions average values 0.71 indicate rock weathering of halite from the evaporites in the rocks (Hounslow, 1995)

- HCO_3^-/sum anions average values 0.16 indicate seawater (sulfate low)

3.5.2.2 The Wells of Frush Bait Dajan (F.B.D):

3.5.2.2.1 Saturation Index and Durov Diagram:

The water of all wells in F.B.D is undersaturated with respect to anhydrite and gypsum mineral phases and oversaturated with respect to aragonite, calcite and dolomite mineral phases except the sample of well 19-17/046 (11/1/2004), which is in equilibrium with respect to the calcite phase (Table 3.25). However, the water of samples of the well 19-17/034 (11/1/2004) and of well code 19-17/046 (11/1/2004) are undersaturated with respect of aragonite mineral phases.

In fact this indicates that the aragonite, calcite and dolomite are the three dominant mineral phases (the three main carbonate minerals) affecting the water composition through its transformation from the rainwater to groundwater wells in the recharge area of this watershed. The sample of the well 19-17/034 (14/05/2004) is the most oversaturated with respect to aragonite, calcite and dolomite. Oversaturation suggests mineral precipitation.

Table (3.25): Saturation indices of the water Frush Bait Dajan (F.B.D) Wells with respect to some mineral phases.

No.	Well Code	Date	Saturation Indices				
			Anhydrite	Gypsum	Aragonite	Calcite	Dolomite
1-	19-17/034	11/01/2004	-2.11	-1.89	-0.07	0.07	0.15
2-	19-17/034	14/05/2004	-2.09	-1.87	0.11	0.25	0.50
3-	19-17/046	11/01/2004	-1.69	-1.47	-0.15	0.00	0.08
4-	19-17/046a	14/05/2004	-1.87	-1.65	0.07	0.22	0.50
5-	19-17/046b	14/05/2004	-1.78	-1.56	0.02	0.17	0.36

The water of samples from the well code (19 – 17/034) plots in the Field (8) on Durov diagram "Cl dominant anion and Na dominant cation, indicate that the ground waters be related to reverse ion exchange of Na-Cl waters". (Figure 3.24).

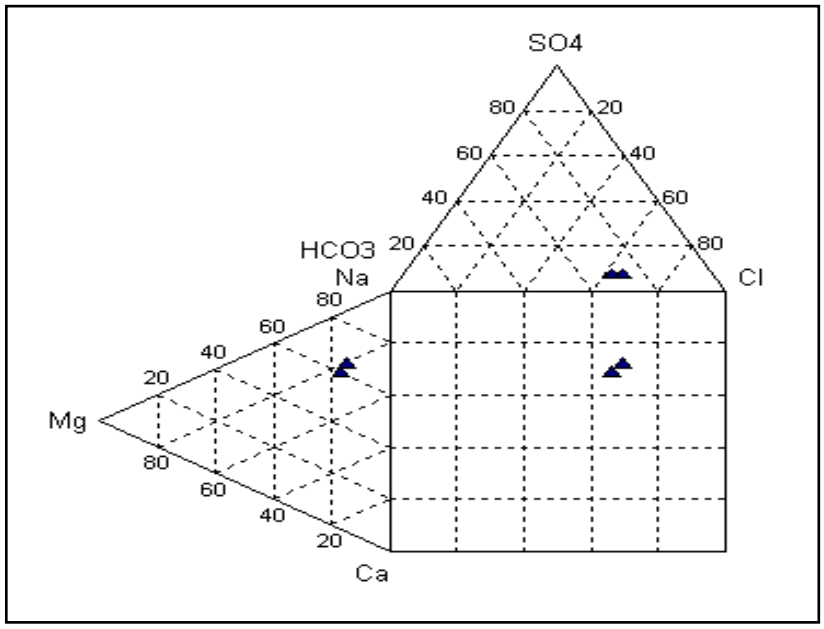

Figure (3.24): Durov Diagram showing Wells of the F.B.D (19-17/034)

While the water of samples from the well (19-17/046) plots in Filed (5) on Durov diagram "No dominant anion or cation, indicates water exhibiting simple dissolution" Figure (3.25).

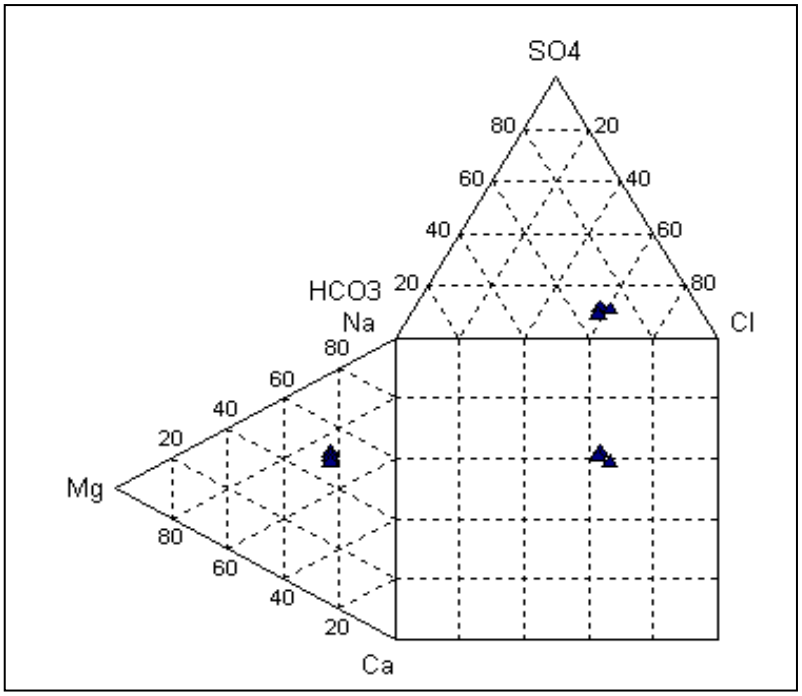

Figure (3.25): Durov Diagram showing Wells of the F.B.D (19-17/046)

3.5.2.2.2 Ionic Ratios and Water Type:

The groundwater of this group is characterized by sodium – chloride water type with the following ionic sequences $Na^{+} > Ca^{+2} > Mg^{+2} > K^{+}$ and $Cl^{-} > HCO_3^{-} > SO_4^{-2} > NO_3^{-}$ (Appendix 3.14 B). The calculation of ionic ratios (expressed in meq/L) and water types are tabulated in Appendix (3.17).

The Mg^{+2}/Ca^{+2} ratio (0.79) is comparable to the one (0.5–0.9) for limestone and dolomite aquifer, which reflects water movement through limestone and dolomitic limestone (Kattan, 1997).

The Na^{+}/Cl^{-} ratio (0.9) is close to that of the precipitation water (0.86 to 1), indicate dissolution of halite. In addition, this group is characterized by low SO_4^{-2}/ HCO_3^{-} ratio (0.15) accompanied by low HCO_3^{-}/Cl^{-} ratio (0.49) and low $Ca^{+2} + Mg^{+2}/Na^{+} + K^{+}$ ratio 0.86 (Moller et al., 2006).

The ratio of HCO_3^{-}/Cl^{-} is commonly far less than 1 being the result of NaCl dissolution from the evaporites in the Upper Cretaceous rocks (Moller et al., 2006).

3.5.2.2.3 Deduction of rock source:

Results indicate the following (Appendix 3.18):

- $Na^{+} /Na^{+} + Cl^{-}$ average value 0.47 (less than 0.5) in combination with a high TDS suggest a reverse softening and dissolution of NaCl from the evaporites in the Upper Cretaceous rocks (Moller et al, 2006)

- $Mg^{+2}/Ca^{+2} + Mg^{+2}$ average value 0.44 values which is around 0.5 indicate limestone-dolomite weathering (Hounslow, 1995).

- $Ca^{+2}/Ca^{+2} + SO_4^{-2}$ ratio average value (0.74) indicate that in addition to calcite precipitation there is gypsum dissolution. Low saturation index of gypsum, indicate gypsum dissolution (Khayat et al., 2006).

- TDS average value 1416.7 indicates brackish water (Todd, 1980)..

- Cl^{-} /sum anions average values 0.58 indicate Rock weathering of halite

- HCO_3^{-}/sum anions average values 0.28 indicate seawater (sulfate low)

3.5.2.3 Spring of Al Himmah:

3.5.2.3.1 Saturation Index and Durov Diagram:

The water of spring Al Himmah samples is undersaturated with respect to anhydrate, aragonite and gypsum, and oversaturated with respect to calcite and dolomite mineral phases. Only water of the sample collected in 9/1/2004 shows oversaturated which is close to equilibrium with respect to the aragonite phase (Table 3.26).

This indicates that the calcite and dolomite are the main carbonate minerals affecting the water composition through its transformation from the rainwater to spring in the recharge area of this watershed.

The sample collected in 09/01/2004 is the most oversaturated with respect to calcite and dolomite, which is also close to equilibrium with respect to aragonite mineral phase.

Table (3.26): Saturation indices of the water of Al Himmah Spring with respect to some mineral phases.

No.	Spring Code	Date	Saturation Indices				
			Anhydrite	Gypsum	Aragonite	Calcite	Dolomite
1-	AC/030A	10/07/2003	-2.25	-2.03	-0.08	0.07	0.22
2-	AC/030A	09/01/2004	-2.17	-1.95	0.06	0.21	0.46
3-	AC/030A	14/05/2004	-2.25	-2.03	-0.06	0.09	0.23

The water from Al Himmah spring plots in the Field (5) on Durov diagram "No dominates anion or cation, indicates water exhibiting simple dissolution" (Figure 3.26)

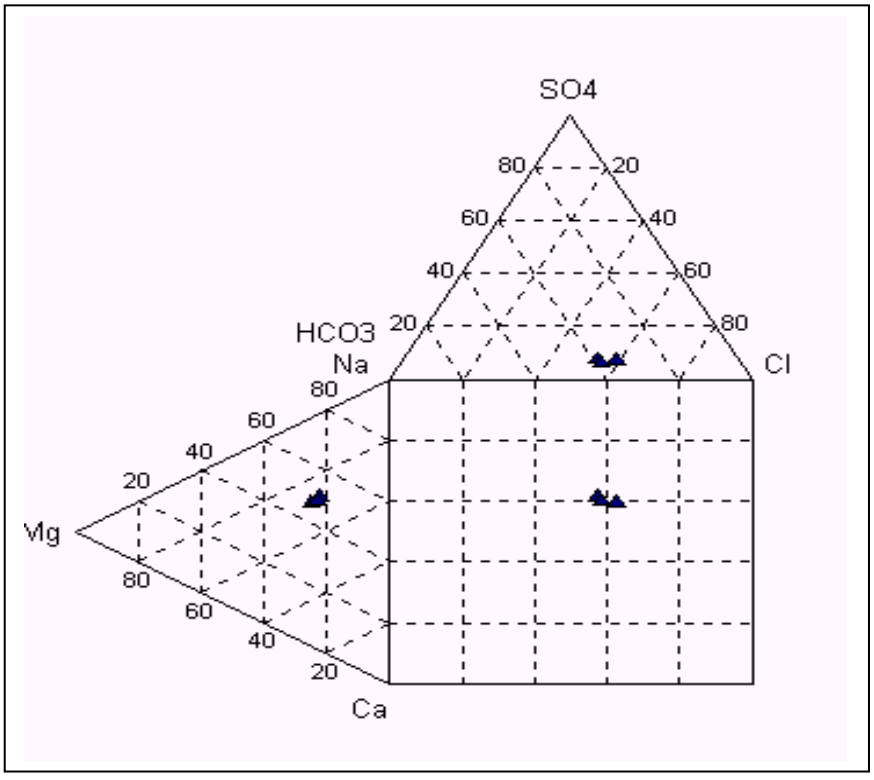

Figure (3.26): Durov Diagram showing the spring of Al –Himmah

3.5.2.3.2 Ionic Ratios and Water Type:

The groundwater of this group is characterized by sodium– chloride water type with the following ionic sequences $Na^{+} > Ca^{+2} > Mg^{+2} > K^{+}$ and $Cl^{-} > HCO_3^{-} > SO_4^{-2}$ (Appendix 3.14 C). The calculation of ionic ratios (expressed in meq/L) and water types are shown in Appendix (3.19).

The Mg^{+2}/Ca^{+2} ratio (0.85) is comparable to the (0.5–0.9) for limestone and dolomite aquifer, which reflects water movement through limestone and dolomitic limestone (Kattan, 2001).

The Na^{+2}/Cl^{-} ratio (0.84) is close to that of the precipitation water (0.86 to 1), indicate dissolution of halite.

Moreover, this group is characterized by low SO_4/ HCO_3 ratio (0.19) accompanied by low HCO_3^{-}/Cl^{-} ratio (0.67) and low $Ca^{+2} + Mg^{+2}/ Na^{+} + K^{+}$ ratio 1.04 . The ratio of HCO_3^{-}/Cl^{-} is commonly far less than 1 being the result of NaCl dissolution from the evaporates (Moller et al., 2006).

3.5.2.3.3 Deduction of rock source:

Results indicate the following (Appendix 3.20):

- $Na^{+} /Na^{+} + Cl^{-}$ average value 0.45 (less than 0.5) suggest a reverse softening and the Na^{+}/Cl^{-} ratio around one indicate dissolution of halite.

.

- $Mg^{+2} / Ca^{+2} + Mg^{+2}$ average values 0.46 which is around 0.5 indicate limestone-dolomite weathering.

- $Ca^{+2}/Ca^{+2} + SO_4^{-2}$ ratio 0.8 indicate that in addition to calcite precipitation there is gypsum dissolution. Relatively low SO_4^{-2} concentration in parallel with very low saturation index of gypsum, indicate gypsum dissolution (Khayat et al, 2006).

- TDS average value 795.5 mg/L. This group was characterized by Low TDS (<1000 mg/L) and can be classified as fresh water according to TDS classification (Todd, 1980).

- Cl^{-}/sum anions average values 0.55 indicate Rock weathering of halite

- HCO_3^{-}/sum anions average values 0.37 indicate Seawater (sulfate low)

3.5.2.4 Springs of Al Maleh:

3.5.2.4.1 Al Maleh Warm (Thermal Springs):

3.5.2.4.1.1 Saturation Index and Durov Diagram:

The water of the all samples of Al Maleh Warm springs is undersaturated with respect to the anhydrite and gypsum phase. In addition, most of the samples are oversaturated with respect to calcite and dolomite, and undersaturated with respect to aragonite mineral phases. However, the water of samples collected in 14/5/2004 of Al Maleh East is oversaturated with respect to aragonite phase. While samples of Al Maleh east (10/7/2003) and west (9/1/2004) are undersaturated with respect to calcite and dolomite mineral phases. Samples of Al Maleh west (14/5/2004) is also undersaturated with respect to dolomite phase (Table 3.27).

This indicates that the calcite and dolomite are the main dominate mineral phases affecting the water composition through its transformation from the rainwater to springs in the recharge area of this watershed.

Table (3.27): Saturation indices of Al Maleh Warm Springs with respect to some mineral phases.

No.	Spring Code	Date	Saturation Indices				
			Anhydrite	Gypsum	Aragonite	Calcite	Dolomite
1-	AC/041E	10/07/2003	-1.10	-0.88	-0.20	-0.05	-0.23
2-	AC/041E	09/01/2004	-1.17	-0.95	-0.01	0.13	0.15
3-	AC/041E	14/05/2004	-1.10	-0.88	0.09	0.24	0.09
4-	AC/041W	09/01/2004	-1.08	-0.86	-0.26	-0.11	-0.53
5-	AC/041W	10/07/2003	-1.14	-0.92	-0.09	0.05	0.02
6-	AC/041W	14/05/2004	-1.09	-0.87	-0.14	0.01	-0.22

The water from Al Maleh West and East springs plots in the Field (8) on Durov diagram " Cl dominant anion and Na dominant cation, indicate that the ground waters be related to reverse ion exchange of Na – Cl waters". (Figure 3.27)

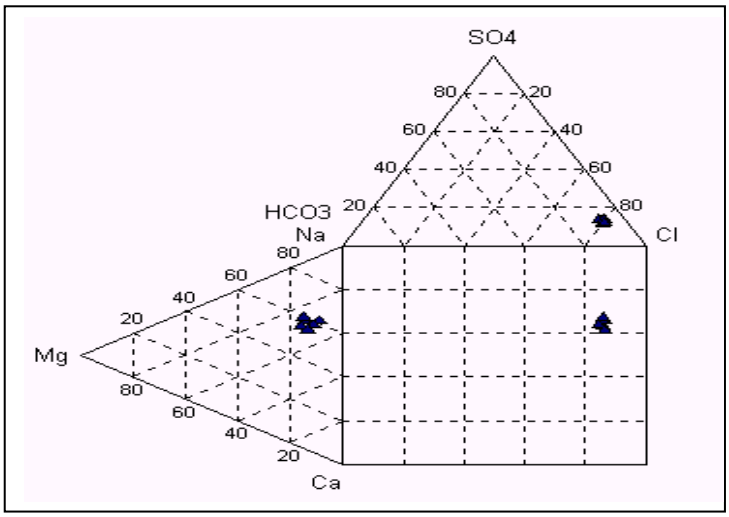

Figure (3.27): Durov Diagram showing the springs of Al-Maleh Warm

3.5.2.4.1.2 Ionic Ratios and Water Type:

The groundwater of this group is characterized by sodium -chloride water type with the following ionic sequences $Na^{+} > Ca^{+2} > Mg^{+2} > K^{+}$ and $Cl^{-} > SO_4^{-2} > HCO_3^{-}$ (Appendix 3.14 D). The calculation of ionic ratios (expressed in meq/L) and water types are shown in Appendix (3.21).

This group is characterized by a relative low Mg^{+2}/Ca^{+2} ratio (0.47) is somewhat comparable to (0.5– 0.9) which reflects water movement through limestone and dolomitic limestone (kattan, 2001).

The Na^{+}/Cl^{-} ratio (0.71) is lower than that of water in the hydrological cycle (0.86 to 1) , this may be probably because of a cationic exchange between sodium and both calcium and magnesium (Kattan, 1997). This ratio was somewhat comparable to the composition

of thermal hypersaline springs that emerge along the western shore of the Dead Sea (Marie and Vangosh, 2001).

Moreover, this group is characterized by high SO_4^{-2}/HCO_3^- ratio (1.64) which is comparable to that of thermal groundwater 2 to 13 (kattan, 2001) and low $Ca^{+2}+ Mg^{+2}/ Na^+ +K^+$ ratio 0.84.

The salinity of the groundwater increases with decreasing HCO_3^-/Cl^- ratio. The ratio of HCO_3^-/Cl^- (0.1) is commonly far less than 1 being the result of NaCl dissolution from the evaporites in the rocks (Moller et al , 2006).

3.5.2.4.1.3 Deduction of rock source:

Results indicate the following (Appendix 3.22):

- $Na^+ /Na^+ + Cl^-$ average value 0.42 (less than 0.5) with a high TDS suggest a reverse softening and upwelling from a deep brine aquifer. Below the zone of surface influence groundwater temperatures increases approximately 2.9 ^{0}C for each 100 m of depth in accordance with the geothermal gradient's of the earth crust (Todd, 1980) .

- $Mg^{+2} /Ca^{+2} +Mg^{+2}$ average values 0.32 indicate Limestone-dolomite weathering.

- $Ca^{+2}/Ca^{+2}+ SO_4^{-2}$ ratio 0.69 indicate that in addition to calcite precipitation there is gypsum dissolution. Relatively high SO_4^{-2} concentration in parallel with low saturation index of gypsum, indicate gypsum dissolution (Khayat et al., 2006).

- TDS average value 3377.5 indicate Brackish water. This group was characterized by high TDS.

- Cl^-/sum anions average values 0.8 indicate evaporites.

- HCO_3^-/sum anions average values 0.10 indicate gypsum dissolution (sulfate high).

Review of the data of the springs responsible for the Dead sea suggests that these waters are of meteoric-continental origin and that it is likely that these waters have experienced deep circulation in the rift system before discharging at the surface due to convective forces operating in the rift (Abu-Jaber, 1998)

On the basis of new Chemical and isotopic analyses, the saline waters could represent residual pockets of groundwater in equilibrium with those filling the Dead Sea depression before the last retreat of lake Lisan or with the ancient seawaters of the Sedom Lagoon in the early Pleistocene, in both cases unaffected by significant evaporation processes but chemically and isotopically modified by water/rock interaction (Capaccioni et al, 2003).

3.5.2.4.2 Al Maleh Cold:

3.5.2.4.2.1 Saturation Index and Durov Diagram:

The water sample of Al Maleh Cold spring is undersaturated with respect to the anhydrite and gypsum phase. In addition, the majority of samples are oversaturated with respect to calcite and dolomite, and undersaturated with respect to aragonite mineral phases. However, the water of samples of Al Maleh Cold collected in 9/1/2004 and 10/7/2003 are oversaturated with respect to aragonite phase. While samples collected in (4/8/2003) is undersaturated with respect to calcite and dolomite mineral phases (Table 3.28).

This indicates that the calcite and dolomite are the main dominate mineral phases affecting the water composition through its transformation from the rainwater to springs in the recharge area of this watershed. The sample collected in (10/07/2003) is the most oversaturated with respect to calcite and dolomite.

Table (3.28): Saturation indices of Al Maleh with respect to some mineral phases.

No.	Spring Code	Date	Saturation Indices				
			Anhydrite	Gypsum	Aragonite	Calcite	Dolomite
27-	AC/041C	04/08/2003	-2.43	-2.21	-0.23	-0.08	-0.33
28-	AC/041C	09/01/2004	-2.41	-2.19	0.05	0.19	0.21
29-	AC/041C	10/07/2003	-2.36	-2.14	0.08	0.23	0.32

The water from Al Maleh Cold spring plots in the Field (5) on Durov diagram “No dominant anion or cation, indicates water exhibiting simple dissolution or mixing" along the mixing – dissolution line may be due to the leaching of aquifer material. (Figure 3.28)

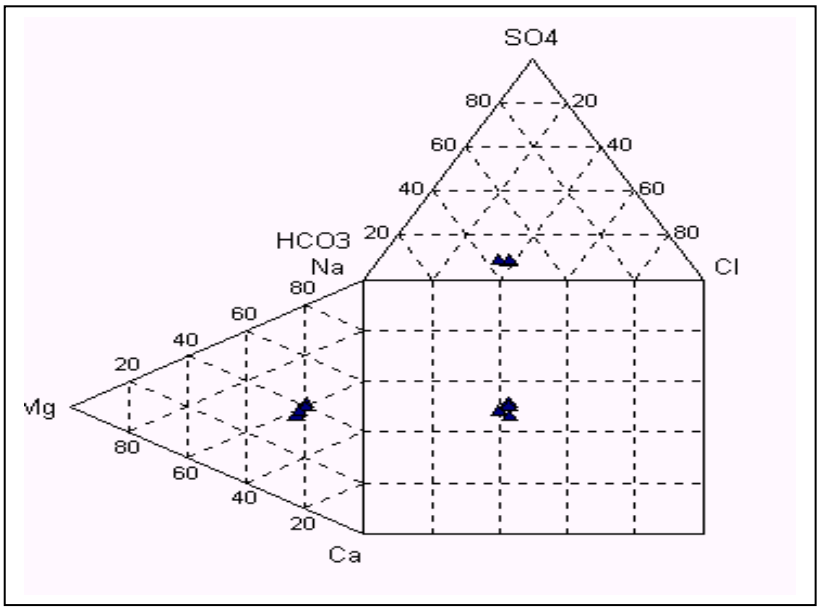

Figure (3.28): Durov Diagram showing the springs of Al-Maleh Cold

3.5.2.4.2.2 Ionic Ratios and Water Type:

The groundwater of this group is characterized by sodium -Bicarbonate water type with the following ionic sequences $Na^{+} > Ca^{+2} > Mg^{+2} > K^{+}$ and $HCO_3^{-} > Cl^{-} > SO_4^{-2}$ (Appendix 3.14 E). The calculation of ionic ratios (expressed in meq/L) and water types are shown in Appendix (3.23).

The Mg^{+2}/Ca^{+2} ratio (0.52) is comparable to the (0.5–0.9) for limestone and dolomite aquifer, which reflects water movement through limestone and dolomitic limestone (Kattan, 2001).

The Na^{+}/Cl^{-} ratio (1.1) is close to that of the precipitation water (0.86 to 1), indicate dissolution of halite. Moreover, this group is characterized by low SO_4/HCO_3 ratio (0.15) but accompanied by relatively high HCO_3^{-}/ Cl^{-} ratio (1.42) and low $Ca^{+2} + Mg^{+2}/ Na^{+} + K^{+}$ ratio 1.61. The Na^{+}/Cl^{-} ratio close to 1 and EC 600-700 µS/cm accompanied by high HCO_3^{-}/Cl^{-} indicate that the groundwater of this spring resembles the recharge water with a moderate water-rock interaction (Moller et al. , 2006).

3.5.2.4.2.3 Deduction of rock source:

Results indicate the following (Appendix 3.24):

- $Na^{+} /Na^{+} + Cl^{-}$ average value 0.5 indicate seawater.
- $Mg^{+2} /Ca^{+2} + Mg^{+2}$ average values 0.34 indicate Limestone-dolomite weathering.
- $Ca^{+2}/Ca^{+2} + SO_4^{-2}$ ratio 0.85 indicate that in addition to calcite precipitation there is gypsum dissolution. Relatively low SO_4^{-2} concentration in parallel with very low saturation index of gypsum, indicate gypsum dissolution.
- This group was characterized by low TDS 448.92 indicate Fresh water.
- Cl^{-} /sum anions average values 0.37 indicate Rock weathering of halite
- HCO_3^{-}/sum anions average values 0.52 indicate Sea Water (sulfate low)

3.6 ENVIRONMENTAL ISOTOPES ANALYSIS

3.6.1 Introduction:

Isotope hydrology is an emerging discipline with expanding investigation tools for many environmental problems. The use of environmental isotopes as tracers in the hydrosphere is increasing as analytical instrumentation improves and more applications are discovered. Naturally occurring isotopes in the environment describe hydrological processes, estimate ages, fingerprint sources and pathways (Slide, 1997).

Environmental isotopes in groundwater studies are not only used as tracers of the groundwater provenance and age but to study groundwater quality, geochemical evolution, recharge processes, rock – water interaction, the origin of salinity, and contamination processes (Clark and Fritz, 1997).

Oxygen and hydrogen isotopes provide intrinsic, conservative fingerprints to study the origin, sources, and flow path of water. Different isotopic ratios arise among water bodies because of geographic and meteoric input and subsequent evolutionary differences; consequently, these isotopes are of great value in tracing the sources of springs and groundwater (Criss et al., 2001).

The stable isotopes in the groundwater are the pointer which relates theses water to their origin, means precipitation, infiltration, surface water (Gat and Dansgaard, 1972). On the other hand, radioisotopes decay provides us with measure of circulation time, and thus groundwater renewability (Gat, 1996).

In this research the isotopic composition of stable isotopes, deuterium (D, ^{2}H) and oxygen–18 (^{18}O), and the radioactive isotope, tritium (^{3}H) in springs and wells were determined and evaluated.

3.6.2 Sampling and Analysis:

In this study 13 samples were collected from 10 wells and springs from different Locations of study area between July, 2003 and January 2004 to be analyzed for their isotopic composition (^{18}O and ^{2}H), and only 3 samples of Marj Na'ja and Az Zubiedat group were collected during January 2004 to be analyzed for the isotopic composition (^{3}H). The water samples for ^{18}O and ^{2}H were collected in 50 ml dark glass bottles and 500 ml polyethylene were used for ^{3}H determination.

The most common method for determining the oxygen isotope composition of water is by equilibration with CO_2 first proposed by Cohn and Urey (1938). At UFZ laboratory for stable isotopes a principle device set –up after Roether (1970) is operated. Generally is easily applied in commercial automated preparation lines to handle a larger number of samples at one time. In case of the "HDOeq48" automated preparation system of IsoCal, Graz installed at UFZ each run comprises determination of twenty and eight standards samples. At the end of the equilibrated CO_2 gas is measured by connected mass spectrometer (Finnigan).

Base of the CO_2 equilibrium method are the physical solution of CO_2 in water with.

$CO_{2(gas)} \longleftrightarrow CO_{2(aqua)}$

And its chemical reaction to HCO_3^- and H_3O^+:

$CO_{2\,(aqua)} + 2H_2O \longleftrightarrow HCO_3^- + H_3O^+$

The isotopic exchange reaction can be written as :

$C^{16}O_2 + H_2{}^{18}O \longleftrightarrow C^{18}O^{16}O + H_2{}^{16}O$

The $\delta\,{}^{18}O$ value is referred to the (VSMOW) standards and exhibit an error of 1‰.

Hydrogen isotope analysis is carried out in principle the same way as for $\delta^{18}O$ but using Hydrogen of known isotopic composition as equilibrium gas. The sample is referred to the VSMOW standard. The error is specified to be 0.81‰.

The isotopic concentration of ^{18}O and ^{2}H in water is expressed in per mil (‰) deviation from the Standard Mean Ocean Water (SMOW). These deviations are expressed using the delta (δ) notation:

$\delta^{18}O\,‰ = (({}^{18}O/{}^{16}O)_{sample} - ({}^{18}O/{}^{16}O)_{SMOW})/\,({}^{18}O/{}^{16}O)_{SMOW})*1000$ and

$\delta^{2}H\,‰ = (({}^{2}H/{}^{1}H)_{sample} - ({}^{2}H/{}^{1}H)_{SMOW})/\,({}^{2}H/{}^{1}H)_{SMOW})*1000$

Tritium concentrations are expressed as absolute concentrations using tritium units (TU). The TU represent the ration of ^{3}H atoms to ^{1}H atoms, where $^{3}H/^{1}H = 10^{-18}$ is defined as 1 tritium unit (1TU) (Mazor,1997).

3.6.3 Deuterium (^{2}H)-Oxygen (^{18}O) relationship:

In spite the complexity of the hydrological cycle, the ^{2}H and ^{18}O in the precipitation and the fresh surface water correlate on the global scale. This correlation, as a best –fit line termed meteoric line, is expressed as follows:

$\delta\,{}^{2}H = 8 * \delta\,{}^{18}O + 10$ (Craig, 1961)

This line 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. The Mediterranean or Middle East Meteoric Line (MMWL), representing the ^{2}H and ^{18}O relation in our area, has the following formula:

$\delta\,{}^{2}H = 8 * \delta\,{}^{18}O + 22$ (Gat, 1971)

Both the MWL and the MMWL are presented in Figure 3.29.

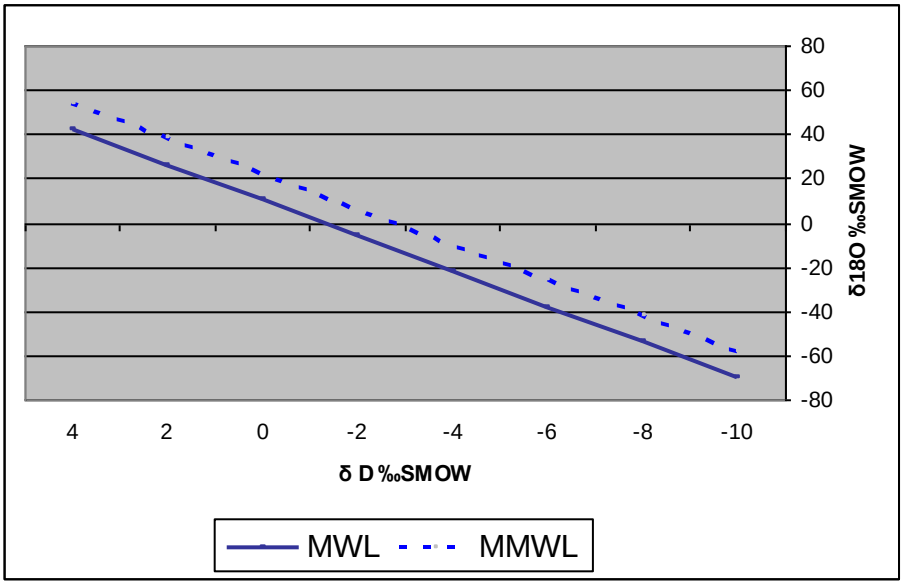

Figure (3.29): The ^{2}H and ^{18}O isotopic composition of precipitation and fresh surface water in the Mediterranean Meteoric Water region (MMWL) compared to global meteoric line (MWL).

An important term in the $\delta\ ^{2}H$ - $\delta\ ^{18}O$ correlation is the d-excess which is expressed as:

d-excess = $\delta\ ^{2}H - 8 * \delta\ ^{18}O$

D-excess is a measure of the deuterium enrichment that exceeds the $\delta\ ^{18}O$ value by more than 8 times (Clark and Fritz, 1997). It is also a measure of evaporation effects both during primary evaporation, when water is evaporated to form a vapor mass, and during secondary evaporation. High d-value indicates low humidity and rapid or kinetic evaporation effects on the isotopes. d-excess is around 22‰ in the Mediterranean region which result from cold and dry fronts that comes from the Atlantic Ocean to the east the Mediterranean region (Gat,1996).

3.6.4 The ^{2}H and ^{18}O composition of the springs and wells:

Both Table (3.29) and Figure (3.30) show that the isotopic contents of the water samples collected from the wells and springs of Marj Na'ja Area plot on the Mediterranean Meteoric Water Line (MMWL) with average values of -4.82 ‰ for $\delta\ ^{18}O$, -21.6‰ for $\delta\ ^{2}H$ and 16.9 ‰ for d-excess, which means that the water of these springs and wells originated from the rain water.

As seen in Table (3.29) the samples of Al Maleh Cold collected in summer seasons show the most enriched isotopic composition, -4.35 ‰ $\delta\ ^{18}O$ and -21.7‰ $\delta\ ^{2}H$ for sample collected in 4/8/2003 and -4.33 ‰ $\delta\ ^{18}O$ and -20.6‰ $\delta\ ^{2}H$ for samples collected in 10/07/2003. This may took place as a result of evaporation and temperature effect; the vapor is enriched in light water molecules, reflected in relatively negative $\delta\ ^{18}O$ and $\delta\ ^{2}H$ values. In contrast, the residual water phase becomes relatively enriched in heavy isotopes, reflected in more positive $\delta\ ^{18}O$ and $\delta\ ^{2}H$ values (Mazor, 1991).

Temperature is the major parameter that determines the isotopic values of precipitation increase of mean annual temperature increase the annual mean of $\delta\ ^{18}O$ (Mazor, 1991).

Table (5.18) shows that the samples collected during winter had the lowest enriched isotopic composition, the lowest values observed -5.21 ‰ $\delta\ ^{18}O$ and -22.4‰ $\delta\ ^{2}H$ for F.B.D samples and this may be as a result of temperature and amount effect.

The more negative are the vaules of both $\delta\ ^{18}O$ and $\delta\ ^{2}H$ proposed two major explanations for their amount effect (Dansgaard, 1964):

- Lower ambient temperatures cause the formation of clouds with lighter isotopes composition (temperature effect) and lower temperatures also cause heavier rains.
- Falling rain drops undergo evaporation, enriching the falling rain in the heavy isotopes. this effect is less severe both when ambient temperatures are low, and when the amount of rain is large (as the rain gets more saturated).

The d-excess is of the order 13.1 -19.30‰, which is lower than that for the eastern Mediterranean meteoric water (d=22 ‰). This decreses may be the result of interaction with more humid masses. High d-values indicate low humidity and rapid kinetic evaporation effects of isotopes.

Table (3.29): The ^{18}O and ^{2}H Composition of the Samples Collected from Marj Na'ja Area Wells and Springs (from July, 2003 to January, 2004)

No.	Well ID	Date	Temp. ^{0}C	Location	$\delta\ ^{2}H$	$\delta\ ^{18}O$	d-excess
1-	19-17/011	10/07/03	29.3	Az Zubeidat	-21.3	-4.81	17.14
2-	20-17/010	04/08/03	29.5	Marj Na'ja	-21.4	-4.74	16.46
3-	20-17/010	09/01/04	27.1	Marj Na'ja	-21.1	-4.76	17.00
4-	20-17/016	10/07/03	29.6	Marj Na'ja	-21.6	-4.82	17.00
5-	20-17/018	04/08/03	29.9	Marj Na'ja	-21.9	-4.79	16.41
6-	20-17/018	09/01/04	28.0	Marj Na'ja	-21.9	-5.11	19.00
7-	20-17/019	10/07/03	29.3	Marj Na'ja	-21.4	-4.87	17.53
8-	AC/030A	09/01/04	27.2	Al Himmah	-22.0	-5.07	18.52
9-	AC/041E	10/07/03	34.3	W.M.E	-21.7	-4.87	17.24
10-	AC/041C	04/08/03	26.3	W.M.C	-21.7	-4.35	13.07
11-	AC/041C	10/07/03	26.6	W.M.C	-20.6	-4.33	14.03
12-	AC/041W	10/07/03	34.9	W.M.W	-22.1	-4.88	16.90
13-	19-17/034	11/01/04	20.6	F-B-D	-22.4	-5.21	19.30
				Average	**-4.82**	**-21.6**	**16.9**

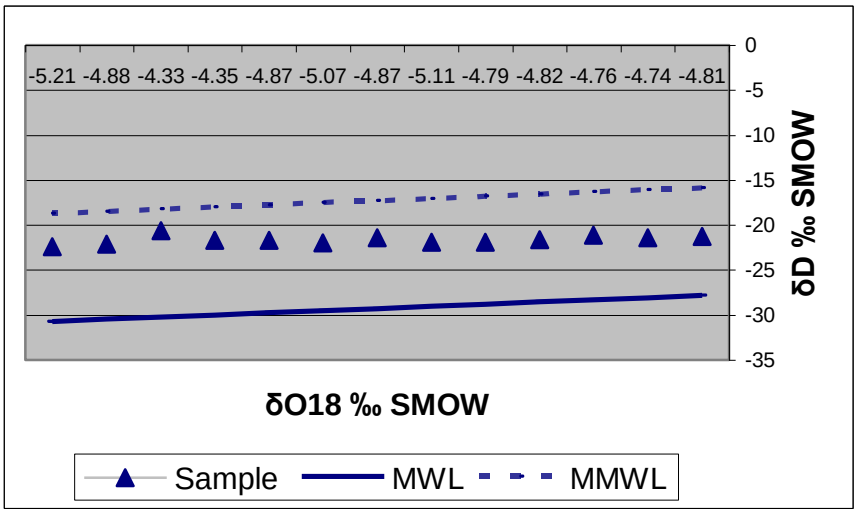

Figure (3.30): The δ ^{18}O and δ ^{2}H relation of the samples collected from the wells and springs of Marj Na'ja Area compared to MWL and the MMWL

3.6.4 Tritium:

Tritium (^{3}H) was used to estimate the relative ages of water. The natural level of tritium in rainfall averages 2-6 TU (ITU = 1^{3}H atoms in 10^{183} (Libby, 1971), but varies with seasons and location. Above ground nuclear weapons tests in the late 1950s and early 1960s introduced a large spike of tritium and other radioisotopes into the atmosphere (Eriksson, 1965). According to Cami and Gat (1973), the tritium concentrations in the precipitation is similar for the whole West Bank and Israel, it was about 5TU during 1950s (Kaufam and Libby, 1954). After 1963, the nuclear tests stopped and the concentrations depend on precipitation. Under the assumption of piston flow recharge mode and no mixing, based on that the half –life of tritium is 12.3 years, the expected tritium to stay in water in the year of 1998 is 0.4 TU if tritium in precipitation in 1998 was 5TU. While if ^{3}H in 1998 was 5.4 TU it was indicated that the ^{3}H in precipitation from 1991 (Qannam, 2003).

Results of tritium concentrations in the water of groundwater in collected from study area in spite its only few samples, show that the ^{3}H concentrations ranges from between 0.4 TU and 1.2 TU (Table 3.30), which means that the concentrations are within the range of old water before to 1950s.

However, it should take into consideration that only three samples were conducted and collected from Marj Na'ja and Az Zubiedat and not include samples from other site of the study area thus further investigations of tritium concentration in study area are essentially

Table (3.30): The Tritium Concentration in the samples of Marj Na'ja Area

Location	Tritium (^{3}H) (TU)	Uncertainty
Zubaidat	0.4	0.5
Marj Naja	0.1	0.5
Zubaidat	1.2	0.5

CHAPTER FOUR

CONCLUSIONS AND RECOMMENDATIONS

4.1 Conclusions

The aim of this research was to study the characteristics and genesis of the groundwater of Marj Na'ja Area in Jericho district. The study area include four different geographical are that was Marj Na'ja, Az Zubiedat and Frush Bait Dajan wells and springs of Al-Himmah and Wadi Al-Maleh .

The results show a great diversity in the chemical and physical characteristics of the wells and springs. The EC ranges between 663 µS/cm and 7580 µS/cm, which reflects significant variations in the concentrations of most of the major ions, also TDS ranges between 435.6mg/L and 3488.2 mg/L.

Calcium ranges between 68.1 mg/L and 365.5 mg/L, while sodium ranges between 65 mg/L and 798.8 mg/L. The anions show the same trend of variation as the bicarbonate and chloride ranges, between 244 and 463.7 mg/L and 99 and 1765.5 mg/L, respectively.

On piper diagram, the most abundant water type of the study is the "Alkaline water with prevailing chloride". Other samples of wells and springs plot on a piper diagram in area of "Earth alkaline water with increased portions of alkalis with prevailing sulfate and chloride" and only samples of Al Maleh cold plot on the area of "Earth alkaline water with increased portions of alkalis with prevailing bicarbonate"

The water parameters interrelationships between the different analyzed parameters of samples collected from the springs show a linear correlation between the variables which classify the relationship from very high significant relationship with correlation coefficient ≥ 0.9 to medium and poor relationship with correlation coefficient <0.7 showing the high significant relation, good relationship and medium relationship.

Cluster analysis using SPSS 11.0 and excel under windows classified the samples in this research into four groups.

Cluster (I): This cluster includes springs that are located in Himmah and Al-Maleh Cold. This cluster includes 18.4 % of the study samples with average EC of 1003.6µS/cm. It is dominated by Sodium cation (46 % of the total cation) and the Chloride anion (59 % of the total anion).

Cluster (II): This cluster includes samples of wells that are located in Marj Na'ja and F.B.D. It is dominated by Sodium cation (56 % of the total cation) and the Chloride anion (70% of the total anion). This cluster includes 28.9 % of the research samples with average EC of 2243.09 µS/cm.

Cluster (III): This cluster includes samples of springs that are located in Wadi Al Maleh Warm (East and West). It is dominated by Sodium cation (58 % of the total cation) and the Chloride anion (79 % of the total anion). This cluster includes 15.8 % of the research samples with average EC of 6505.0 µS/cm.

Cluster (IV): This cluster includes samples of wells that are located in Marj Na'ja. It is dominated by Sodium cation (53 % of the total cation) and the Chloride anion (74 % of the total anion). This cluster includes 36.8 % of the research samples with average EC of 4155.7 µS/cm.

The water of the groundwater wells and springs of the study area are not suitable for drinking purposes except the spring of Al Maleh cold and they are ranged from "hard" to "very hard". The high concentration of Cl^- gives the water a very unacceptable salty taste, thus making it unsuitable for drinking. In the EC-SAR classification these wells and springs are suitable for irrigation with limitation except springs of Al -Maleh Warm which are not suitable for irrigation and Al-Maleh Cold that is suitable for irrigation without any limitation.

Water genesis

The groundwater of Maj Na'ja, Az Zubiedat, F.B.D, Al-Himmah and Al – Maleh Warm are characterized by sodium and chloride water type with the following ionic sequences:

$$Na^+ > Ca^{+2} > Mg^{+2} > K^+ \text{ and } Cl^- > HCO_3^- > SO_4^{-2} > NO_3^-$$

On the other hand, ground water of Al Maleh Cold is characterized by Sodium and Bicarbonate water type with the following ionic sequences:

$$Na^+ > Ca^{+2} > Mg^{+2} > K^+ \text{ and } HCO_3^- > Cl^- > SO_4^{-2} > NO_3^-$$

The wells and springs of Marj Na'ja , Az Zubiedat, F.B.D (19-17/034) and Al Maleh Warm plots in the Field 8 on Durov diagram "Cl dominant anion and Na dominant cation, indicating that the ground waters be related to reverse ion exchange of Na-Cl waters". While wells and springs of F.B.D (19-17/046), Al Himmah and Al Maleh Cold plots in the Field 5 on Durov diagram "No dominant anion or cation, indicates water exhibiting simple dissolution".

Most of the sample of wells and spring undersaturated with respect to anhydrate, gypsum and aragonite, and oversaturated with respect to calcite and dolomite mineral phases. In Fact, this indicates that the calcite and dolomite are the main dominate mineral phases affecting the water composition through its transformation from the rainwater to groundwater wells in the recharge area of this watershed.

Mg^{+2}/Ca^{+2} ratios are comparable to the one (0.5–0.9) for limestone and dolomite aquifer, which reflects water movement through limestone and dolomitic limestone. However Marj Na;ja and Az Zubiedat wells had surplus Mg^{+2} which originates from dolomite dissolution of the Lisan formation

Na^+/Cl^- ratios of Marj Na'ja, Az Zubiedat and Al Maleh Warm lower than that of water in the hydrological cycle (0.86 to 1). This may be probably because of a cationic exchange between sodium and both calcium and magnesium.

While Na^+/Cl^- ratios of F.B.D wells, Al Himmah and Al Maleh Cold springs are close to that of the precipitation water (0.86 to 1).

HCO_3^- /Cl^- ratios of Marj Na'ja, Az Zubiedat, F.B.D, Al Himmah, AL Maleh Warm wells and springs are far less than 1 being the result of NaCl dissolution from the evaporites in the rocks.

In Al Maleh Cold the ratio of HCO_3^- /Cl^- is higher than one accompanied with Na^+/Cl^- ratio around 1 and EC 600 – 700 µS/cm indicate that this groundwater resembles the recharge water with moderate water-rock interaction

The isotopic contents of the water samples collected from the wells and springs of Marj Na'ja Area plot on the Mediterranean Meteoric Water Line (MMWL) with average values of -4.82 ‰ for $\delta\ ^{18}O$, -21.6‰ for $\delta\ ^{2}H$ and 16.9 ‰ for d-excess, which means that the water of these springs and wells originated from the rain water.

Results of tritium concentrations in the water of groundwater in collected from study area in spite its only few samples, show that the ^{3}H concentrations within the range of old water before to 1950s.

4.1 Recommendations

Depends on the results of this research the following recommendations may take into consideration:

1- Detail Isotopic studies (18O, 2H and 3H) for understanding the groundwater quality, geochemical evolution, and recharge processes, rock – water interaction, the origin of salinity, and contamination processes.

2- Further details on geological and hydrological studies are required to determine the hydrogeological characteristics of each springs and wells in the study area and flow pattern of aquifer system.

3- Long-term spatial and temporal monitoring of the water quality, especially the fecal coliform count, EC, NO3 - and Cl- concentrations in major wells and springs.

4- Constructing an appropriate drainage infrastructure that can prevent the onset of the serious soil and groundwater salinity problems. Without proper drainage to remove the leaching water, the water table will rise, resulting in water logging and soil salinization.

5- Selecting crops or varieties of crops, such as barely, grain and date palms, which tolerate salt. This is necessary to control salinity and reduce the water required for leaching.

REFERENCES

Abdul – Jaber, Q.(1995): **Water Chemistry of Some Groundwaters from the West Bank** . Proceedings of the Symposium. A Strategy for Water Sector Capacity Building in Palestine, 6 – 7 September , Bir Zeit, Palestine.

Abdul–Jaber, Q., Abed Rabbo, A., Scarpa, D., Qannam, Z. and Younger, P. (1999): **Wells in the West Bank–Water Quality and Chemistry**. Palestinian Hydrology Group, Newcastle University and Bethlehem University. Bethlehem University/ (PHG)/UNUT.

Abed Rabbo, A., Scarpa, D. and Qannam, Z., Abdul–Jaber, Q and Younger, P. (1999): **Springs in the West Bank–Water Quality and Chemistry**. Palestinian Hydrology Group, Newcastle University and Bethlehem University. Bethlehem University/(PHG)/UNUT.

Abu-Jaber, N.S. (1998): "A New Look at the Chemical and hydrological Evolution of the Dead Sea". Geochimica et Cosmochimica Acta, **62** (9):1471 -1479.

American Health Association, (1995): **Standards Method for the Examination of Water and Wastewater**, Washington.

Arij (Applied Research Institute – Jerusalem), 1995: **Environmental profile for the West Bank – Jericho District.** Bethlehem, Palestine. Vol.2:1–28.

Arij (Applied Research Institute – Jerusalem), 1997: **The Status of the Environmental in the West Bank**. Bethlehem, Palestine.

Arij (Applied Research Institute – Jerusalem), 1998: **Water Resources and Irrigated Agriculture in the West Bank**. Bethlehem, Palestine.

Awadallah, W. and Owaiwi, M (2005): **Springs and Dug Wells of Hebron District, Hydrology and Hydrochemistry**. The Palestinian Hydrology Group, Hebron, Palestine.

Calmbach, L. (1997): **AquaChem 3.7** (Aqueous Geochemical Data Analysis and Plotting) – software designed for hydrochemical data analysis. Waterloo Hydrogeologic. Ontario, Canada.

Caroll, D. (1962): **Rainwater as a Chemical Agent of Geologic Processes**–A review. US Geological Survey, Water supply paper, 1535 – G, 18 p.

Capaccioni,B., Vaselli, O., Moretti, E., Tassi,F. and Franchi, R. (2003): "The Origin of Thermal Waters from the Eastern Flank of the Daed Sea Rift Valley (Western Jordan)". Terra Nava, **15**, 145–154.

Carmi, I.and Gat, J.R. (1973)): "Tritium in precipitation and Fresh water Sources in Isreal", Israel Journal of Science, **22**:71-92.

Clark, I.D. and Fritz, P. (1997): **Environmental Isotopes in Hydrology**. Lewis Publishers, New York..

Cohn, M and Urey, H.C.(1938): "Oxygen exchange reactions of organic compounds and water". J. Am. Chem. Soc., **60**, p 679.

Criag, H. (1961): "Isotopic Variations in Meteoric Waters". Science, **133**: 1702–1703.

Criss, R., Fernandes, S.A. and Winston, W.E.(2001): "Isotopic, Geochemical and biological Tracing of the Source of an Impacted Krast spring, Weldon Spring, Missouri". Environmental Forensics.**2**:99 – 103.

Dansgaard, W. (1964): "Stable isotopes in precipitation". Tellus,**16:** 436-468.

De Zuane, J. (1990). **Handbook for Drinking Water Quality Standards and Controls**. Van Nostrand Reinhold, New York.

Durov, S.A. (1948): **Natural Waters and Graphical Representation of their Compositions**. Dokl Akad Nauk SSSR 59:87-90.

Environmental Research Laboratory of Al – Quds University, 2006, Abo Dies, Palestine.

Erikson, E. (1965): "An account of Major pulses of tritium and their effect in the atmpsphere". Tellus, **17**:118-130.

Fetter, C.W. (1994): **Applied Hydrology**, 3rd edition, Macmillan College Publishing Company, INC. New York, USA.

Gat, J.R. (1971): "Comments on stable isotopes method in regional groundwater investigations". Water Resources Research, **7**: p980 .

Gat, J.R. (1996): **Oxygen and Hydrology Isotopes in the Hydrological Cycle**. Annual Review of Earth and Planetary sciences, 24. A non Profit Publisher. USA: 225 – 262.

Gat, J.R. and Dansgaard, W (1972): "Stable Isotopes Survey of the Fresh Water Occurance in Isreal and Northen Jordan Rift Valley". Jouranl of Hydrology, **16**: 117 – 212.

Handbook of the HDOeq48 device (IsoCal, Graz).

Helena, B. A., Vega, M., Barrado, E., Pardo, R. and Fernandez, L.(1999): "Case of Hydrochemical Characterization of an Alluvial Aquifers Influenced by Human Activity". Water, Air, and Soil Pollution, **112:** 365 – 387.

Hounslow, A.W. (1995): **Water Quality Data, Analysis and Interpretation**. Lewis Publishers CRC Press, Inc. United States of America.

Kaufman, S. and Libby, W. (1954): "Natural Distribution of Tritium". Phys. Rev. **93**: 337-1344.

Kattan, Z. (1997): "Environmental Isotope Study of the Major Karst Springs in Damascus Limestone Aquifer Systems: Case of the Figeh and Barada Springs". Journal of Hydrology, **139**: 161–182.

Kattan, Z. (2001): "Use of Hydrochemistry and Environmental Isotopes for Evaluation of Groundwater in the Paleogene limestone Aquifer of the Ras Al-Ain Area (Syrina Jezireh)". Environmental Geology, **41**: 128–144.

Khayat, S., Hotzl, H., Geyer, S. and Ali, W. (2006): "Hydrochemical Investigation of Water from the Pleistocene Wells and Springs, Jericho area, Palestine". Hydrology. J. **14:**192–202.

Languth, H.R. (1966). **Die Grundwasserverhaltnisse Berecich des Velberter Sattles, Rheinisches Schiefergeberge, Der Minister fur Ernahrung**. Landwirtschaft und forsten, NRW, Dusseldorf.

Libby, W.F.(1971): **History of Trituim**. In:Moghissi AA, Carter MW(ed)Tritium Messenger Graphics/Las Vegas Publishers, Las Vagas, pp3-11.

LIoyd, J. W. and Heathcoat, J. A. (1985): **Natural Inorganic Chemistry In Relation to Groundwater**. Clarendon Press, Oxford.

Marei, A. and Vangosh, A. (2001): "Sources of Salinity in Groundwater from Jericho Area, Joradn Valley". Groundwater, **39** (2):240 – 248.

Mazor, E. (1997): **Chemical and Isotopic Groundwater Hydrology, the Applied Approach**, 2nd Edition. Marcel Dekker, Inc. New York.

Moller, P., Dulski, P., Salameh, E. and Geyer, S. (2006): "Characterization of the Source of Thermal Springs- and Well Water in Jordan by rare earth Element and Yttrium Distribution and satble Isotopes of H_2O". Acta Hydrochim. Hydrobil. **34**:101 -116.

Moller, P., Geyer, S., Salameh, E. and Dulski, P. (2006): "Sources of Mineralization and Salinization of Thermal Groundwater of Jordan". Acta Hydrochim. Hydrobil. **34**:86 - 100.

Palestinian Hydrology Group, 2005. Ramalleh, Palestine.

Palestinian National Authority-Palestinian Water Authority. Ramalleh, Palestine, 2005

PWA-Palestinian Water Authority (2004): **Drinking Water Standards**. Ramalleh, Palestine.

Palestinian National Authority (1998): Ministry of Planning and International Cooperation. **Sensitive Water Resources Recharge Areas in the West Bank Governorates-Emergency Natural Resources Protection Plan**, 2nd edition .Rammallah, Palestine.

Palestinian National Authority (2004), Ministry of transport, **Metrological Office, Jericho Climatic Station**. Jericho, Palestine.

Palestinian Central Bureau of Statistics, Jericho Profile (2005).

Parkhurst , D.L. and Appelo, C.A.J. (2001): **PHREEQC** – A Computer Program for Speciation, batch reactions, one dimensional transport and inverse geochemical calculations. US Geological Survey.

Piper, A.M. (1944): Graphical Procedure in Geochemical Interpretation of Water analysis.**Tans-American Geophysical Union**, **25:** 914 – 928.

Qannam, Z.S.:(2003): **A Hydrological, Hydrochemical and Environmental Study of Wadi Al Arroub Drainage Basin, South West Bank, Palestine**.TU Bergakademie Freiberg, Germany.

Richard, L.A. 1954: **Diagnosis and Improvement of Saline and Alkali Soils**. USAD Agricultural Handbook 60, US Departement of Agriculture, Washington, DC.

Roether, W.(1970): "Water CO_2 Exchange set-up for Routine ^{18}O assay of natural Waters". Int. J. Appl. Radiat. Isot, **21**,p 379.

Rofe and Raffety (1963): **Jerusalem District Water Supply, Geological and Hydrological Report.** Hashimite Kingdom of Jordan Central Water Authority.

Rofe and Raffety (1965): **Nabuls District Water Resources Survey, Geological and Hydrological Report**. Hashimite Kingdom of Jordan Central Water Authority.

Sawyer, C.N. and McCarty, P.L. (1967): **Chemistry and Sanitary Engineers**, 2nd edition. McGraw – Hill, New York.

Scarpa, D.J., Abed Rabbo, A., Qannam, Z. and Abdul-Jaber, Q. (1998): "Groundwater Pollution in Unconfined Aquifers in the Northern West Bank, Palestine. Proceedings of the British Hydrological Society International Conference, Exeter". Hydrology in a Changing Environment, **Vol.II.** John Wiley and Sons, Chichester. 33-40.

Silde, W.C. (1998): "Environmental Isotopes for Resolution of Hydrology Problems". Environmental Monitoring and Assessment, **52**:389 -410.

SPSS Inc. (2000): **SPSS 11 FOR WINDOWS** – Statistical Package for the Social Science. Chicago, USA. (www.spss.com).

Todd, D. (1980): **Groundwater**. Prentice-Hall Inc. London.

United Nations (1995**): Groundwater Software for Windows (GWW).** New York.

WHO-Word Health Organization (2004): **Guidelines for drinking water quality**.

Wilcox, L.V.(1955): **Classification and Use of Irrigation Waters**, US Dept. Agric. Circ. 969, Washington, D.C., USA. pp19.

APPENDIXCES

Appendix (1.1): Generalized Stratigraphy of the West Bank (Rofe and Raffety 1963, 1965; Qannam, 2003)

Geological Time Scale			Group			Formation		Lithology	Thickness (m)	Hydrostati graph
Era	**System**	**Epoch**	**Palestinian**		**Israeli**	**Palestinian**	**Israeli**			
CENOZOIC	Quaternary	Holecene	Recent		Kurkar	Alluvium	Alluvium	Marl, alluvium, gravel	Variable	Aquifer
						Gravel	River gravel			Aquifer
		Pleistocene	Lisan		Dead Sea	Lisan	Lisan	Thinly laminated marl with gypsum bands	200+	
	Tertiary Neogene	Pleistocene-Miocene	Beida	Jenin Sub Series	Saqia	Beida	Bit Nir and Ziplag	Conglomerate	0-200	Aquifer
	Paleogene	Eocene	Belqa		Avidat	Reef nummulitic limestone	Zor'a	Reef limestone, bedded limestone, chalk with limestone undifferentiated	100-500	Aquifer in limestone and aquiclude in chalk
		Paleocene			Mount Scopus	Nummulitic limestone	Taqiya	Marl, chalk and clay		Aquiclude
MESOZOIC	Senonian	Mastrichtian				Khan Al Ahmar and Zerqa	Ghareb	Yellowish chalk		Aquiclude
	Cretaceous	Campanian				Amman and Abu Dies	Mishash	Chalk with back chert		Aquiclude
		Santonian					Menuha	Chalk		Aquiclude
		Turonian	Ajlun		Judea	Jerusalem	Bina	Limestone and dolomite(karastic)	90-120	Aquifer
		Cenomanian				Bethlehem	Weradim	Hard gray porous dolomite	90-100	Aquifer
							Kfar Shaul	Chalky limestone, chalk and marl	30-40	Aquitard
						Hebron	Aminadav	Karastic limestone and dolomite	110-140	Aquifer
						Yatta	Moza	Marl, clay and marly limestone	10-20	Aquiclude
							Beit Meir	Limestone, chalky limestone and dolomite	120-140	Aquifer
								Limestone inter-bedded with marl		Aquclude
		Albian				Upper Beit Khahil	Kersalon	Limestone inter-bedded with marl	30-50	Aquifer
							Sorreq	Dolomite inter-bedded with marl	110-170	Aquifer
						Lower Beit Khahil	Giva't Yearim	Limestone, dolomite	20-70	Aquifer
							Kefira	Limestone, dolomite and marly limestone	120-180	Aquifer
			Kurnub			Kobar	Qatana	Marl and clay	50	Aquitard
							Ein Qinyia	Marl and marly limestone	60-70	Aquitard
							Tammum	Clay and marl	80-150	Aquitard
		Aptian					Ein Al Asad	Limestone		Aquifer
					Kurnub		Nabi Said	Limestone		Aquifer
		Neocomian	Zerqa		'Arad	Ramali	Hatira	Sandstone	150	Aquifer
	Jurassic	Callovian-Bajocian				Upper Malih	Upper Malih	Marl interbedded with chalky limestone	190	Aquitard
						Lower Malih	Lower Malih	Dolomitic limestone, jointed and krastic	55	Aquifer

Appendix (3.1): Physical and Chemical Characteristics of Marj Na'ja and Az Zubiedat Wells

No.	Well Code	Date	Location	Temp. ^{0}C	EC µS/cm	pH	TDS mg/L	Ca^{2+} mg/L	Mg^{+2} mg/L	Na^{+} mg/L	K^{+} mg/L	HCO_3^{-} mg/L	SO_4^{2-} mg/L	Cl^{-} mg/L	NO_3^{-} mg/L
1-	19-17/011	10/07/2003	Az Zubeidat	29.3	2230	7.27	1381.7	101.0	73.8	329.5	23.2	292.9	110.0	580.0	17.8
2-	19-17/011	09/01/2004	Az Zubeidat	27	2620	7.07	1290.1	95.0	75.0	301.0	17.4	329.0	120.0	498.0	19.2
3-	19-17/011	14/05/2004	Az Zubeidat	28.6	3240	7.12	1671.1	127.5	99.2	330.3	22.6	311.2	188.5	723.0	24.4
4-	19-17/020	04/08/2003	Az Zubeidat	29	3360	7.08	2147.0	148.2	123.9	486.8	31.3	292.9	230.0	956.0	24.3
5-	19-17/020	09/01/2004	Az Zubeidat	26.5	4840	7.19	2184.8	153.0	129.0	492.0	31.6	329.6	214.0	978.0	22.4
6-	19-17/020	14/05/2004	Az Zubeidat	28.2	4170	7.40	2219.4	157.9	130.3	441.2	32.3	341.7	285.0	964.0	37.8
7-	20-17/010	04/08/2003	Marj Na'ja	29.5	2350	7.48	1466.9	101.0	70.9	357.0	26.6	280.6	98.7	655.0	17.4
8-	20-17/010	09/01/2004	Marj Na'ja	27.1	2670	7.05	1382.2	97.0	77.8	333.0	25.1	308.0	105.3	590.0	5.2
9-	20-17/010	14/05/2004	Marj Na'ja	29.4	2900	7.16	1429.6	109.8	87.0	300.5	22.6	317.3	130.0	595.6	25.4
10-	20-17/011	09/01/2004	Marj Na'ja	27.6	5110	6.97	3036.5	210.2	157.0	619.0	170.0	330.0	483.8	1211.6	19.9
11-	20-17/011	14/05/2004	Marj Na'ja	29.1	5550	7.01	3182.6	208.4	175.0	574.0	209.9	317.3	520.0	1304.6	32.0
12-	20-17/016	10/07/2003	Marj Na'ja	29.6	3560	7.13	2259.8	160.3	121.5	519.2	32.0	305.0	260.0	986.0	28.4
13-	20-17/016	09/01/2004	Marj Na'ja	27.2	4190	7.01	2229.4	160.3	132.2	514.0	28.4	341.7	229.0	970.0	24.6
14-	20-17/016	14/05/2004	Marj Na'ja	28.7	4700	7.21	2341.6	185.2	146.8	523.5	30.7	341.7	172.5	1067.0	45.0
15-	20-17/018	04/08/2003	Marj Na'ja	29.9	3310	6.96	2114.7	143.5	119.6	494.3	32.7	305.1	184.5	963.0	24.5
16-	20-17/018	09/01/2004	Marj Na'ja	28	3750	7.06	1920.7	135.5	110.3	438.6	28.4	353.9	115.5	894.8	20.7
17-	20-17/019	14/05/2004	Marj Na'ja	29.7	4160	7.09	2107.6	152.3	125.9	430.0	30.7	329.5	215.0	964.0	24.9
18-	20-17/019	10/07/2003	Marj Na'ja	29.3	3430	7.21	1943.3	138.6	121.0	361.8	32.0	292.9	150.0	977.0	16.4
19-	20-17/019	09/01/2004	Marj Na'ja	28.1	4250	7.11	2167.9	151.5	121.5	488.9	28.4	341.7	287.6	907.0	12.2
20-	20-17/019	14/05/2004	Marj Na'ja	29.3	3800	7.12	1849.3	137.9	117.2	360.0	26.0	292.8	155.0	886.0	20.8

Appendix (3.2): Physical and Chemical Characteristics of F.B.D Wells studied in

No.	Well Code	Date	Temp. ^0C	EC µS/cm	pH	TDS mg/L	Ca^{2+} mg/L	Mg^{+2} mg/L	Na^{+} mg/L	K^{+} mg/L	HCO_3^{-} mg/L	SO_4^{2-} mg/L	Cl^{-} mg/L	NO_3^{-} mg/L
1-	19-17/034	11/01/2004	20.6	788	7.18	1098.5	84.1	37.4	250.0	8.0	360.0	65.0	430.0	44.0
2-	19-17/034	14/05/2004	22.4	826	7.39	1186.6	84.1	37.0	300.0	3.2	341.0	70.0	480.0	41.8
3-	19-17/046	11/01/2004	24	2430	6.83	1512.3	141.0	75.3	305.6	4.7	463.7	135.9	503.0	114.9
4-	19-17/046a	14/05/2004	25.9	2310	7.12	1255.9	125.8	64.6	256.3	8.1	414.9	90.0	432.5	71.2
5-	19-17/046b	14/05/2004	25.8	2310	7.12	1241.7	128.0	60.8	232.8	12.9	360.0	108.0	453.8	65.4

Appendix (3.3): Physical and Chemical Characteristics of the Al Himmah Spring

No.	Spring Code	Date	Temp. ^0C	EC µS/cm	pH	TDS mg/L	Ca^{2+} mg/L	Mg^{+2} mg/L	Na^{+} mg/L	K^{+} mg/L	HCO_3^{-} mg/L	SO_4^{2-} mg/L	Cl^{-} mg/L	NO_3^{-} mg/L
1-	AC/030A	10/07/2003	31.7	1225	7.27	763.2	76.3	41.1	145.7	5.5	292.9	47.0	294.4	6.7
2-	AC/030A	09/01/2004	27.2	1467	7.31	828.4	80.2	39.9	169.0	4.7	360.0	55.0	289.3	10.4
3-	AC/030A	14/05/2004	30.9	1505	7.21	795.8	79.4	39.9	157.0	6.9	341.7	45.0	283.6	13.2

Appendix (3.4): Physical and Chemical Characteristics of Al Maleh Warm Springs

No.	Spring Code	Date	Location	Temp. ^0C	EC µS/cm	pH	TDS mg/L	Ca^{2+} mg/L	Mg^{+2} mg/L	Na^{+} mg/L	K^{+} mg/L	HCO_3^{-} mg/L	SO_4^{2-} mg/L	Cl^{-} mg/L	NO_3^{-} mg/L
1-	AC/041E	10/07/2003	W.M.E	34.3	5180	6.83	3426.5	316.6	105.9	798.8	49.7	244.1	390.0	1632.0	11.4
2-	AC/041E	09/01/2004	W.M.E	30	6500	6.9	3382.4	322.3	109.4	709.5	45.8	311.2	321.7	1697.6	20.7
3-	AC/041E	14/05/2004	W.M.E	33	6880	7.03	3358.6	332.6	60.8	777.0	32.3	280.7	350.0	1659.0	6.6
4-	AC/041W	09/01/2004	W.M.W	35	7470	6.65	3236.0	340.7	75.3	733.0	48.6	292.9	360.0	1512.0	19.9
5-	AC/041W	10/07/2003	W.M.W	34.9	5420	6.94	3373.2	298.1	106.9	793.8	50.4	256.3	370.0	1613.0	12.8
6-	AC/041W	14/05/2004	W.M.W	35.3	7580	6.76	3488.2	365.5	94.3	722.8	40.4	286.8	350.0	1765.5	6.3

Appendix (3.5): Physical and Chemical Characteristics of Al Maleh Cold Spring

No.	Spring Code	Date	Location	Temp. ^0C	EC µS/cm	pH	TDS mg/L	Ca^{2+} mg/L	Mg^{+2} mg/L	Na^{+} mg/L	K^{+} mg/L	HCO_3^{-} mg/L	SO_4^{2-} mg/L	Cl^{-} mg/L	NO_3^{-} mg/L
1-	AC/041C	04/08/2003	W.M.C	26.3	706	7.19	442.6	68.1	20.9	81.8	0.61	244.8	27.3	103.9	17.5
2-	AC/041C	09/01/2004	W.M.C	17.8	663	7.43	461.2	69.7	20.9	79.1	2.05	262.4	28.3	111.2	18.8
3-	AC/041C	10/07/2003	W.M.C	26.6	716	7.46	435.6	70.5	23.0	65.0	3.4	244.0	31.0	103.5	17.2
4-	AC/041C	14/05/2004	W.M.C	23.4	743	7.37	456.3	68.1	22.4	70.4	3.8	268.9	33.0	99.0	25.2

Appendix (3.6): The strength of the relation between the different studied variables based on Spearman Correlation coefficients

Variable	EC	T^0C	pH	Ca	Mg	Na	K	Cl	SO_4	NO_3	HCO_3	TDS	SAR	TH	SI-calcite	SI-aragonite	SI-dolomite	SI-gypsum	SI-anhydrite	Na/Cl	Ca/HCO_3	Ca/Mg	Ca/SO_4	TDS/EC
EC	1																							
T^0C	.61	1																						
pH	-.70	-.40	1																					
Ca	.96	.58	-.71	1																				
Mg	.75	.32	-.72	.72	1																			
Na	.95	.62	-.70	.96	.72	1																		
K	.91	.65	-.63	.91	.77	.94	1																	
Cl	.96	.64	-.65	.96	.73	.98	.94	1																
SO_4	.94	.56	-.71	.95	.77	.94	.92	.93	1															
NO_3	-.11	-.44	.06	.02	.21	-.11	-.10	-.09	-.02	1														
HCO_3	-.03	-.38	-.05	.01	.22	-.10	-.12	-.11	-.04	.54	1													
TDS	.97	.61	-.69	.98	.75	.99	.94	.99	.96	-.06	-.06	1												
SAR	.85	.56	-.66	.88	.60	.95	.86	.90	.87	-.12	-.09	.91	1											
TH	.97	.57	-.71	.98	.78	.95	.93	.97	.96	.01	.01	.98	.86	1										
SI-calcite	-.22	-.26	.69	-.21	-.16	-.25	-.24	-.19	-.31	.10	.15	-.22	-.23	-.22	1									
SI-aragonite	-.23	-.21	.70	-.20	-.20	-.26	-.26	-.19	-.30	.18	.14	-.22	-.24	-.22	.95	1								
SI-dolomite	-.06	-.20	.57	-.07	.33	-.11	-.06	-.05	-.09	.35	.42	-.07	-.14	-.01	.68	.69	1							
SI-gypsum	.95	.57	-.73	.98	.71	.94	.90	.94	.98	.01	-.01	.97	.87	.99	-.27	-.25	-.11	1						
SI anhydrite	.95	.57	-.73	.98	.71	.94	.90	.94	.98	.01	-.01	.97	.87	.97	-.27	-.25	-.11	1	1					
Na/Cl	-.78	-.68	.42	-.71	-.64	-.68	-.75	-.77	-.70	.08	.08	-.72	-.52	-.75	.12	.01	-.11	-.71	-.71	1				
Ca/HCO_3	.92	.64	-.65	.94	.69	.94	.92	.95	.91	-.10	-.28	.94	.83	.93	-.25	-.24	-.13	.91	.9	-0.76	1			
Ca/Mg	-.20	.01	.00	-.12	-.72	-.16	-.16	-.17	-.21	-.26	-.33	-.16	-.06	-.20	.04	.01	-.55	-.13	-.13	0.34	-0.13	1		
Ca/SO_4	-.64	-.30	.43	-.62	-.84	-.65	-.70	-.64	-.79	-.12	-.10	-.66	-.61	-.67	.27	.30	-.19	.70	-.70	0.48	-0.60	0.62	1	
TDS/EC	-.52	-.26	.28	-.36	-.31	-.28	-.26	-.34	-.31	.12	-.20	-.33	-.16	-.37	.01	.03	-.10	-.36	-.36	0.48	-0.30	0.19	0.21	1

TH: Total hardness

Appendix (3.7): Variables that have correlation coefficient ≥0.9

Variables		Correlation coefficient
EC µS/cm versus each of: Ca^{+2}, Na^{+}, K^{+}, Cl^{-}, SO_4^{-2}, TDS mg/L, Total Hardness, SI-gypsum, SI-anhydrite and Ca^{+2}/HCO_3^{-}		0.96, 0.949, 0.914, 0.961, 0.94, 0.967, 0.969, 0.95, 0.95 and 0.917 respectively
EC µS/cm versus each of: Ca^{+2}, Na^{+}, K^{+}, Cl^{-}, SO_4^{-2}, TDS mg/L, Total Hardness, SI-gypsum, SI-anhydrite and Ca^{+2}/HCO_3^{-}		0.96, 0.949, 0.914, 0.961, 0.94, 0.967, 0.969, 0.95, 0.95 and 0.917 respectively
Ca^{+2} mg/L versus each of: Na^{+}, K^{+}, Cl^{-}, SO_4^{-2},TDS mg/L, Total Hardness, SI-gypsum, SI-anhydrite and Ca^{+2}/HCO_3^{-}		0.957, 0.907, 0.964, 0.949, 0.981, 0.984, 0.977, 0.977 and 0.935, respectively
Na^{+} mg/L versus each of: K^{+}, Cl^{-}, SO_4^{-2}, TDS mg/L, SAR, Total Hardness, SI-gypsum, SI-anhydrite and Ca^{+2}/HCO_3^{-}		0.939, 0.977, 0.937, 0.985, 0.952, 0.953, 0.936, 0.936 and 0.935, respectively
K^{+} mg/L versus each of: Cl^{-}, SO_4^{-2},TDS mg/L, Total Hardness and Ca^{+2}/HCO_3^{-}mg/L		0.942, 0.921, 0.935, 0.931 and 0.918, respectively
Cl^{-} mg/L versus each of: SO_4^{-2}, TDS mg/L, SAR, Total Hardness, SI-gypsum, SI-anhydrite and Ca^{+2}/HCO_3^{-}		0.933, 0.986, 0.904, 0.968, 0.937, 0.937and 0.951, respectively
SO_4^{-2}mg/L versus each of: TDS mg/L, Total Hardness, SI-gypsum, SI-anhydrite and Ca^{+2}/HCO_3^{-}		0.957, 0.959, 0.982, 0.982 and 0.905, respectively
TDS mg/L versus each of: SAR, Total Hardness, SI-gypsum, SI-anhydrite and Ca^{+2}/HCO_3^{-}		0.914, 0.983, 0.965, 0.965 and 0.943, respectively
Total Hardness versus each of: SI-gypsum, SI-anhydrite and Ca^{+2}/HCO_3^{-}		0.97, 0.97 and 0.93, respectively

Appendix (3.8): The mathematical expressions of the relation between different parameters in class (I)

Mathematical expressions	R- square
Cl^{-} =0.51*TDS-135.11	0.98
TDS=2.82*Total Hardness-253.13	0.96
Ca^{+2} =85.90* Ca^{+2} /HCO3+22.45	0.96
Na^{+}=0.43* Cl^{-} +51.64	0.96
TDS=2226.36*SI-gypsum+5178.72	0.95
Total Hardness=768.88*SI-gypsum+1894.73	0.94
Na^{+}= 92.15*SAR-161.48	0.94
Cl^{-} =1.43*Total Hardness-257.80	0.93
Cl^{-} =1118.34*SI-gypsum+2481.23	0.91
EC = 1.98 TDS – 304.47	0.91
EC = 5.69*Total Hardness-886.70	0.91
EC= 3.84 Cl^{-} +248.66	0.91
Na^{+}= 431.40*SI-gypsum+1133.99	0.91
Na^{+}= 0.62*Total Hardness-60.04	0.90
EC = 447.53*SI-gypsum+10001.60	0.89
Ca^{+2} =0.17* Cl^{-} +20.28	0.88
SO_4^{-2} =300.89*SI-gypsum+634.81	0.88
SO_4^{-2} =0.13TDS-57.53	0.87
EC= 8.53* Na^{+} – 49.87	0.87
EC= 21.21* Ca^{+2} + 98.93	0.86
Ca^{+2} =0.08*TDS-1.69	0.86
Ca^{+2} =0.37* Na^{+}+6.71	0.85
Cl^{-} =200.90*SAR-412.87	0.85
SO_4^{-2} =0.37*Total Hardness-93.05	0.85
TDS=389.87*SAR-521.02	0.85
Ca^{+2} = 184.07*SI-gypsum+429.47	0.79
Na^{+}=1.42*SO4-2+136.99	0.79
Na^{+}=0.22*TDS-11.94	0.79
Ca^{+2} =0.23 Total Hardness-17.42	0.78
EC= 1.80 SO_4^{-2} +990.69	0.76
Cl^{-} =3.23* SO_4^{-2} +212.80	0.76
EC=1738.25* Ca^{+2}/HCO_3^{-}+691.30	0.75
Ca^{+2} =0.53* SO_4^{-2} + 56.27	0.68

Appendices (3.9): Figures for the Relationships between the variables of the classes

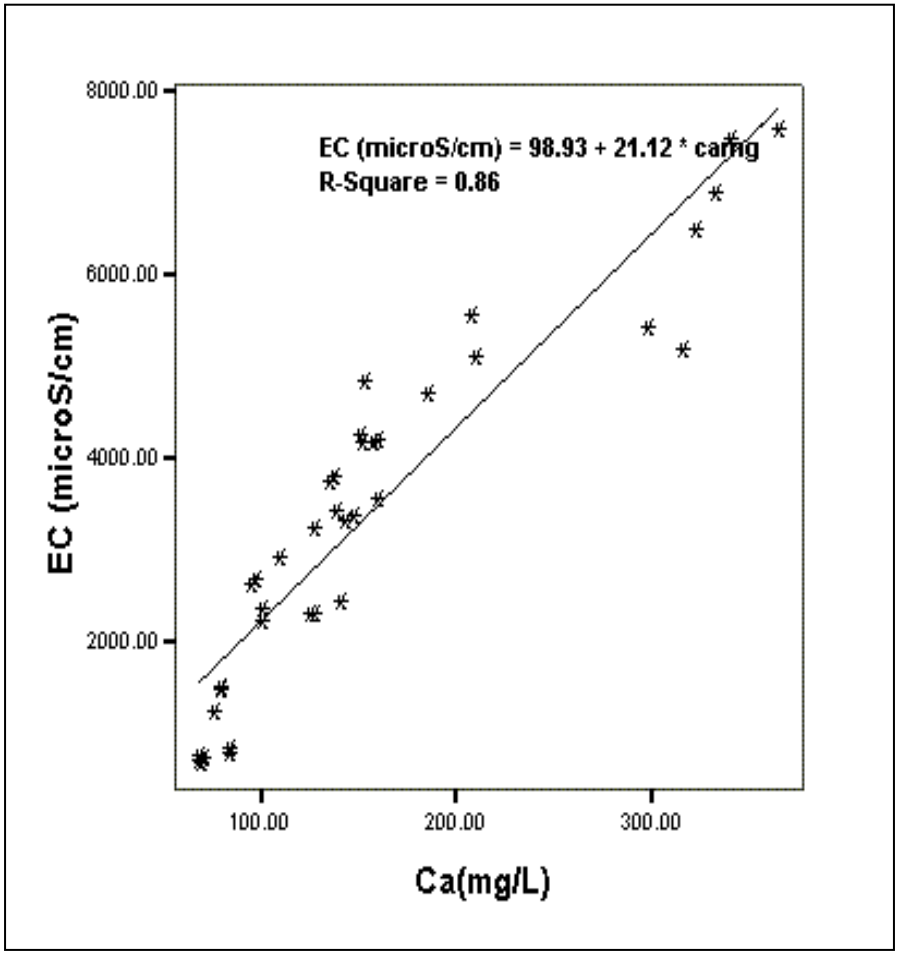

Figure (A): Relation between Ca^{+2} and EC in Class (I)
of very high significant relationship

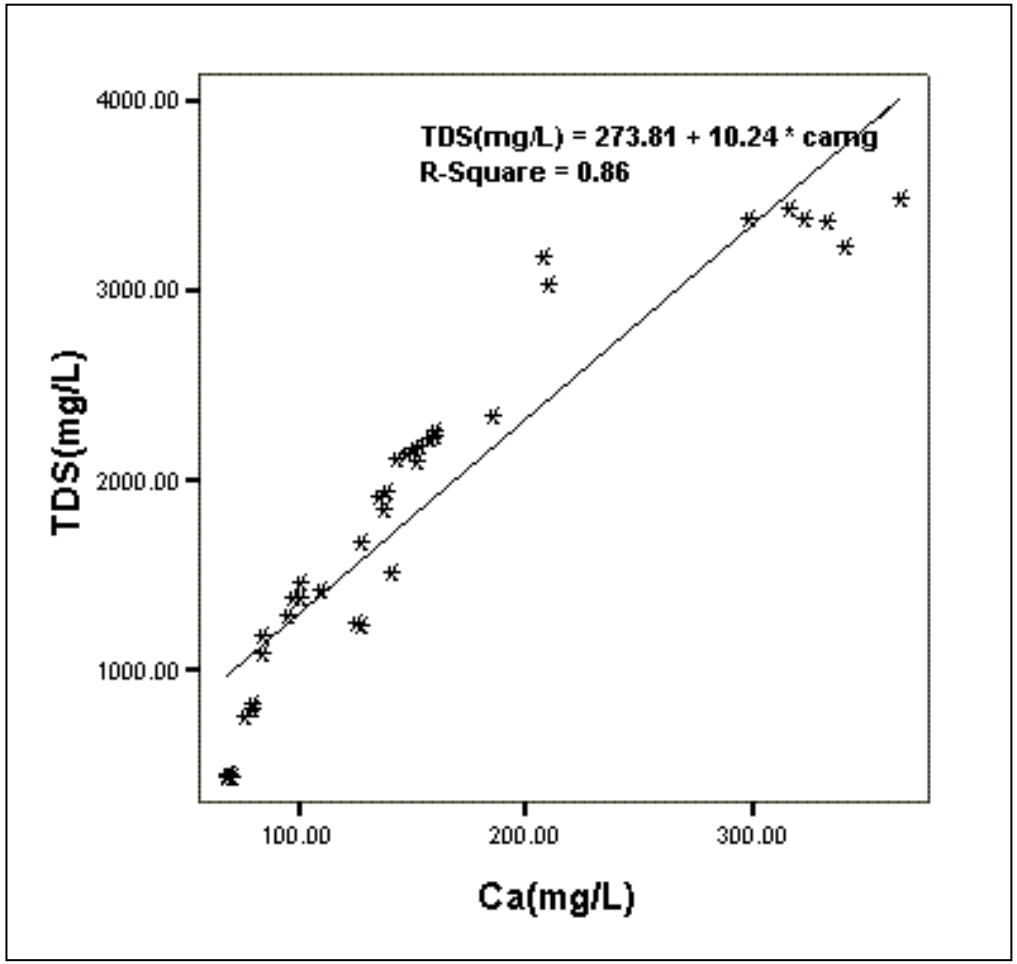

Figure (B): Relation between Ca^{+2} and TDS in Class (I)
of very high significant relationship

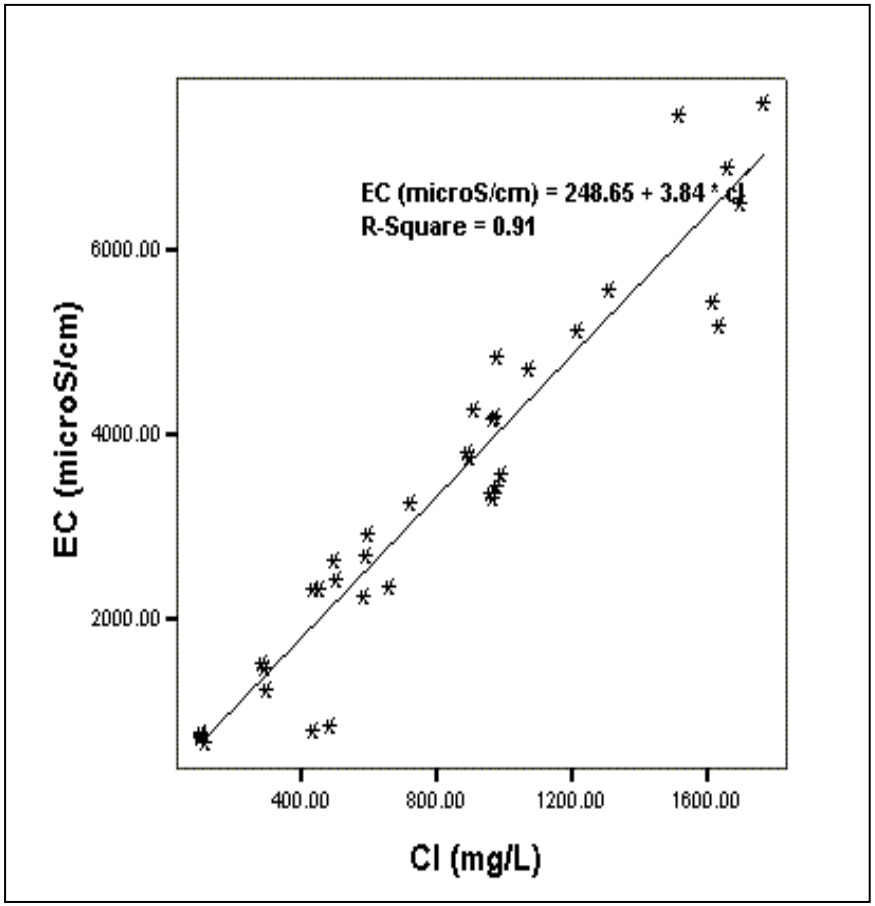

Figure (C): Relation between Cl^- and EC in Class (I) of very high significant relationship

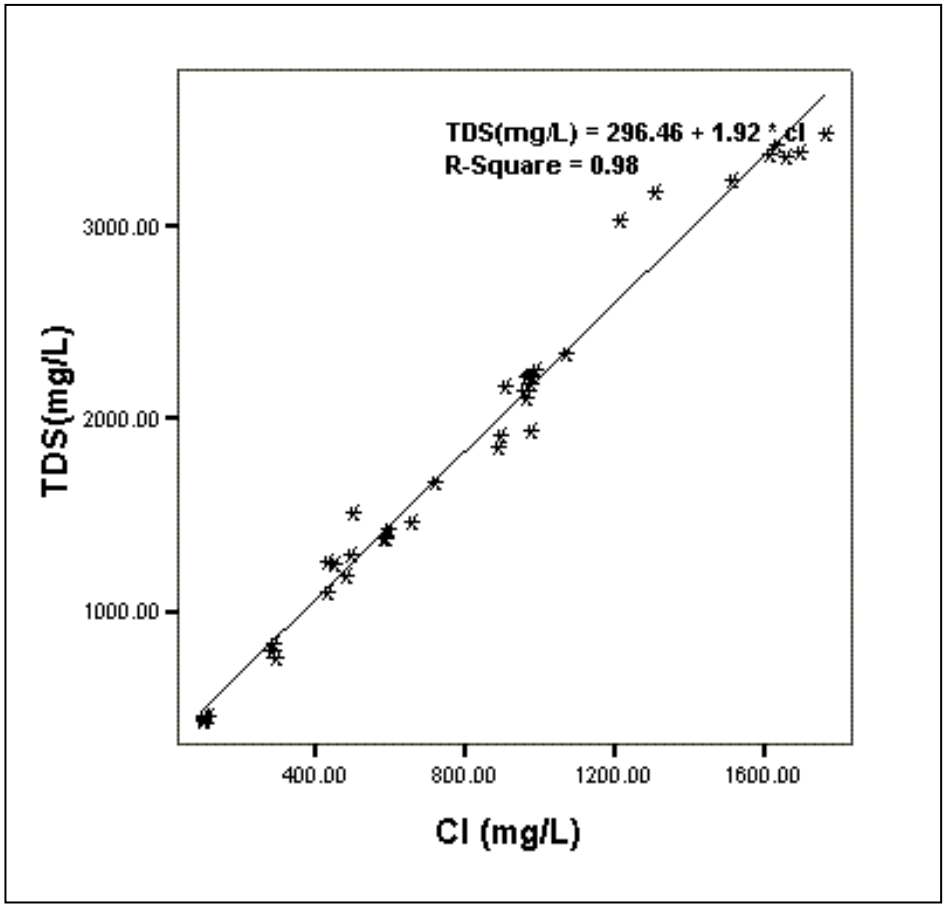

Figure (D): Relation between Cl^- and TDS in Class (I) of very high significant relationship

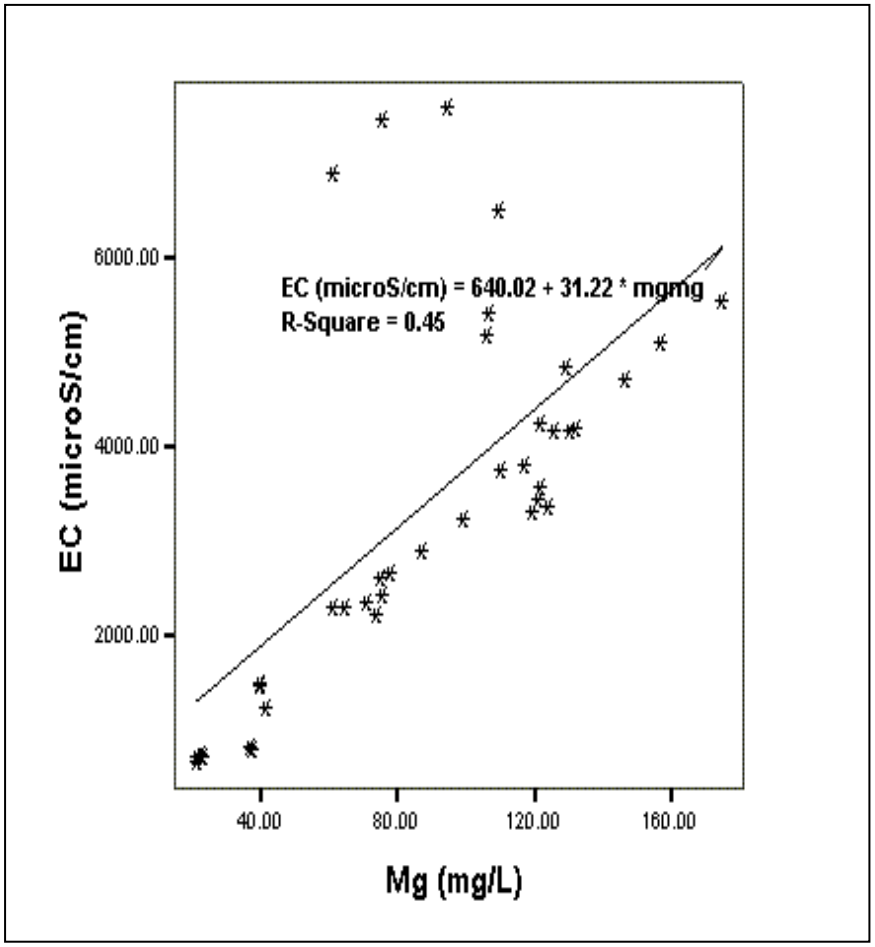

Figure (E): Relation between Mg^{+2} and EC in Class (III) of good relation

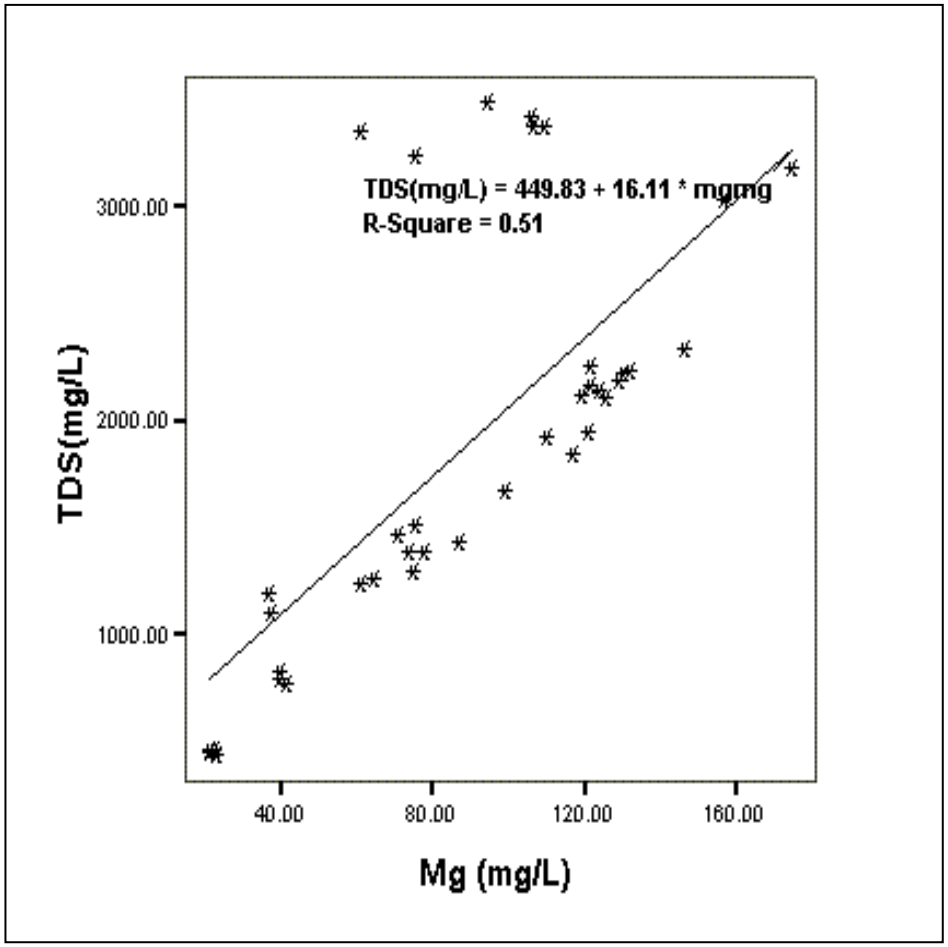

Figure (F): Relation between Mg^{+2} and TDS in Class (III) of good relation

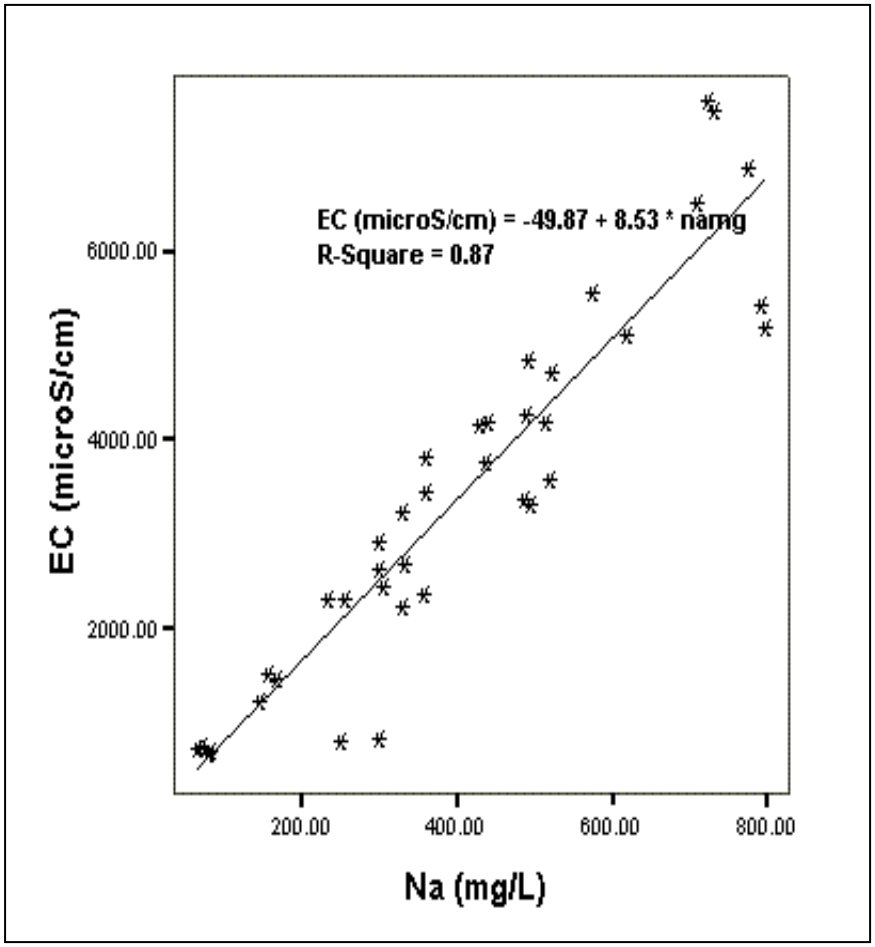

Figure (G): Relation between Na^+ and EC in Class (I) of very high significant relationship

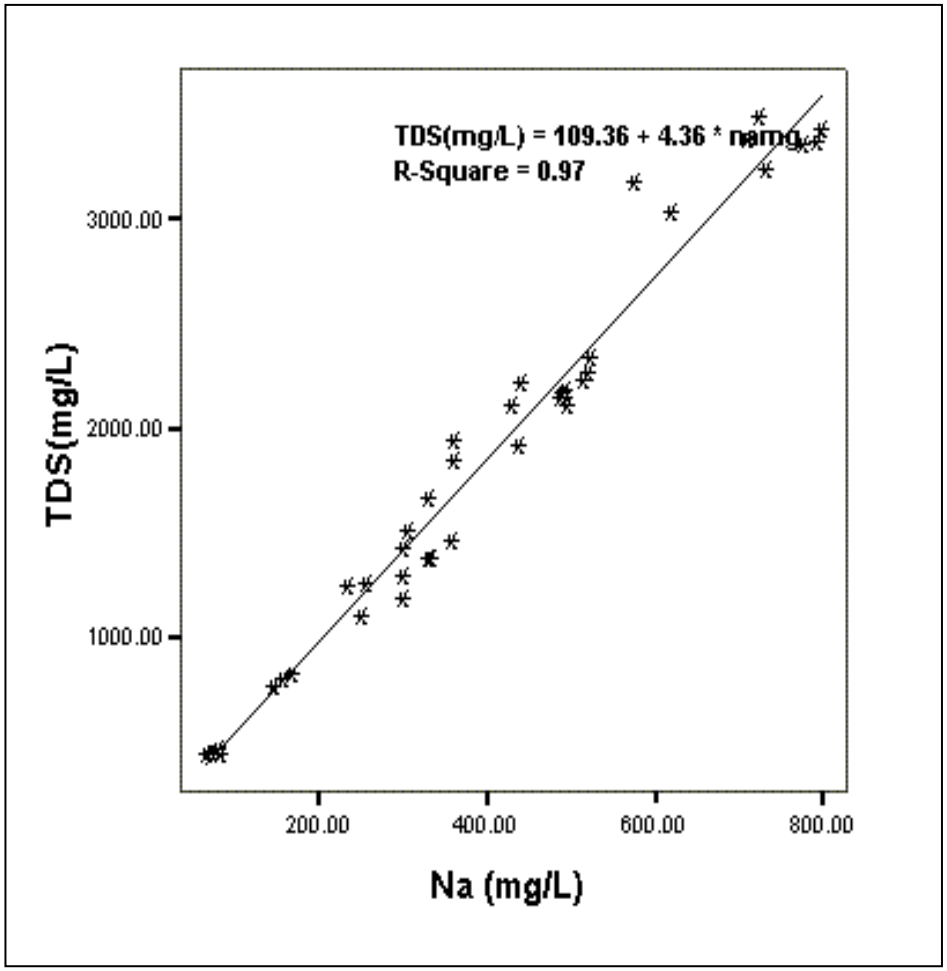

Figure (H): Relation between Na^+ and TDS in Class (I) of very high significant relationship

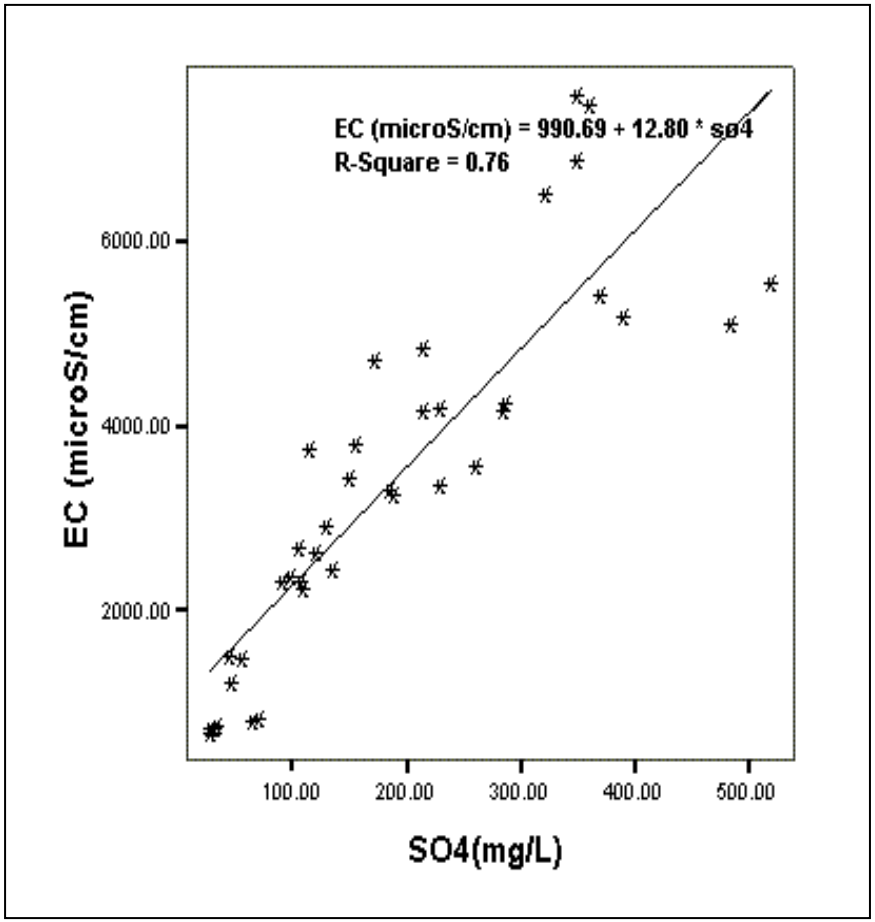

Figure (I): Relation between SO_4^{+} and EC in Class (I) of very high significant relationship

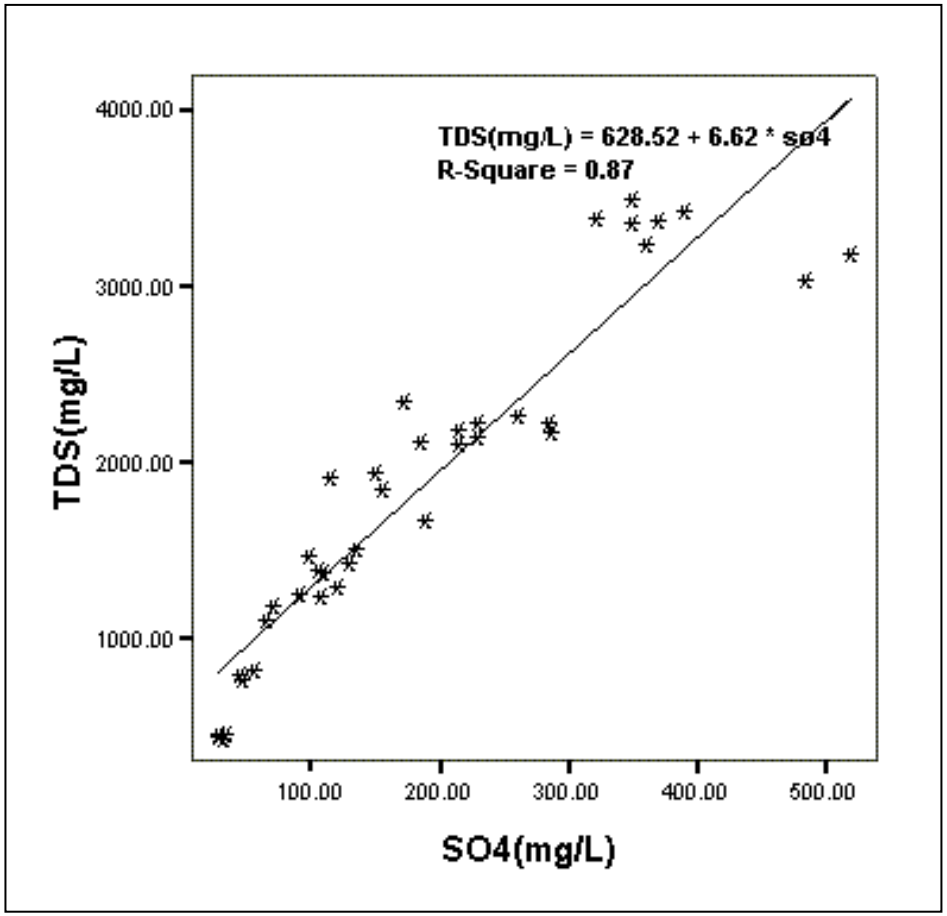

Figure (J): Relation between SO_4^{+2} and TDS in Class (I) of very high significant relationship

Appendix (3.10): Descriptive Statistics of Cluster (I)

Variables	Minimum	Maximum	Mean	Std. Deviation	N
Temp (^{0}C)	17.8	31.7	26.27	4.69	7
EC (µS/cm)	663	1505	1003.6	380.9	7
pH	7.19	7.49	7.32	0.11	7
TDS (mg/L)	435.6	828.4	597.6	186.6	7
Ca^{2+} (mg/L)	68.1	80.2	73.2	5.3	7
Mg^{+2} (mg/L)	20.9	41.1	29.7	9.9	7
Na^{+} (mg/L)	65	169	109.7	45.3	7
K^{+} (mg/L)	0.61	6.9	3.7	2.11	7
HCO_3^{-} (mg/L)	244	360	287.8	46.4	7
SO_4^{2-} (mg/L)	27.3	55	38.1	10.8	7
Cl^{-}(mg/L)	99.0	294.4	183.6	98.8	7
NO_3^{-}(mg/L)	6.72	25.2	15.6	6.1	7
Total Hardness	256.1	364.1	305.0	53.5	7
SAR	1.72	3.85	2.68	0.88	7
SI-calcite	-0.08	0.23	0.12	0.11	7
SI-aragonite	-0.23	0.08	-0.03	0.11	7
SI-dolomite	-0.33	0.46	0.18	0.25	7
SI-gypsum	-2.21	-1.95	-2.10	0.10	7
SI-anhydrite	-2.43	-2.17	-2.32	0.10	7
Na^{+}/Cl^{-}	0.76	1.21	0.98	0.16	7
Ca^{2+} / HCO_3^{-}	0.68	0.88	0.78	0.07	7
Ca^{2+} / Mg^{+2}	1.13	2.02	1.61	0.40	7
Ca^{+2}/ SO_4^{2-}	3.49	5.97	4.84	0.99	7

Appendix (3.11): Descriptive Statistics of Cluster (II)

Variables	Minimum	Maximum	Mean	Std. Deviation	N
Temp (^{0}C)	20.6	29.5	26.33	2.98	11
EC (µS/cm)	788	3240	2243.1	770.1	11
pH	6.83	7.48	7.16	0.17	11
TDS (mg/L)	1098.5	1671.1	1356.0	162.8	11
Ca^{2+} (mg/L)	84.1	141	108.6	19.3	11
Mg^{+2} (mg/L)	37	99.2	69.0	18.8	11
Na^{+} (mg/L)	232.8	357	299.6	38.8	11
K^{+} (mg/L)	3.2	26.6	15.9	8.7	11
HCO_3^{-} (mg/L)	280.6	463.7	343.5	54.6	11
SO_4^{2-} (mg/L)	65	188.5	111.1	33.9	11
Cl^{-}(mg/L)	430	723	540.1	95.8	11
NO_3^{-}(mg/L)	5.2	114.9	40.61	32.2	11
Total Hardness	362.3	726.5	555.0	110.3	11
SAR	4.24	6.86	5.60	0.80	11
SI-calcite	-0.06	0.3	0.12	0.11	11
SI-aragonite	-0.25	0.16	-0.05	0.13	11
SI-dolomite	0.05	0.8	0.34	0.23	11
SI-gypsum	-1.89	-1.4	-1.65	0.15	11
SI-anhydrite	-2.11	-1.62	-1.87	0.15	11
Na^{+}/Cl^{-}	0.7	0.96	0.86	0.08	11
Ca^{2+} / HCO_3^{-}	0.71	1.25	0.97	0.16	11
Ca^{2+} / Mg^{+2}	0.76	1.38	1.01	0.26	11
Ca^{+2}/ SO_4^{2-}	1.62	3.35	2.46	0.54	11

Appendix (3.12): Descriptive Statistics of Cluster (III)

Variables	Minimum	Maximum	Mean	Std. Deviation	N
Temp (^{0}C)	30	35.3	33.8	2.01	6
EC (µS/cm)	5180	7580	6505.0	1015.9	6
pH	6.65	7.03	6.9	0.14	6
TDS (mg/L)	3236.0	3488.2	3377.5	83.8	6
Ca^{2+} (mg/L)	298.1	365.5	329.3	23.0	6
Mg^{+2} (mg/L)	60.8	109.4	92.1	19.9	6
Na^{+} (mg/L)	709.5	798.8	755.8	38.7	6
K^{+} (mg/L)	32.3	50.41	44.5	7.01	6
HCO_3^{-} (mg/L)	244.1	311.2	278.7	24.6	6
SO_4^{2-} (mg/L)	321.7	390	356.9	22.9	6
Cl^{-}(mg/L)	1512	1765.5	1646.5	85.3	6
NO_3^{-}(mg/L)	6.3	20.65	12.9	6.2	6
Total Hardness	1080.6	1300.7	1201.2	77.3	6
SAR	8.72	10.28	9.5	0.68	6
SI-calcite	-0.11	0.24	0.0	0.13	6
SI-aragonite	-0.26	0.09	-0.1	0.13	6
SI-dolomite	-0.53	0.15	-0.1	0.26	6
SI-gypsum	-0.95	-0.86	-0.9	0.03	6
SI-anhydrite	-1.17	-1.08	-1.1	0.03	6
Na^{+}/Cl^{-}	0.63	0.76	0.7	0.06	6
Ca^{2+} / HCO_3^{-}	3.15	3.95	3.6	0.28	6
Ca^{2+} / Mg^{+2}	1.69	3.32	2.3	0.65	6
Ca^{+2}/ SO_4^{2-}	1.93	2.5	2.2	0.24	6

Appendix (3.13): Descriptive Statistics of Cluster (IV)

Variables	Minimum	Maximum	Mean	Std. Deviation	N
Temp (^{0}C)	26.5	29.9	28.59	1.02	14
EC (µS/cm)	3310	5550	4155.7	687.8	14
pH	6.96	7.4	7.11	0.12	14
TDS (mg/L)	1849.3	3182.6	2264.6	384.2	14
Ca^{2+} (mg/L)	135.5	210.2	160.2	24.2	14
Mg^{+2} (mg/L)	110.3	175	130.8	17.5	14
Na^{+} (mg/L)	360	619	481.7	71.9	14
K^{+} (mg/L)	26	209.9	53.2	58.5	14
HCO_3^{-} (mg/L)	292.8	353.9	322. 6	21.3	14
SO_4^{2-} (mg/L)	115.5	520	250.1	118.0	14
Cl^{-}(mg/L)	886	1304.6	1002.1	118.6	14
NO_3^{-}(mg/L)	12.2	45	25.3	8.5	14
Total Hardness	792.3	1240.5	938.3	131.0	14
SAR	5.42	7.87	6.84	0.73	14
SI-calcite	-0.09	0.42	0.11	0.13	14
SI-aragonite	-1.1	0.27	-0.11	0.31	14
SI-dolomite	0.09	1.1	0.49	0.25	14
SI-gypsum	-1.62	-0.94	-1.30	0.19	14
SI-anhydrite	-1.84	-1.15	-1.52	0.19	14
Na^{+}/Cl^{-}	0.57	0.83	0.74	0.08	14
Ca^{2+} / HCO_3^{-}	1.17	2	1.52	0.22	14
Ca^{2+} / Mg^{+2}	0.69	0.81	0.74	0.03	14
Ca^{+2}/ SO_4^{2-}	0.96	2.81	1.74	0.54	14

Appendix (3.14): Schoellar Diagram for Different Groups of the study Area

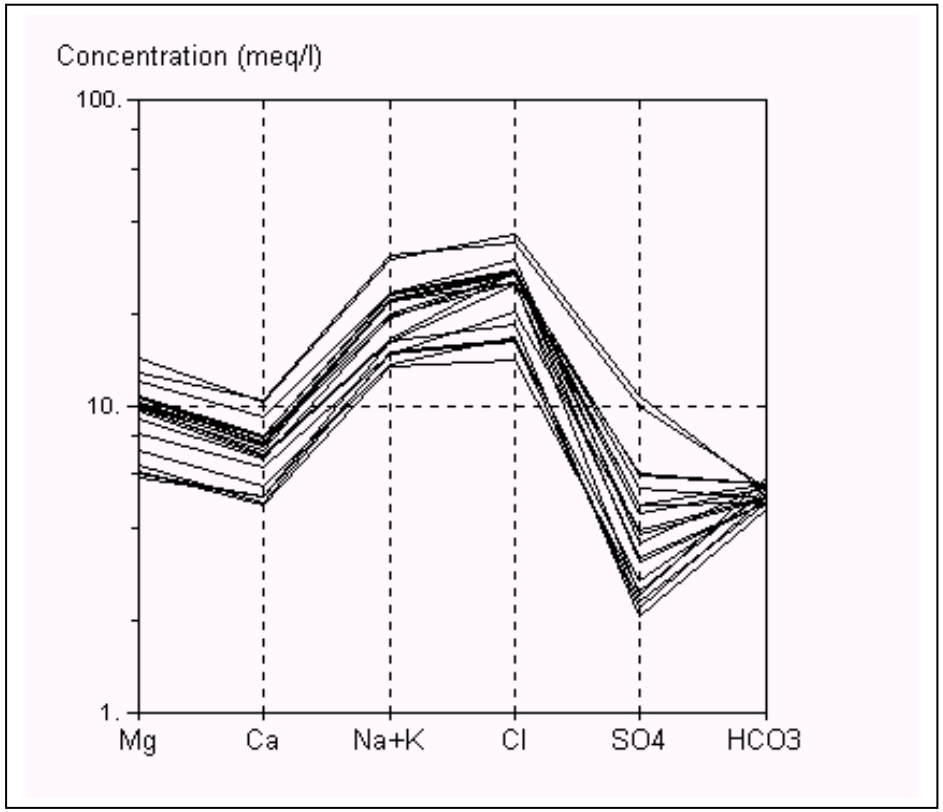

Figure (A): Schoellar Diagram showing the wells of Marj Na'ja and Az Zubiedat

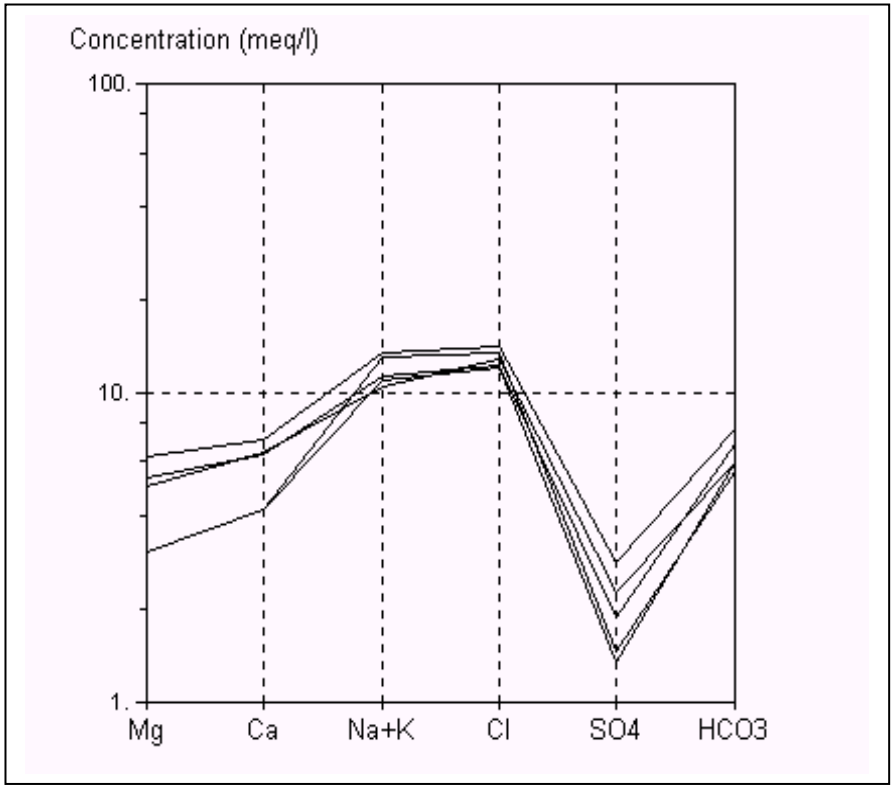

Figure (B): Schoellar Diagram showing the wells of Frush Bait Dajan (F.B.D)

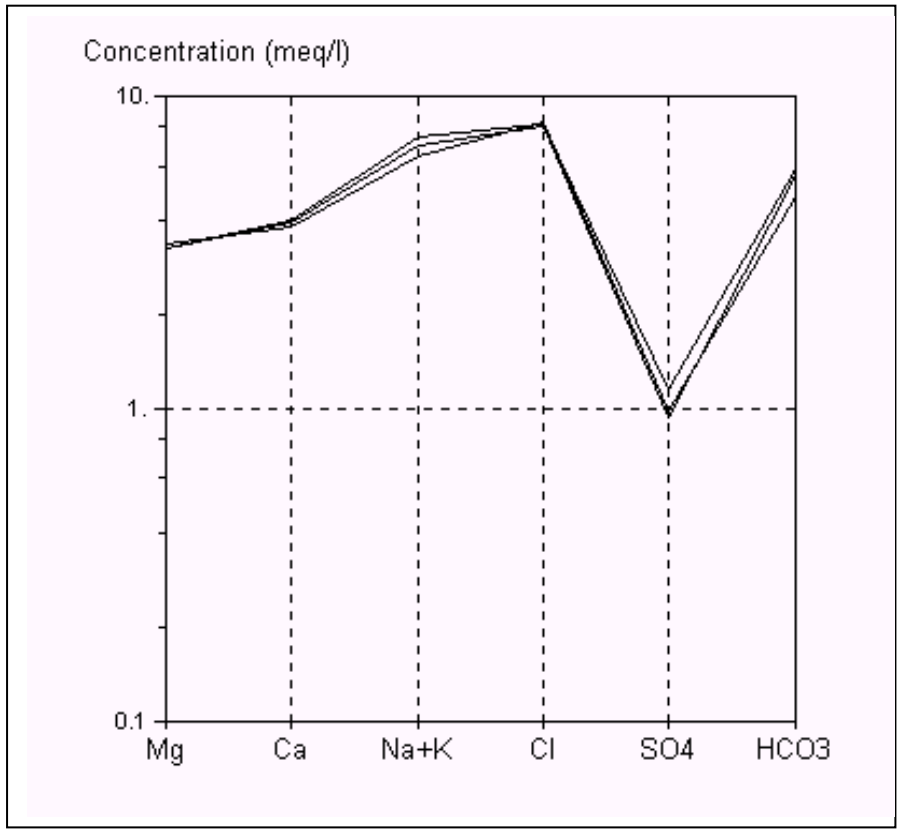

Figure (C): Schoellar Diagram showing the spring of Al Himmah

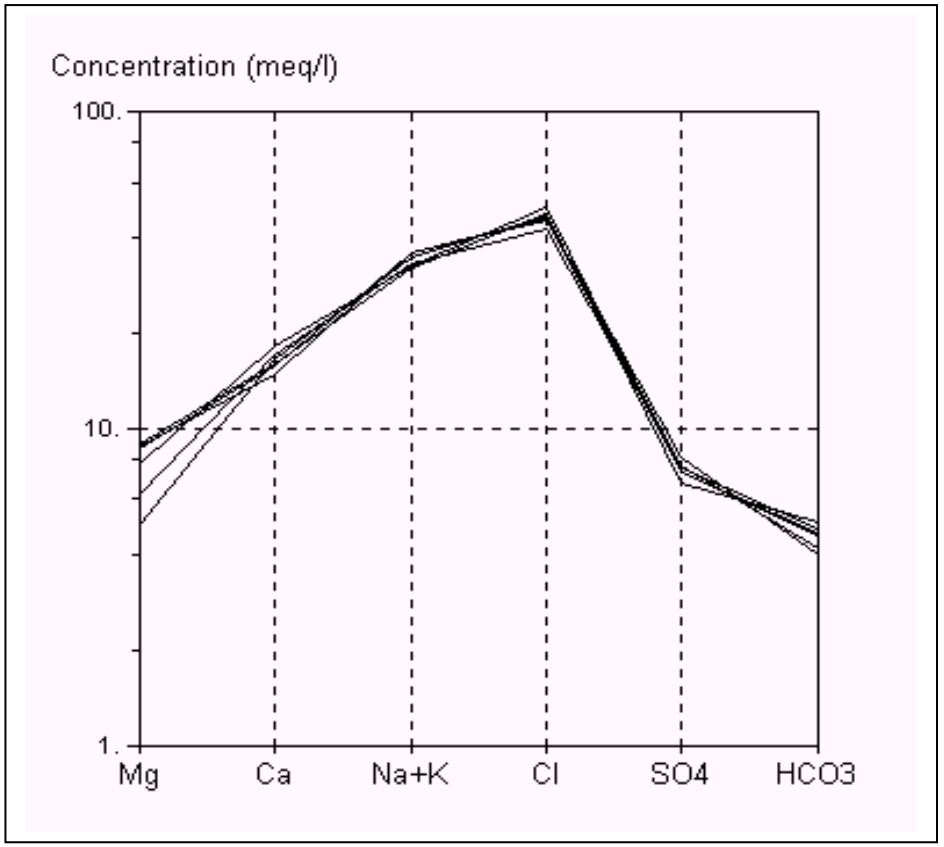

Figure (D): Schoellar Diagram showing the spring of Al Maleh Warm

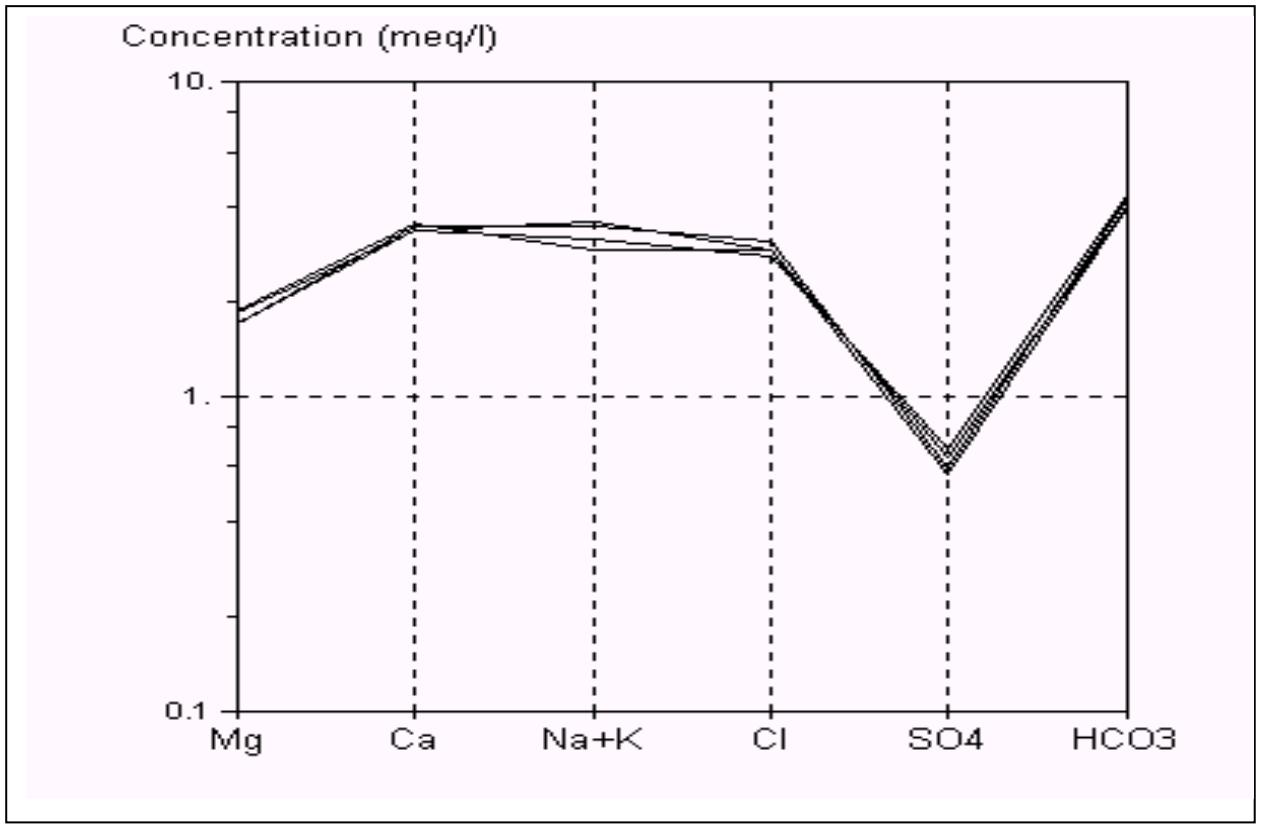

Figure (E): Schoellar Diagram showing the spring of Al Maleh Cold

Appendix (3.15): Ionic Characteristics Ratios and Water Type of Marj Na'ja and Az Zubiedat Wells

No.	Well Code	Date	Mg^{+2}/Ca^{+2}	Na^{+}/Cl^{-}	Na^{+}/K^{+}	$(Ca^{+2}+Mg^{+2})/(Na^{+}+K^{+})$	HCO_3^{-}/Cl^{+}	SO_4^{2-}/HCO_3^{-}	SO_4^{2}/Cl^{-}	$Ca^{+2}/(SO_4^{2-}+HCO_3^{-})$	Water Type
1-	19-17/011	10/07/2003	1.11	0.88	24.2	0.74	0.29	0.48	0.14	0.71	Na-Mg-Ca-Cl
2-	19-17/011	09/01/2004	1.25	0.93	29.5	0.81	0.38	0.46	0.18	0.60	Na-Mg-Ca-Cl-HCO3
3-	19-17/011	14/05/2004	1.28	0.7	24.9	0.97	0.25	0.77	0.19	0.71	Na-Mg-Ca-Cl
4-	19-17/020	04/08/2003	1.28	0.79	26.4	0.80	0.18	1.0	0.18	0.77	Na-Mg-Cl
5-	19-17/020	09/01/2004	1.19	0.78	26.5	0.82	0.20	0.82	0.16	0.77	Na-Mg-Cl
6-	19-17/020	14/05/2004	1.16	0.71	23.2	0.93	0.21	1.06	0.22	0.68	Na-Mg-Ca-Cl
7-	20-17/010	04/08/2003	1.16	0.84	22.9	0.67	0.25	0.45	0.11	0.76	Na-Mg-Cl
8-	20-17/010	09/01/2004	1.22	0.87	22.6	0.74	0.30	0.43	0.13	0.67	Na-Mg-Cl-HCO3
9-	20-17/010	14/05/2004	1.21	0.78	22.6	0.93	0.31	0.52	0.16	0.69	Na-Mg-Ca-Cl-HCO3
10-	20-17/011	09/01/2004	1.23	0.79	6.2	0.75	0.16	1.86	0.29	0.68	Na-Mg-Ca-Cl
11-	20-17/011	14/05/2004	1.28	0.68	4.7	0.82	0.14	2.08	0.29	0.65	Na-Mg-Cl
12-	20-17/016	10/07/2003	1.25	0.81	27.6	0.77	0.18	1.08	0.19	0.77	Na-Mg-Cl
13-	20-17/016	09/01/2004	1.26	0.82	30.8	0.82	0.20	0.85	0.17	0.77	Na-Mg-Cl
14-	20-17/016	14/05/2004	1.21	0.76	29	0.91	0.19	0.64	0.12	1.01	Na-Mg-Ca-Cl
15-	20-17/018	04/08/2003	1.27	0.79	25.7	0.76	0.18	0.77	0.14	0.81	Na-Mg-Cl
16-	20-17/018	09/01/2004	1.24	0.76	26.3	0.80	0.23	0.41	0.10	0.82	Na-Mg-Cl
17-	20-17/019	14/05/2004	1.16	0.69	23.8	0.92	0.20	0.83	0.16	0.77	Na-Mg-Ca-Cl
18-	20-17/019	10/07/2003	1.24	0.57	19.2	1.02	0.17	0.65	0.11	0.87	Na-Mg-Cl
19-	20-17/019	09/01/2004	1.12	0.83	29.3	0.80	0.22	1.07	0.23	0.65	Na-Mg-Cl
20-	20-17/019	14/05/2004	1.28	0.63	23.6	1.01	0.19	0.67	0.13	0.86	Na-Mg-Ca-Cl
		Average	**1.22**	**0.77**	**23.4**	**0.84**	**0.22**	**0.85**	**0.17**	**0.75**	

Appendix (3.16): Results of Rock Source Deduction of Marj Na'ja and Az Zubiedat Wells

No.	Well Code	Date	$Na^{+}/Na^{+}+Cl^{-}$	$Mg^{+2}/Ca^{+2}+Mg^{+2}$	$Ca^{+2}/Ca^{+2}+SO_4^{-2}$	TDS (mg/L)	Cl^{-}/sum anions	HCO_3^{-}/ sum anions
1-	19-17/011	10/07/2003	0.47	0.55	0.69	1381.7	0.69	0.20
2-	19-17/011	09/01/2004	0.48	0.57	0.65	1290.1	0.63	0.24
3-	19-17/011	14/05/2004	0.41	0.56	0.62	1671.1	0.68	0.17
4-	19-17/020	04/08/2003	0.44	0.58	0.61	2147.0	0.73	0.13
5-	19-17/020	09/01/2004	0.44	0.58	0.63	2184.8	0.73	0.14
6-	19-17/020	14/05/2004	0.41	0.58	0.57	2219.4	0.69	0.14
7-	20-17/010	04/08/2003	0.46	0.54	0.71	1466.9	0.73	0.18
8-	20-17/010	09/01/2004	0.47	0.57	0.69	1382.2	0.69	0.21
9-	20-17/010	14/05/2004	0.44	0.57	0.67	1429.6	0.67	0.21
10-	20-17/011	09/01/2004	0.44	0.55	0.51	3036.5	0.68	0.11
11-	20-17/011	14/05/2004	0.4	0.58	0.49	3182.6	0.69	0.10
12-	20-17/016	10/07/2003	0.45	0.56	0.6	2259.9	0.72	0.13
13-	20-17/016	09/01/2004	0.45	0.58	0.63	2229.4	0.72	0.15
14-	20-17/016	14/05/2004	0.43	0.57	0.72	2341.6	0.75	0.14
15-	20-17/018	04/08/2003	0.44	0.58	0.65	2114.7	0.75	0.14
16-	20-17/018	09/01/2004	0.43	0.57	0.74	1920.7	0.75	0.17
17-	20-17/019	14/05/2004	0.41	0.58	0.63	2107.6	0.73	0.14
18-	20-17/019	10/07/2003	0.36	0.59	0.69	1943.3	0.77	0.13
19-	20-17/019	09/01/2004	0.45	0.57	0.56	2167.9	0.68	0.15
20-	20-17/019	14/05/2004	0.39	0.58	0.68	1849.3	0.75	0.14
		Average	**0.43**	**0.57**	**0.64**	**2016.3**	**0.71**	**0.16**

Appendix (3.17): Ionic Characteristics Ratios and Water Type of F.B.D Wells

No.	Well Code	Date	Mg^{+2}/Ca^{+}	Na^{+}/Cl^{-}	Na^{+}/K^{+}	$(Ca^{+2}+Mg^{+2})/(Na^{+}+K^{+})$	HCO_3^{-}/Cl^{-}	SO_4^{2-}/HCO_3^{-}	SO_4^{2}/Cl^{-}	$Ca^{+2}/(SO_4^{2-}+HCO_3^{-})$	Water Type
1-	19-17/034	11/01/2004	0.73	0.90	53.2	0.66	0.49	0.23	0.11	0.58	Na-Ca-Cl-HCO3
2-	19-17/034	14/05/2004	0.73	0.96	159.4	0.55	0.41	0.26	0.11	0.60	Na-Ca-Cl-HCO3
3-	19-17/046	11/01/2004	0.88	0.94	109.9	0.99	0.54	0.37	0.20	0.67	Na-Ca-Mg-Cl-HCO3
4-	19-17/046a	14/05/2004	0.85	0.91	54.0	1.02	0.56	0.28	0.15	0.72	Na-Ca-Mg-Cl-HCO3
5-	19-17/046b	14/05/2004	0.78	0.79	30.7	1.09	0.46	0.38	0.18	0.78	Na-Ca-Mg-Cl-HCO3
		Average	**0.79**	**0.9**	**81.4**	**0.86**	**0.49**	**0.30**	**0.15**	**0.67**	

Appendix (3.18): Results of Rock Source Deduction of F.B.D Wells

No.	Well Code	Date	$Na^{+}/Na^{+}+Cl^{-}$	$Mg^{+2}/Ca^{+2}+Mg^{+2}$	$Ca^{+2}/Ca^{+2}+SO_4^{-2}$	$Ca^{+2}+Mg^{+2}/SO_4^{-2}$	TDS	Cl^{-}/sum anions	HCO_3^{-}/ sum anions
1-	19-17/034	11/01/2004	0.47	0.42	0.76	5.38	1598.3	0.60	0.29
2-	19-17/034	14/05/2004	0.49	0.42	0.74	4.97	1475.1	0.64	0.26
3-	19-17/046	11/01/2004	0.48	0.47	0.71	4.68	1512.3	0.54	0.29
4-	19-17/046a	14/05/2004	0.48	0.46	0.77	6.19	1256.0	0.55	0.31
5-	19-17/046b	14/05/2004	0.44	0.44	0.74	5.06	1241.7	0.58	0.27
		Average	**0.47**	**0.44**	**0.74**	**5.23**	**1416.7**	**0.58**	**0.28**

Appendix (3.19): Ionic Characteristics Ratios and Water Type of Al Himmah Spring

No.	Spring Code	Date	Mg^{+2}/Ca^{+2}	Na^{+}/Cl^{-}	Na^{+}/K^{+}	$(Ca^{+2}+Mg^{+2})/(Na^{+}+K^{+})$	HCO_3^{-}/Cl^{-}	SO_4^{2-}/HCO_3^{-}	SO_4^{2}/Cl^{-}	$Ca^{+2}/(SO_4^{2-}+HCO_3^{-})$	Water Type
21-	AC/030A	10/07/2003	0.89	0.76	44.73	1.11	0.58	0.20	0.12	0.66	Na-Ca-Mg-Cl-HCO3
22-	AC/030A	09/01/2004	0.82	0.9	61.15	0.97	0.72	0.19	0.14	0.57	Na-Ca-Mg-Cl-HCO3
23-	AC/030A	14/05/2004	0.83	0.85	38.7	1.03	0.7	0.17	0.12	0.61	Na-Ca-Mg-Cl-HCO3
		Average	**0.85**	**0.84**	**48.19**	**1.04**	**0.67**	**0.19**	**0.13**	**0.61**	

Appendix (3.20): Results of Rock Source Deduction of Al Himmah Spring

No.	Spring Code	Date	$Na^{+}/Na^{+}+Cl^{-}$	$Mg^{+2}/Ca^{+2}+Mg^{+2}$	$Ca^{+2}/Ca^{+2}+SO_4^{-2}$	$Ca^{+2}+Mg^{+2}/SO_4^{-2}$	TDS	Cl^{-}/sum anions	HCO_3^{-}/ sum anions
21-	AC/030A	10/07/2003	0.43	0.47	0.80	7.35	763.2	0.59	0.34
22-	AC/030A	09/01/2004	0.47	0.45	0.78	6.36	828.4	0.53	0.38
23-	AC/030A	14/05/2004	0.46	0.45	0.81	7.73	795.8	0.54	0.38
		Average	**0.45**	**0.46**	**0.8**	**7.15**	**795.5**	**0.55**	**0.37**

Appendix (3.21): Ionic Characteristics Ratios and Water Type of Al Maleh Warm Springs

No.	Spring Code	Date	Location	Mg^{+2}/Ca^{+2}	Na^{+}/Cl^{-}	Na^{+}/K^{+}	$(Ca^{+2}+Mg^{+2})/(Na^{+}+K^{+})$	HCO_3^{-}/Cl^{-}	SO_4^{2-}/HCO_3^{-}	SO_4^{2}/Cl^{-}	$Ca^{+2}/(SO_4^{2-}+HCO_3^{-})$	Water type
1-	AC/041E	10/07/2003	W.M.E	0.55	0.75	27.3	0.68	0.09	2.03	0.18	1.30	Na-Ca-Cl
2-	AC/041E	09/01/2004	W.M.E	0.56	0.64	26.4	0.78	0.11	1.31	0.14	1.36	Na-Ca-Cl
3-	AC/041E	14/05/2004	W.M.E	0.30	0.72	40.9	0.62	0.10	1.58	0.16	1.40	Na-Ca-Cl
4-	AC/041W	09/01/2004	W.M.W	0.36	0.75	25.7	0.70	0.11	1.56	0.18	1.38	Na-Ca-Cl
5-	AC/041W	10/07/2003	W.M.W	0.59	0.76	26.8	0.66	0.09	1.83	0.17	1.25	Na-Ca-Cl
6-	AC/041W	14/05/2004	W.M.W	0.43	0.63	30.4	0.80	0.09	1.55	0.15	1.52	Na-Ca-Cl
			Average	**0.47**	**0.71**	**29.6**	**0.71**	**0.1**	**1.64**	**0.16**	**1.36**	

Appendix (3.22): Results of Rock Source Deduction of Al Maleh Warm Springs

No.	Spring Code	Date	Location	$Na^{+}/Na^{+}+Cl^{-}$	$Mg^{+2}/Ca^{+2}+Mg^{+2}$	$Ca^{+2}/Ca^{+2}+SO_4^{-2}$	TDS	Cl^{-}/sum anions	HCO_3^{-}/ sum anions
24-	AC/041E	10/07/2003	W.M.E	0.43	0.36	0.66	3426.5	0.79	0.07
25-	AC/041E	09/01/2004	W.M.E	0.39	0.36	0.71	3382.4	0.80	0.08
26-	AC/041E	14/05/2004	W.M.E	0.42	0.23	0.69	3358.6	0.80	0.08
31-	AC/041W	09/01/2004	W.M.W	0.43	0.27	0.69	3236.0	0.77	0.09
32-	AC/041W	10/07/2003	W.M.W	0.43	0.37	0.66	3373.2	0.79	0.07
33-	AC/041W	14/05/2004	W.M.W	0.39	0.3	0.71	3488.2	0.80	0.08
			Average	**0.42**	**0.32**	**0.69**	**3377.5**	**0.79**	**0.1**

Appendix (3.23): Ionic Characteristics Ratios and Water Type of Al Maleh Cold Spring

No.	Spring Code	Date	Location	Mg^{+2}/Ca^{+2}	Na^{+}/Cl^{-}	Na^{+}/K^{+}	$(Ca^{+2}+Mg^{+2})/(Na^{+}+K^{+})$	HCO_3^{-}/Cl^{-}	SO_4^{2-}/HCO_3^{-}	SO_4^{2}/Cl^{-}	$Ca^{+2}/(SO_4^{2-}+HCO_3^{-})$	Water Type
1-	AC/041C	04/08/2003	W.M.C	0.51	1.21	228.1	1.43	1.37	0.14	0.19	0.74	Na-Ca-Mg-HCO3-Cl
2-	AC/041C	09/01/2004	W.M.C	0.49	1.10	65.6	1.49	1.37	0.14	0.19	0.71	Ca-Na-Mg-HCO3-Cl
3-	AC/041C	10/07/2003	W.M.C	0.54	0.97	32.5	1.86	1.37	0.16	0.22	0.76	Ca-Na-Mg-HCO3-Cl
4-	AC/041C	14/05/2004	W.M.C	0.54	1.10	31.5	1.66	1.58	0.16	0.25	0.67	Ca-Na-Mg-HCO3-Cl
			Average	**0.52**	**1.10**	**89.4**	**1.61**	**1.42**	**0.15**	**0.21**	**0.72**	

Appendix (3.24): Results of Rock Source Deduction of Al Maleh Cold Spring

No.	Spring Code	Date	Location	$Na^{+}/Na^{+}+Cl^{-}$	$Mg^{+2}/Ca^{+2}+Mg^{+2}$	$Ca^{+2}/Ca^{+2}+SO_4^{-2}$	TDS	Cl^{-}/sum anions	HCO_3^{-}/ sum anions
27-	AC/041C	04/08/2003	W.M.C	0.55	0.34	0.86	442.6	0.38	0.51
28-	AC/041C	09/01/2004	W.M.C	0.52	0.33	0.86	461.2	0.38	0.52
29-	AC/041C	10/07/2003	W.M.C	0.49	0.35	0.84	435.6	0.37	0.51
30-	AC/041C	14/05/2004	W.M.C	0.52	0.35	0.83	456.3	0.34	0.53
			Average	**0.52**	**0.34**	**0.85**	**449.0**	**0.37**	**0.52**