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Hydrogeochemical and isotopic study of the groundwater of Ein Samia, Al Auja, and Al Jiftlic wells

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Thesis Approval

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Dedication

To the ever light candle that always lead me all through the tunnel …, to the dear memory of my late mother.

To my first and virtuous mentor who filled me with hope …, to the memory of my late father.

To the "flower" who unconditionally encouraged and supported me all the way long to come to this hopefully successful accomplishment …., to my faithful wife Heba.

To my brothers, sisters, and friends who spared no effort to help……

To all of the above mentioned , I dedicate this work

Declaration

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

Signed: ……………………………..……….
(Rafeeq Ibrahim Mohammed Hijjeh)

Date: 15/07/2006.

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Abstract

The present study was conducted in Ein Samia, Al Auja, and Al Jiftlic areas which lie in the eastern slope of Palestine topography within coordinates 180-200E and 148-180N.

This study aimed mainly to provide a hydrological, hydrogeological, hydrochemical, and isotopical data base to assess the groundwater quality, identify the groundwater genesis and the major sources of pollutants, estimation the groundwater age, and finally evaluate the average quantity of surface runoff, water infiltration, and water recharge in the drainage basin of Wadi Al Auja.

Salinity is the main problem in the groundwater Al Auja, and Al Jiftlic wells in the eastern basin where the concentration of sodium and chloride are the main dominant ions in those shallow groundwater wells. Hydrogeochemically, the most common water type of the Eocene-Holocene aquifers are of alkaline water with increased portion of alkalis and prevailing sulphate and chloride due to the dissolution of dolomitic carbonate rocks that interbedded with chalk, gypsum band, and impermeable layers of saline marl of lacustrine deposits of Alluvium–Lisan during water recharge. The statistical processes showed very high correlations between Na^+-Cl^--Ca^{2+}-Mg^{2+}, and some times Ca^{2+}-SO_4^{2-}. These correlations point to the presence of carbonate sediments, halite, and some times gypsum in the geological formation of Al Auja and Al Jiftlic areas. The study attained that the majority groundwater wells expose to the processes of calcium precipitation and ion exchange (water softening). Furthermore, the groundwater wells of Al Jiftlic expose to the process of mixing with agricultural and domestic waste water that flow along Wadi Al Far'a. Thermodynamically, all groundwater wells are often oversaturated with respect to the calcite and dolomite and under saturated with respect to gypsum, anhydrate, and fluorite mineral phases. From the chemical point of view; the majority groundwater wells of Al Auja and Al Jiftlic face serious deterioration in drinking water quality where some chemical constituents i.e. Na^+, Cl^- are much exceeded WHO (2005) standards, therefore; those groundwaters wells are unsuitable for drinking purpose. The quality of irrigation water is classified as permissible to doubtful for irrigate salt-sensitive crops in Al Auja and doubtful to unsuitable for irrigate salt-moderately sensitive crops in Al Jiftlic area, with some hazardous on soil permeability.

The water type of the Albian-Upper Cenomanian aquifers is of earth alkaline water with prevailing bicarbonate in the area of Ein Samia and increased with alkalis portion in the area of Fruish Bait Dajan. The study explained the very high correlation between the main dominant ions of Ca^{2+} and HCO_3^- is resulted from water recharge and percolation through different type of sedimentary carbonate rocks. Based on the low standard deviation of the measured parameters; the study presumed that groundwater wells of Ein Samia are share a common recharge area, and/or existence interconnection between the Cenomanian aquifers due to the presence of deep faults. Thermodynamically, the water of the upper Cenomanian aquifer in Ein Samia are over saturated with respect calcite and dolomite, anhydrate, gypsum, and fluorite mineral phases while, the water of the Albian-middle Cenomanian aquifer are undersaturated with respect to all those minerals. The study indicates that all the measured chemical and physical parameters of the groundwaters within the Cenomanian aquifers are less than WHO (2005) standards, therefore these groundwaters are acceptable for drinking and agricultural purposes without limitation.

On the light of the isotopic analysis (^{18}O, ^{2}H, ^{3}H), the isotopic composition of the studied samples ranges from -4.9 to -6.0 for $\delta^{18}O$, and from -21.8 to -26.7 for $\delta^{2}H$, while d-excess varies from 18.31 to 21.74. This variation is explained due to variation in the watershed where the study showed that the groundwater wells of Ein Samia and Al Auja feed water from higher watershed than those in Al Jiftlic. Based on the $\delta^{18}O$- $\delta^{2}H$ diagram, all samples plot around the Mediterranean meteoric line as a sign that those waters originated from recent meteoric precipitations. The statistical study illustrate that the best relationship between $\delta^{18}O$-$\delta^{2}H$ in the study area is fit the following linear equation $\delta^{2}H = 5.48*\delta^{18}O + 6$.

The study explicated the direct relation between water salinity (EC) and isotopic composition ($\delta^{18}O$ & $\delta^{2}H$) in Al Auja and Al Jiftlic wells is due to increasing the dissolution of carbonate rocks interbedded with salts (marine salts) during long distance of water recharge. Based on the combination of tritium and chloride results; the groundwater wells of Al jiftlic recharged water from the drainage basin of Al Far'a and Al Bathan area. The flow path is determined from the NW toward the SE with average seepage rate varies from 0.025 to 0.098 m/hr. The tritium values ranged from 5.4 – 0.4 TU which means that the older water age is dating after 1950 where the groundwater wells of Al Jiftlic are more older than those in Al Auja. Despite the groundwater wells of Ein Samia share the same recharge area; the study illustrated that deeper groundwater wells contain lower tritium concentration than the other groundwells of less depth.

الملخص

دراسة هيدروجيوكيميائية ونظائرية للمياه الجوفية لآبار عين سامية، والعوجا، والجفتلك

أجريت هذه الدراسة في مناطق عين سامية، العوجا، والجفتلك التي تقع في الانحدار الشرقي لطبوغرافية فلسطين بين خطي عرض 180–200 شرقاً وخطي طول 148–180 شمالاً.

هدفت هذه الدراسة بشكل رئيسي إلى تزويد قاعدة بيانات هيدرولوجية، هيدروجيولوجية، هيدروكيميائية، ونظائرية من اجل تقييم جودة المياه الجوفية، وتحديد المصادر الرئيسة للملوثات، وتقدير عمر المياه الجوفية، وحساب معدل كمية المياه السطحية الجارية، وكمية الرشح، وكمية التغذية في حوض التصريف لمنطقة العوجا.

تشير الدراسة أن الملوحة هي المشكلة الرئيسة في مياه الآبار الجوفية لمناطق العوجا، والجفتلك من الحوض الشرقي حيث وُجِدَ أن تركيز الصوديوم والكلور هي الأيونات السائدة في المياه الجوفية الضحلة. ومن الناحية الهيدروجيوكيميائية، دلت الدراسة أن نوعية معظم المياه التابعة للأحواض المائية الأيوسونية–الهلوسونية هي مياه قلوية ترابية مع زيادة القلويات وسيادة الكبريتات والكلوريدات، وهذا يعود إلى إذابة الأملاح في المياه الجارية خلال المسافات الطويلة عبر الصخور الدولوماتية الكربوني ة والتي يتخللها طبقات من الصخور الطباشيرية، الجبسية، وطبقات غير منفذة من الأملاح المارلية والتي تتبع مرحلة تكوينات اللسان–الطمية الحديثة. أثبتت الدراسة الإحصائية وجود علاقات بمعاملات ارتباط عالية بين أيونات Na، Cl، Ca، Mg وفي بعض الأحيان علاقة ارتباط عالية بين ايونٍ SO_4 و Ca كدليل على وجود الصخور الكربونية، والأملاح، وفي بعض الأحيان الجبس في المكونات الجيولوجية لمناطق العوجا والجفتلك. توصلت الدراسة أن معظم المياه الجوفية تتعرض إلى عمليات ترسيب الكالسيوم وعملية التبادل الأيوني بين Ca^{+2} و Mg^{2+} مع Na^+ و K^+ وكذلك تعرض المياه الجوفية في الجفتلك إلى عمليات خلط مع المياه العادمة المنزلية والزراعية التي تتدفق على طول واد الفارعة. ومن الناحية الثيرموديناميكية، أظهرت جميع المياه الجوفية أنها فوق الإشباع بالنسبة للمعادن الذائبة كالكلسس، الدولوميت، وتحت الإشباع بالنسبة إلى الجبس، الأنهيدريت، والفلوريت. من وجهة النظر الكيميائية, أظهرت الدراسة أن معظم مياه الآبار الجوفية مناطق العوجا والجفتلك تواجه تدهوراً في جودة مياه الشرب، حيث أن معظم المكونات الكيميائية مثل تركيز Na^+ و Cl^- قد تجاوزت كثيراً قيم منظمة الصحة العالمية لعام 2005، وهذا يعني أن تلك المياه غير مناسبة لأغراض الشرب. صُنفت كفاءة المياه الزراعية ما بين مسموح به إلى مشكوك فيه لاستخدامات ري المحاصيل الحساسة للملوحة في منطقة العوجا، ومشكوك فيه إلى غير ملائمة لاستخدامات ري المحاصيل متوسطة الحساسية للملوحة في منطقة الجفتلك، مع إظهار قليل من الخطورة على نفاذية التربة.

إن نوع مياه الخزانات الألبية–السينومانية هي من القلويات الترابية مع سيادة البايكربونات في منطقة عين سامية وبزيادة قليلة في القلويات في منطقة الجفتلك. فسرت الدراسة علاقات الارتباط العالية جداً بين الأيونات السائدة Ca^{+2} و HCO_3^- بأنها ناتجة عن الماء المتدفق والمرتشح عبر طبقات مختلفة من الصخور الكربونية الرسوبية. اعتمادا على الانحراف المعياري المنخفض للعناصر المقاسة ، تفترض الدراسة أن تكون المياه الجوفية لآبار عين ساميا تشترك في منطقة التغذية و/أو أن الخزانات السينومانية متصلة مع بعضها بسبب وجود تصدعات أرضية. أما من الناحية الثيرموديناميكية، فقد دلت الدراسة أن ماء الخزان السينوماني الأعلى في عين سامية فوق مشبعة بالنسبة إلى معدن الكلس، الدولوميت، الأنهيدريت، الجبس، والفلوريت، بينما مياه الخزانات الألبية–السينومانية المتوسطة غير مشبعة بالنسبة إلى المعادن المذكورة سابقاً. تشير الدراسة أن جميع المكونات الكيميائية والفيزيائية المقاسة في آبار عين سامية أقل من القيم الموصى بها من وزارة الصحة العالمية لعام2005 مما يعني أن المياه مقبولة للأغراض الشرب والزراعة.

وفي ضوء التحليل النظائري لعناصر $^{3}H, ^{2}H, ^{18}O$ فان المحتوى النظائري للعينات يتراوح بين –4.9 إلى –6 بالنسبة إلى $\delta^{18}O$، ومن –21.8 إلى –26.7 بالنسبة إلى $\delta^{2}H$. وبالرجوع إلى شكل العلاقة بين $\delta^{18}O$ و $\delta^{2}H$، فإن جميع العينات رسمت حول خط البحر الأبيض المتوسط مما يؤكد حداثة هذه المياه وأنها من مياه الأمطار. بينما تدل الدراسة الإحصائية أن أفضل علاقة بين $\delta^{18}O$ و $\delta^{2}H$ في مناطق الدراسة هي المعادلة الخطية $\delta^{2}H = 5.48*\delta^{18}O + 6$.

فسرت الدراسة العلاقة الطردية بين ملوحة المياه والمكونات النظائرية ($\delta^{18}O$ & $\delta^{2}H$) في آبار العوجا والجفتلك بسبب العلاقة الطردية بين بعد منطقة التصريف وكمية الأملاح البحرية والرسوبيات الكربونية المذابة . اعتماداً على الدمج بين نتائج مكونات ^{3}H و تركيز أيونات Cl في الماء ، فان المياه الجوفية في منطقة الجفتلك تحصل على التغذية من حوض التصريف لمنطقة الفارعة والباذان. وقد تم تحديد اتجاه تدفق المياه نحو الجنوب الشرقي وبمعدل سيلان يتراوح بين 0.025 إلى 0.098 م/ساعة . تدل قيم ^{3}H الواقعة بين 0.4 إلى TU 5.4، بأن المياه الأقدم في تلك الآبار الجوفية تعود إلى ما بعد 1950 حيث تعتبر مياه الآبار الجوفية في منطقة الجفتلك أكثر قدماً من العوجا. على الرغم من أن جميع الآبار الجوفية في عين ساميا تتشارك في منطقة التغذية، لقد أظهرت الدراسة بان المياه الجوفية الأكثر عمقاً في تلك المنطقة تحتوي على تركيز ^{3}H أعلى من تلك المياه الأقل عمقاً.

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List of Symbols:

&	and
#	number
%	percent
°	Degree centigrade (Celsius scale)
°F	degree Fahrenheit (Fahrenheit scale)
µm	Micrometer
µS	micro siemens
‰	per mil
^{18}O	oxygen-18
^{2}H	deuterium
^{3}H	tritium
Arij	Applied Research Institute-Jerusalem
C.gw	chloride concentration of the ground water
Ca^{2+}	calcium (ion)
Cen-Tur	Cenomanian-Turonian
Cl^{-}	chloride (ion)
cm	centimeter
Cp	weighted average chloride concentration in precipitation
d-excess	measure of deuterium enrichment that exceeds the $\delta\ ^{18}O$ value by more than 8 times
E	east
e.g.	For example
EAB	Eastern aquifer basin
EC	Electrical Conductivity.
EDTA	ethylenediaminetetraacetic acid
ESR	exchangeable sodium ratio
ESW	Ein Samia Well.
ETP	potential evapotranspiration
F^{-}	fluoride (ion)
Fig.	figure
Fm	Formation
GIS	Geological Information System
GTZ	German Technical Cooperation agency
HCO_3^{-}	bicarbonate (ion)
hr	hour
IAEA	International Atomic Energy Agency
JWU	Jerusalem Water Undertaking
K^{+}	potassium (ion)
K_{IAP}	ion activity product
Km	kilometer
Km^2	square kilometer
K_{sp}	solubility product
L	liter (volume)
L.Cen	Lower Cenomanian
m	meter
m a.s.l	meter above sea level
m b.g.l	meter below ground level
M. Cen.	Middle cenomanian
m^3	cubic meter

Max.	Maximum
MCM/yr	million cubic meter per year
meq	Milliequivalent
mg	Milligram
Mg^{2+}	magnesium (ion)
Min.	minimum
mm	Millimeter
MMWL	Mediterranean Meteoric Water Line
MOPIC	Ministry of Planning and International Cooperation, Palestinian Authority
MWL	meteoric water line
N	north (direction)
Na^+	sodium (ion)
NE	northeast
NO_3^-	nitrate (ion)
NW	northwest
P	precipitation
PE	potential evaporation
PHG	Palestinian Hydrology Group
PNAMO	Palestinian National Authority – Meteorological Office
PO_4^{3-}	phosphate (ion)
PWA	Palestinian Water Authority
Q	runoff
R	recharge (hydrology)
RH%	relative humidity
RSC	sodium carbonate parameters
S	south
SAR	sodium adsorption ratio
SE	Southeast
SI	saturation index
SMOW	Standard Mean Ocean Water
SO_4^{2-}	sulfate (ion)
SSE	south-southeast
SSP	soluble sodium percentage
SSW	south-southwest
std. Dev.	standard deviation
SW	Southwest
SWL	Surface Water Level
TDS	total dissolved solids
Temp	temperature
T.H	total hardness
TU	tritium units
U.Cen	Upper Cenomanian
WAB	Western Aquifer Basin
WHO	World Health Organization
yr	year
δ‰	deviation of the isotopic concentration in water from the SMOW
µS	Micro siemens (units of EC)

Chapter One

INTRODUCTION

1.1 General view

Limitation in water resources, political restrictions on additional drilling or development of groundwater wells, continuous increasing in water demands for drinking and agricultural uses, depression in groundwater level, and deterioration in water quality (due to human activities such as applications of agricultural chemicals, disposal of solid wastes in landfills, operation of septic systems... etc) are the main challenges that threaten the water resources.

Despite the West Bank mountains are the main recharge areas for the western, northeastern, and eastern aquifers with estimated water recharge of 172, 145, and 362 MCM/yr respectively *(Oslo2 Accords, 1995*); about 82% of water resources in the West Bank are out of Palestinians control. Water shortage is one of the main important future strategic issues in the region. The bilateral *Oslo2* agreement (September/1995, article 40) state that Palestinian are needed an additional amount of water with estimated total 70 - 80 MCM/yr.

The eastern basin is considered the main source of water for the Palestinians in the West Bank whereas it contains 150 groundwater wells and 30 springs. Unfortunately most of these resources can't be used for drinking purpose. This forces many peoples to use unsafe water whereas most sources in the study area are characterized by high vulnerability towards pollution with wastewater infiltration or increasing salinity. Hence, most groundwater wells and springs in the study area are used to irrigate specific crops which can be salt-tolerance.

1.2 Location:

Historical Palestine is located between the Mediterranean Sea from the west and the Jordan River from the east, and between the Red Sea from the south, and Syria & Lebanon from the north. Within that location , the boundaries of the West Bank situate between 31º 30' to 32º 30' latitude and 35° to 35° 30' longitude.

The study area consists out of the areas of Al Auja, Al Jiftlic, and Ein Samia (Figure 1.1). Al Auja area is located north of Jericho City (about 9 km); the total district area of Al Auja is 48.6 km^2. Studied groundwater wells are situating within the coordinates 186.5–196.0E and 149.5–151.5 N. The area of Al jiftlic is 50 km^2, it's locate 15 km north of Al Auja district, the aimed groundwater wells are situating within coordinates 192.5– 200.0 E and 168.5–178.5 N. Ein Samia area locates in Ramallah district (west of Wadi Al Auja) within the coordinates 181.5-182.3E and 153.0-155.5 N.

1.3 Topography:

The West Bank can be divided into four major geomorphologic parts including Nablus, Jerusalem, and Hebron mountains as well as the Jordan Valley. The West Bank has two slopes; toward the west and disappears usually in the coastal zone near the Mediterranean, and toward the east vanishing in the beginning of the Jordan valley. The topography of the study area, which lies on the eastern slope, shows continuous decrease in elevation starting from about 500-400 m a.s.l at Ein Samia to about 20m a.s.l-270m b.s.l at Al Auja area and 148-190 b.s.l at Al Jiftlic area. The flanking mountains at the eastern area reach highest of 750m above sea level at horizontal distance of 2.5 km from the valley bottom *(MOPIC, 1999).*

Wadi Al Auja is one of many Wadis that extended through Jericho district and runs W-E such as Wadi Al-Qilt, (characterized by permanent water flow during different seasons), Wadi Nuwema, Wadi Abu Ubeida, and Wadi Ghazal (which are characterized by intermittent water flow). On the other hand Wadi Al- Mallaha is the only Wadi runs N-S direction *(Arij, 1995a).*

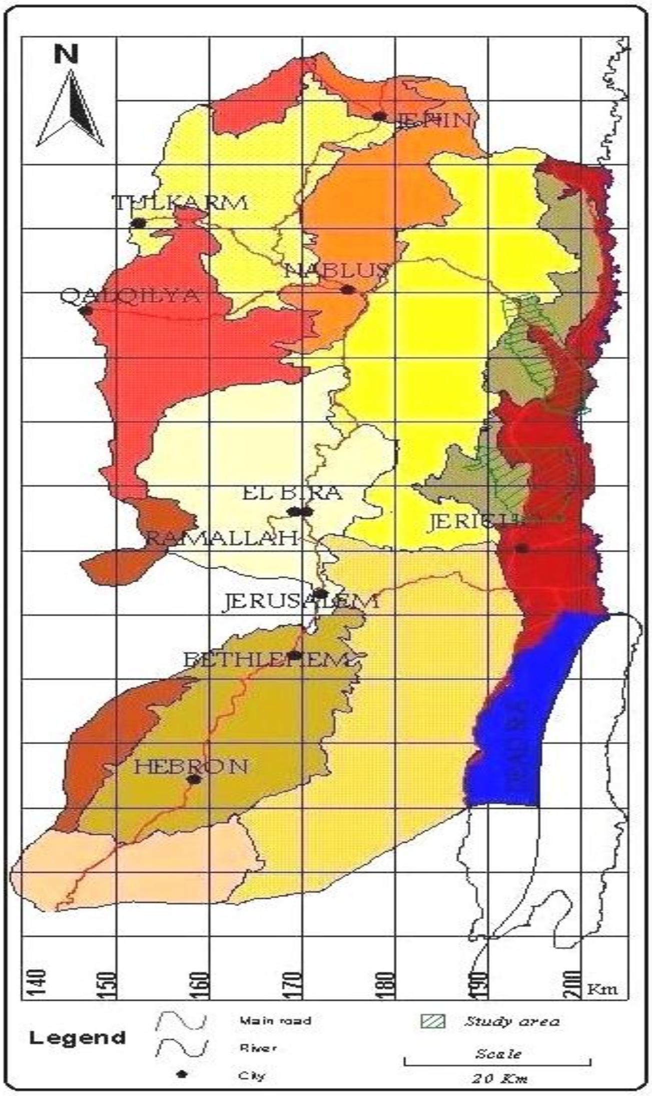


Figure 1.1: Map of the West Bank illustrates the locations of the study basins.

1.4 Land Use:

Palestinians built up areas represent about 1.7% of the total area of Jericho district. Israeli settlements occupied about 1.5% of the region, and the closed military areas occupied 16.5% extended along the western border of the district *(Aronson, 1998).*

The cultivated area in Jericho district cover approximately 1.94% of the total area distributed as 0.42% (625.3 hectares) in Al Auja, and 0.33% (485.7 hectares) in Al Jiftlic area. The irrigated agricultural areas represent 43% of the cultivated area *(SAAR, 1992).*

Based on Figure 1.2 that shows the land use of Al Jiftlic area which is a part of Wadi Al Far'a within the coordinates (190-200E to 165-180N); 25.4% of Al Jiftlic area represents closed military area, 10.3% is of natural reserves, 9.3% is of field crops and vegetation, 6.8% represent Israeli cultivated area, 2.8% urban areas, 2.8% Israeli military base, and 2.1% Israeli colony. The non utilized area represents 40.5% of the total area of Al Jiftlic (50km^2).

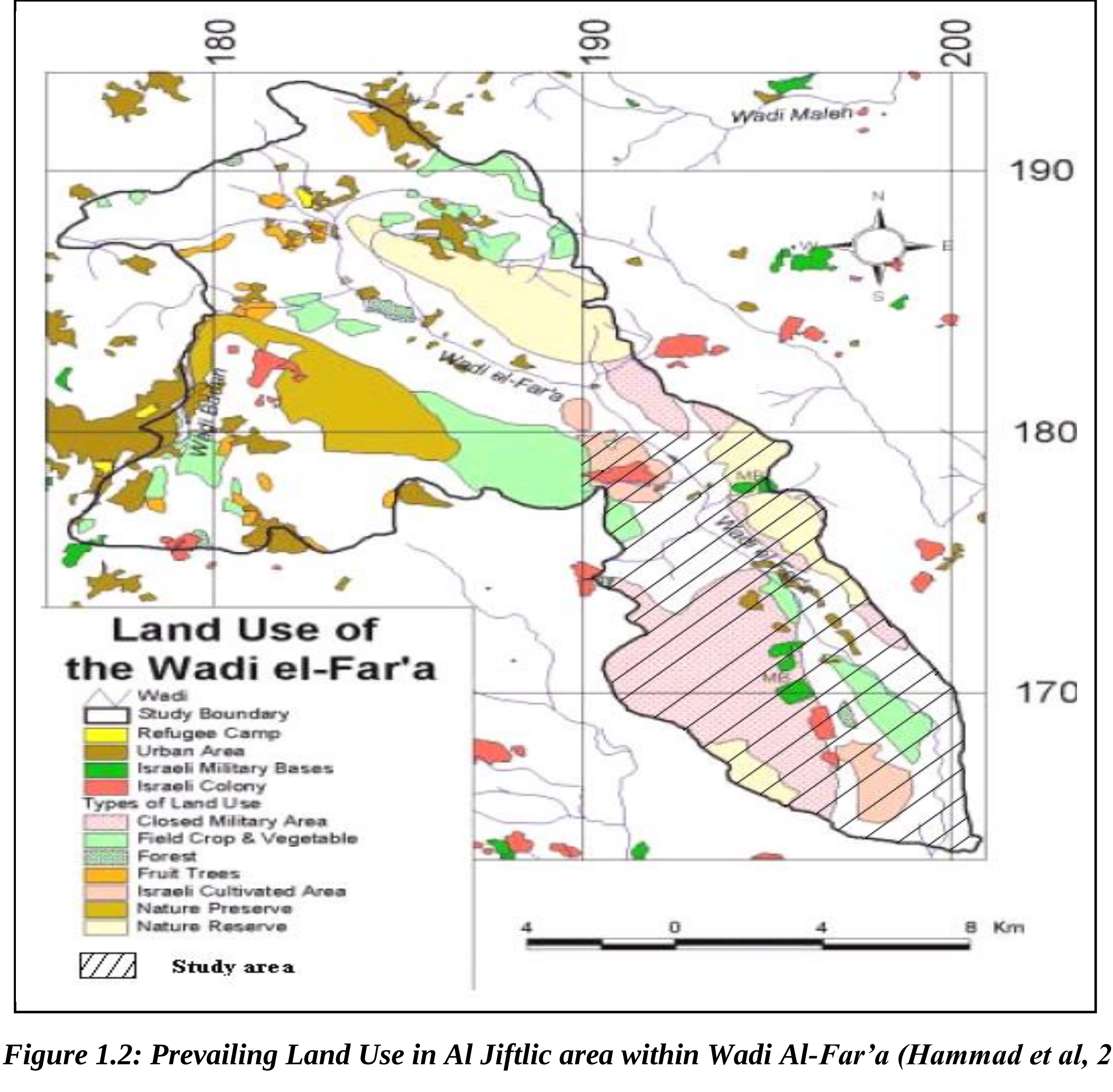


Figure 1.2: Prevailing Land Use in Al Jiftlic area within Wadi Al-Far'a (Hammad et al, 2002).

Agriculture activates are the main land use in the Al Auja and Al Jiftlic areas. Many factors can affect the diversity of the land use in the study area such as topography, human activities, water resources, and climate.

1.5 Distribution of Groundwater Wells:

The number of the groundwater wells that were used in the West Bank reaches approximately 750 well since years ago. Recently, 372 wells are used; Jericho territories shares the large number of wells distributed as 104 groundwater wells in Jericho municipality area, and 37 wells are out of Jericho municipality, all groundwater wells are illustrated in table 1.1. The total wells number in the study area are 58 distributed as, 12 groundwater at Al Auja, 28 at Al jiftlic, 12 at Fruish Bait Dajan, and 6 groundwater wells at Ein Samia. The main notice is shallow groundwater wells of the unconfined aquifers (i.e. Al Auja, Al Jiftlic groundwater wells) are used for agricultural purpose, while deep groundwater wells within the confined aquifers are used for domestic propose (i.e. Ein Samia groundwater wells).

Table 1.1: General distribution of groundwater wells in Jericho territories and Ein Samia area (Source data: PWA, 2000)

Locality	**Type Of Water Use**			**Total**
	Agriculture	**Domestic**	**Unknown**	
Jericho city	48	2	8	58
Wadi Al Qilt	--	3	--	3
Aqbat jabir	--	2	--	2
Dair Hijleh	--	--	2	2
Al Auja	7	4	1	12
Ein Samia	--	6	--	6
Fasayil	1	6	--	7
Al Jiftlic	26	1	1	28
Fruish Bait Dajan	8	4	--	12
Marj Na'ja	--	--	4	4
Marj Al Gazal	9	--	--	9
Az Zubeidat	2	--	2	4
Total	**101**	**28**	**18**	**147**

1.6 Al Auja Spring:

Al Auja spring (AR/020) is one of 12 springs distributed in Jericho territories such as Fasayil (1spring), Al Dyuk (1), Al Nwai’mah (1), Al Shusah (1), Al Sultan (1), Al Jiftlic (2), Wadi Al Qilt and Al Fawwar (1), Ghwair (1), Ghazal Al Shamaliyyah (1), Turba (1). Wadi Al Auja represents the main path of water recharge that feeding the spring AR/020 (Figure 1.3).

Figure 1.3: View of water recharge along Wadi Al Auja that runs forward W-E.

The average annual discharge of the spring through 1980-2001 is approximated 1069 m³/hr *(Table 1.2).* Some times the annual discharge suddenly decreases, i.e. in December 2002 the flow amount started with 1350 m³/hr then decreased after two weeks to reach 835 m³/hr. This decrease may be a natural consequence of high pumping from the nearby three-groundwater wells that drilled by Israeli government on the site of Al Auja spring *(Sbieh, 2002).*

Table 1.2: The approximated average of annual discharge amount for some springs in Jericho area 1980-2002 (Source data: PWA, 2003).

Locality spring	Discharge amount (m³/hr)
Al Auja	1069
Al Nweima	328
Ein Al Sultan	700
Al Fara’	1500
Fasayil	79
Al Dyuk	546
Al Shusah	651
Al Sultan	651
Al Qilt & Al Fawwar	865 m³/hr

1.7 Groundwater Recharge:

The main source of recharged water is from the annual precipitation. Groundwater recharge in the study areas depends mainly on the lithology of the surface deposits and their porosity which controls the depth of percolation. According to *Khatib and Assaf (1994)*, runoff of precipitation in Jericho district includes Al Jiftlic and Al Auja only happen when the rainfall exceeds 50 mm in one day or 70 mm in two consecutive days.

1.8 Soil Type:

Most soils of Al Auja and Al Jiftlic are of Rendzina type with all varieties especially the gray calcareous steppe series. In valleys, alluvial soil series are the most dominant, which are considered to be the best suitable soil for agriculture *(LRC, 2003)*. Terra Rosa soil is found also in some patches of irrigated arable land, it has medium salinity due to their heavy texture *(PIALES, 1996).*

1.9 Previous Studies:

Few studies were published about water quality of groundwells in the Jordan valley. Limited studies were intended the north area of Jericho (Al Auja, Al Jiftlic). The published and unpublished materials (reports, maps, documents,..) that concerning the environmental situation in the Jordan valley were reviewed. The main studies that were published are summarized as the following:

Arij (1995) gives an evaluation about water resources management in Ramallah and Jericho area, and gives general environmental profile for both areas. *Aliewi et al. (1996)* studied some well fields in Ein Samia; this study includes pumping test, well development, and evaluation of potential well locations using Arial Photography. *Strum et al. (1996)* studied water resources management in Ramallah and Jericho area. *Abed Rabbo et al. (1999)* studied the water quality and chemistry for some springs of the Jordan valley, and two groundwater wells of Ein Samia. *Vengosh et al. (2003)* studied the origin and mechanisms of salinization of the lower Jordan River.

1.10 Importance of the Study:

Despite Al Auja and Al Jiftlic areas locate in semi arid zone of hot climate and low rainfall; those areas are agricultural. Some people are using agriculture wells that characterize by medium to high salinity water for domestic purpose, while some farmers use very high salinity groundwater for agriculture purpose, consequently increasing soil salinization and decreasing in crops product. Thus because the shortage in fresh water quality and quantity is the main problem in the study areas of north Jericho and for the reason that Ein Samia groundwater wells are important source of domestic water for consumers in Ramallah district and some parts of Jerusalem; this study aim to provide hydrogeological, hydrochemical, and isotopic data base for surface and subsurface water within Al Auja, Al Jiftlic, and Ein Samia areas in order to determine water recharge, water quality and possible causes of degradation, and date groundwater age. The long-term importance of this study represent that it can be employed in any expected setting up flow model for improving water resources management in the related study areas.

1.11 Objectives of the Study:

This study has the following objectives:

1. Determination of chemical ions (Na^+, K^+, Ca^{+2}, Mg^{+2}, HCO_3^-, Cl^-, SO_4^{-2}, NO_3^-) and isotopic parameters ($^{18}O/^{16}O$, $^{2}H/^{1}H$, and tritium) in the groundwater wells.
2. Test the suitability of groundwater wells for drinking and agricultural purposes.
3. Identify the groundwater genesis, and the possible pollutants source.
4. Evaluating the sampled groundwaters age using tritium technique.
5. Tracing the flow path and estimate its rate in Al Jiftlic area from the north to the south boundary based on the combination of tritium and chloride concentrations in the sampled groundwater wells.
6. Estimation the quantity of surface runoff, infiltration, and water recharge of wadi Al Auja.

Chapter Two

METHODOLOGY

2.1 Literature Review

The literature review aimed mainly to collect the available published and unpublished scientific papers, maps and documents, which related to meteorological, hydrogeochemical, geographical, and isotopic, and other related environmental data of the study areas.

2.2 Sampling

During this work 23 major groundwater wells and one spring within the study region were sampled (usually twice) from july/2003 to August /2004, the total samples were 42, four samples abandoned due to over range of ionic balance error, and 38 water samples remained. Before sampling, all pumps are turned on for about 10-15 minute, this process contribute in given high reliable measurement of groundwater temperature, dissolved gases, groundwater pH, and chemical parameters. All plastic (polyethylene) bottles were rinsed three times with the objected water before full filled (manually). All of the collected samples were placed in a special cold box before transport to the laboratory refrigerator for analysis.

2.3 Field and Laboratory Analysis

The field measurements of temperature, pH, and electrical conductivity (EC) were taken at situ by using field multi-electrode meter (Metter Toledo). The other chemical analysis of Ca^{+2}, Mg^{+2}, Na^{+}, K^{+}, HCO_3^{-}, Cl^{-}, SO_4^{-2}, NO_3^{-}, and F^{-} were carried out by the environmental laboratory (Al Quds university) while isotopic analysis of ^{18}O, ^{2}H and ^{3}H were analyzed at Umwelt Foerschung Zentrum (UFZ) labs in Leipzig/Germany. All samples were analyzed according to the standard methods (Table 2.1). Ca^{+2}, Mg^{+2} and HCO_3^{-} were determined by titration, Na^{+} and K^{+} were determined by flame photometer, Cl^{-} concentration by using ion chromatography. NH_4^{+}, SO_4^{-2}, NO_3^{-}, F^{-} and PO_4^{-3} were determined by using UV/VIS spectrophotometer. ^{18}O and ^{2}H contents were determined according to analytical techniques of *Coleman et al. (1982)* by using mass spectrometer in UFZ-Leipzig-Germany. Both $^{18}O/^{16}O$ and $^{2}H/^{1}H$ ratios are expressed in per mil relative variation with respect to Vienna Standard Mean Ocean Water (V-SMOW) *(Craig, 1961; Gonfiantini, 1978)*. All analytical errors are within the range of ±0.2‰ for $\delta^{18}O$ and ±2‰ for $\delta^{2}H$. Tritium analysis was conducted by using liquid scintillation counting proceeds by electrolytic enrichment at the UFZ laboratory in Germany. Tritium concentration is expressed in tritium unit (1 TU equals one atom of ^{3}H per 10^{18} atoms of hydrogen).

Table 2.1: The standard analytical methods used in determination of the different parameters.

Parameter	**Methods of analysis**
Tem, EC, and pH-value	Field multi-electrode meter (Metter Toledo)
Ca^{2+}	Titration with Na_2-EDTA using Murexide indicator.
Tot. Hardness (Ca^{2+}&Mg^{2+})	Titration with Na_2-EDTA using Eriochrome black-T indicator.
Na^+ & K^+	Flame photometer.
Alkalinity (HCO_3^-)	Titration with HCl using phenolphthalein and bromocresol-green indicator.
Cl^-	Ion chromatography.
SO^{2-}	Spectrophotometer (λ = 200nm).
NO_3^-	UV-Spectrophotometric method (λ = 220nm).
F^-	Spectrophotometer (λ = 570nm).
PO_4^{3-}	Spectrophotometer (λ = 700nm).
^{18}O & ^{2}H	Mass spectrometry.
^{3}H	Liquid scintillation counter.

2.4 Correctness of the Measurements (Ionic Balance)

Based on the principle of electro-neutrality where the ionic balance (sum of cations and anions in meq/l) should be closed to zero. The correctness of the analysis is tested based on the difference of the ionic balance $(B) = ((\Sigma\text{cations} - \Sigma\text{anions}) / (\Sigma\text{cations} + \Sigma\text{anions})) \times 100\%$, where the concentrations of each cations and anions are given in miliequivalent per liter. In this study, only samples that have an error of ionic balance (B) within the range ±10% *(Hem, 1985)* were adopted for interpretations.

2.5 Classification of Water Chemistry Data

According to geographical classification, the study area divided into three sub areas Ein Samia, Al Auja, and Al jiftlic. In each study area the chemistry data are divided into homogeneous groups based on similar classification according to their salinity and water type.

2.6 Data Interpretation

The interpretation of data was carried out using various software packages:

AquaChem Ver. 7.3 is a software package developed specifically for graphical (Piper, Durov) in order to classify into water types and identify the origin of water. Each of these graph types provides a unique interpretation of the many complex interactions between the groundwater and aquifer materials. AquaChem includes also PHREEQC (sub-program) for calculating equilibrium concentrations (or activities) of chemical species in solution and saturation indices of solid phases in equilibrium with a solution.

GWW software (United Nation, 1995) is used in order to plot the Wilcox diagram to determine the suitability of water for irrigation. This program was also used to plot Schoeller diagram that can give chemical comparison between chemical ionic parameters.

Excel program of Microsoft office (2004) is used to calculate total dissolved solids (TDS), sodium adsorption ratio (SAR), soluble sodium percentage (SSP), residual sodium carbonate (RSC) to determine the suitability of water for irrigation and determine the effect of irrigated water on plants and soils.

The statistical analysis (SPSS, 1999) Ver 10.0 and Excel programs were used to classify the studied source water depending on the common characteristics between the calculated and measured variables, and done the most statistical processes (i.e. correlation matrix between the various measured parameters and plot the significant relations).

AutoCAD program (2002) is used to design the geographic maps and determine the area of the study region. Geographic information system (GIS) program ver 3.3 of ArcView was used to modify maps.

2.7 Meteorology and Recharge Area

Most meteorological data (i.e. rainfall (mm), wind speed (Km/hr), temperature (°C), relative humidity (%), and evaporation (mm/yr)) of the study area of Al Auja and Al Jiftlic were obtained from Jericho station that reflects the arid climate in the eastern basin. The meteorological office of Ramallah supplied us the required climatic data about Ein Samia area.

The drainage basin area of Wadi Al Auja was plotted after determination the higher elevations of the watershed by following the elevations contour on the topographic map, after that the higher elevations were conducted and referred by continuous line. The area is divided into sub-areas identified by discrete lines according to the isohyetal contour map of the long-term annual rainfall averages of the West Bank during the period 1961-2004. The total area and each sub-area are plotted and computed by using AutoCAD and GIS programs in order estimating the average depth of rainfall (P_m), effective annual rainfall, average surface runoff, infiltration and water recharge of the drainage basin of Wadi Al Auja.

2.7.1 Estimation of Mean Annual Rainfall (Isohyetal method)

Isohyetal technique was used to estimate the average depth of rainfall over the study area of Al Auja; this technique is based on the formula:

$$P_m = \Sigma \, (Ai * Pi) / A$$

Where P_m is the mean real rainfall in (mm), Ai is sub-area; Pi is the average precipitation between each two successive contour lines, and A represents the total area *(Chow et al., 1990).*

2.7.2 Estimation of Surface Runoff (Goldschmidt formula)

The surface runoff in Wadi Al Auja was estimated using Goldschmidt formula. This formula employed for soil surface of low hydraulic conductivity that leads to average annual runoff of about 20% of the annual precipitation, surface run off was calculated according to the following equation:

$$Q = 0.237 * (P-252)$$

Where Q is the average annual runoff and P is the average annual rainfall, whereas both Q and P are in mm/yr *(Arad and Michaeli, 1967).*

The study of the drainage basin of Wadi Ein Samia and Al Auja showed high runoff according to the low infiltration in the soil due to the presence of marls, clays and lower permeable sands which refer to low hydraulic conductivity rocks *(CDM, 1998)*; hence Goldschmidt formula can be applied.

2.7.3 Estimation of Infiltration (Soil Conservation Service (SCS) method):

The infiltration in Wadi Al Auja is estimated by using soil conservation service method by using the following equation:

$$R = Pe - Q$$

Where R: infiltration (mm/yr), Q: runoff (mm/yr) and Pe is Rainfall effectiveness index (mm/yr) which calculated based on the following equation:

$$\text{Pe index} = \sum_{1}^{n=12} 115 * (P/ (T-10))^{10/9}$$

Where P is monthly precipitation in inches and T is temperature in °F.

2.7.4 Estimation of Water Recharge (Chloride Mass Balance (CMB) method):

The chloride mass balance (CMB) is a common method used to estimate the water recharge in semi arid areas which is based on the assumption of conservative mass between the input of atmosphere chloride and the chloride flux in the subsurface according to the following equation:

$$R = [\ (P-Q) / C_{gw}] * C_{p}$$

Where:

R is the annual recharge (mm).
P is the average annual precipitation (mm).
Q is the average annual runoff (mm).
C_{gw} is the chloride concentration of groundwater (mg/L).
C_{p} is the weighted average chloride concentration in precipitation in mg/L (wet and dry deposition) (*Eriksson & Khunakasem 1969).*

According to the normal concentration of chloride in rainfall and the groundwater wells of Wadi Al Auja due to the farness from the sea water , and normal weathering of fracture rocks of evaporites or mixing with saline water in the drainage basin of Wadi Al Auja; the chloride mass balance is the best suitable method that can be applied for estimating water recharge in the area of Wadi Al Auja *(Bazuhair & Wood, 1996, and Scanlon et al. 2002).*

Chapter Three

RESULTS & DISCUTION

3.1 Meteorological Setting

3.1.1 Climate:

In general, the climate of the Eastern Basin in the West Bank is part of the eastern Mediterranean climate; the climate in winter characterizes by cloudy, stormy, rainy and wet season, often extended from November to May. The summer is characterized by quiet winds, low a mount of clouds, hot and dry season, and this period extends always from June until October. Between the two semesters dry and hot winds of Khamseen climate is blow from the south-east direction. The eastern zone represents the semi-desert climate as transitional zone between the true Mediterranean and desert climate. The hot summers and warm winters in al Auja and Al Jiftlic may be related to the area elevations (below sea level), and their positions where surrounded by two high series of mountains from both eastern and western sides (ARIJ, 1995). The available climatic data of the study areas are tabulated in Appendix 3.1 and 3.2.

3.1.2 Rainfall:

The rainfall in the West Bank increases with elevation and from the south to the north and from the east to the west and inversely proportional with air temperature and pressure. The heaviest falling is always focused near the ridge of the central highlands (800-1000 masl). In general the average rainfall in the West Bank ranges from 100 to 700 millimeters annually depending on the location *(PWA, 1999).*

The annual average rainfall in Ein Samia area during the period (1952-2004) is estimated as 520 mm, Figure 3.1 shows that the maximum monthly rainfall occurs in January and sometimes in December.

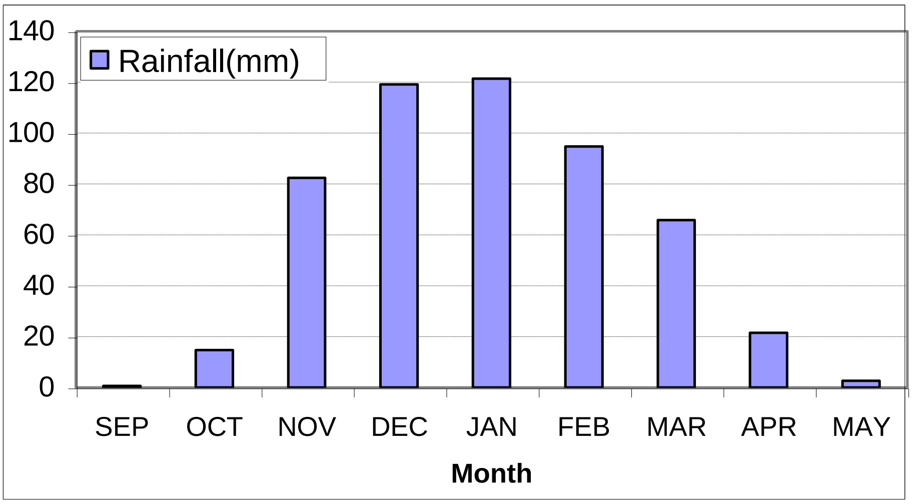


Figure 3.1: Average monthly rainfall over Ramallah area (1952-2004) (PNAMO, 2004).

The average rainfall in Jericho area is 165 mm/year, the maximum rainfall reached 227 mm (at the year 2002/2003), and the minimum is about 50 mm (through the period 1998/1999). Figure 3.2 show that January represents the maximum monthly rainfall between December 1996-2003.

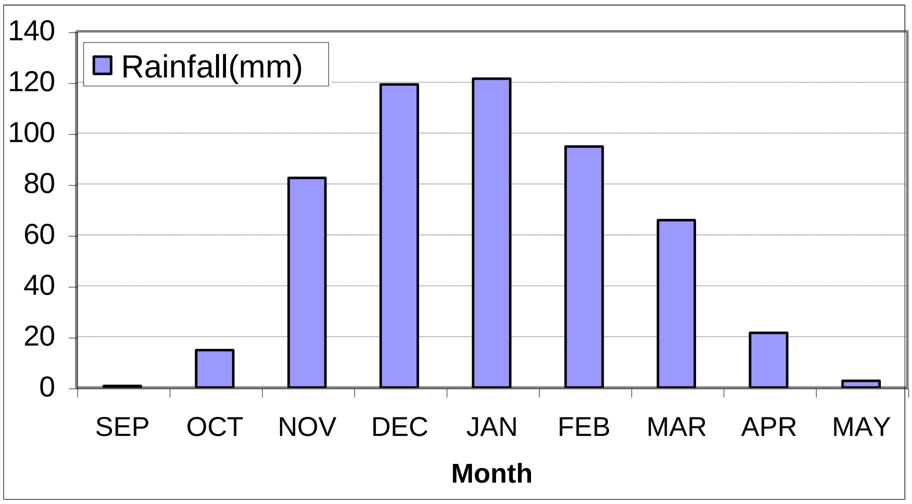


Figure 3.2: The average monthly rainfall in the Jericho district (1996-2003) (PNAMO, 2004).

3.1.3 Wind :

Over the study area, wind blows in winter from the western and the northwest direction, but in summer (from June to August) the wind direction may be changed through one day. For example, at the early morning wind blows from the south, while at afternoon until mid night the wind blows from the north direction *(Kessler, 1994).* Between late April and mid June Khamseen winds blow frequently from Arabian Desert and influence the area.

In Ein Samia area, the wind speed ranged within 3-7m/s in winter and from 8-12m/s in summer, while in Jericho area the wind speed varies between 3-6m/s in winter, and 6-9 m/s in the summer *(PNAMO, 2004).*

3.1.4 Temperature:

The mean monthly temperature in the West Bank varies from 21.7 to 32.7 ºC in summer with an average 25 ºC, and from 8 to 14.2 ºC in winter with an average of 13 ºC. The temperature in the West Bank is increases towards the south and Ghors, which represent high-pressure areas.

Temperature in Ein Samia area which is apart of Ramallah district varies from 6-12 ºC in winter and from 22-27 ºC in summer.

The west high lands of Jericho district plays an important role in preventing the effect of the northwestern wind that cools the area especially in summer, hence, Jericho area distinguishes by higher temperature than Ramallah. In Jericho district, the temperature varies from 13-16 ºC in winter with an average 14.7 ºC, and from 29-34 ºC in summer with an average 31.3 ºC *(PANAMO, 2004).*

3.1.5 Humidity:

The relative humidity in the West Bank varies from 50-70% (For example 52% in Jericho, 61% in Nablus, 69.6 in Tulkarm) with a maximum value in January and minimum in June *(MOPIC, 1998)*. The amount of relative humidity decreases gradually to the east and to the south.

In Ein Samia area, the average annual relative humidity is within 55-77 %; the minimum is recorded in summer 55.8%, while the maximum is recorded in winter 76.9%.

Jericho and the Jordan valley in the Eastern Basin area represent the lowest relative humidity in the West Bank 57-69 % in winter and 43-53% in summer *(PNAMO, 2004).*

3.1.6 Evaporation:

The mean **monthly** potential evaporation rate in summer in the West Bank varies according to location as 215.1 mm at Hebron, 277.3 mm at Nablus, and 284.9 mm at Jericho area. The mean **monthly** potential evaporation rates in winter decreases to 69.4 mm in Hebron, 55.1 mm in Nablus, and 70.9 mm in Jericho *(Arij, 1995).*

Based on *PANAMO (2004)* data base; the average potential evaporation in Ein Samia area is estimated about 210 mm/month in summer, where the maximum evaporation represents in June (271 mm/month). In winter the evaporation rate is estimated a bout 70mm/month, this rate is decreased in December to the minimum value (27.7mm/month).

The Eastern Basin and particularly Jericho area characterizes by low potential evaporation at winter 55-75 mm/month with an average of 64 mm/month and high potential evaporation in summer 250-315 mm/month with an average of 270 mm/month *(PANAMO, 2004).*

Unfortunately, the evaporation a mount in the Eastern Basin is found more than tens time relative to the rainfall (the total annual rainfall in Jericho is 165mm/**yr** while the total potential evaporation is 2070mm/**yr**), this value reflects a bad future consequence on the groundwater storage and agricultural crops that are rainfall dependent. Accordingly, agriculture in Jericho district should be supplied by another source of irrigation such as groundwater wells.

3.1.7 Evapotranspiration:

In the West Bank and depending on various studies, it is obvious that the amount of the evapotranspiration varies between 65-70% of the total annual rainfall. For example the study of *Rofe & Raffety (1963)* estimated the evapotranspiration about 69.1% of the total rainfall in the year 1963/64 and about 66.9% in the year 1964/65.

In Ein Samia area, the average rainfall is 523 mm/yr, the potential evapotranspiration will be about 355mm/yr according to the evapotranspiration coefficient of *Elezar (1982)* (68% of the total annual rainfall). The average evapotranspiration in Jericho area is estimated to be about 110mm/yr, where the total rainfall amount is 165mm/yr (66.7% of the total rainfall) *(PNAMO, 2004). A*ccording to this percentage evapotranspiration of the total rainfall over wadi Al Auja (429mm/yr) will be about 286 mm/yr.

3.2 Water Balance Estimation of Al Auja Spring Drainage Basin

Water balance is comparative analysis of precipitation input and output through evapotranspiration, runoff, infiltration and water recharge with minor importance of soil moisture and depression storage.

3.2.1 Mean Annual Rainfall:

The average depth of rainfall (P_m) over a recharge basin is estimated based on applying the isohyetal method that provide rainfall contour map for each sub area depending on the West Bank contour map of long term annual rainfall average during period (1961-2003).

The total recharge area is calculated using AutoCAD program (2004) after plotting the boundary of the higher elevation contour around the study area (watershed). The recharge basin is subdivided into small areas (sub-areas) A, B, C, D, E, F, and G based on the differentiation in the annual rainfall contour lines (Figure 3.3). Table 3.1 describes the calculation technique for the evaluation of the mean annual rainfall *(Chow et al. 1990).*

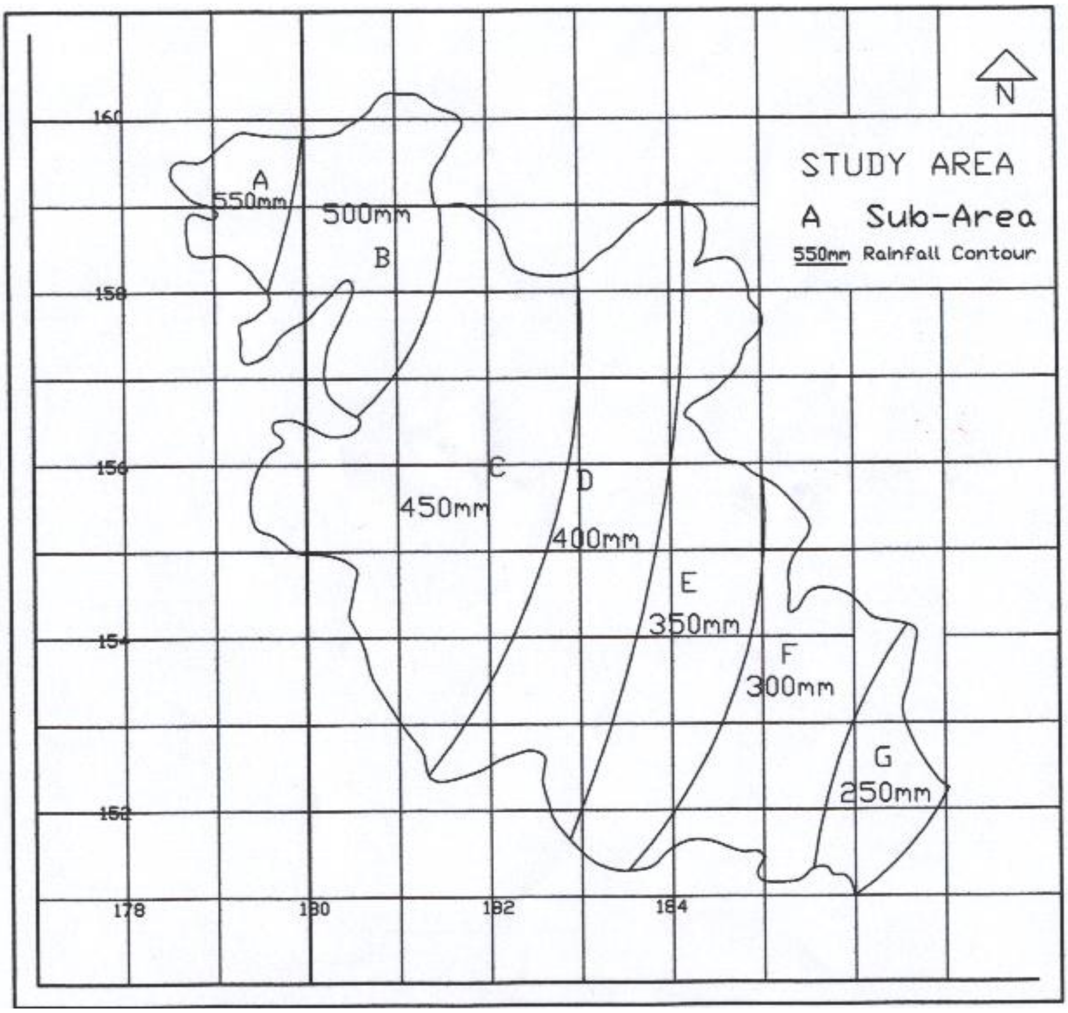


Figure 3.3: The sub areas of Wadi Al Auja recharge area on which the calculation of the mean annual rainfall was based.

Table 3.1: The basic data used to calculate the mean annual rainfall.

Sub area	**Counter (1) P_1 (mm)**	**Counter (2) P_2 (mm)**	***Area (m^2)***	**Pi* Ai**
A	550	575	1623000	912937500
B	500	550	4932100	2589352500
C	450	500	12025500	5712112500
D	400	450	8100000	3442500000
E	350	400	6707000	2515125000
F	300	350	5110000	1660750000
G	250	300	2151000	591525000
Total			40648600	17424302500
P_m: average depth of the rainfall in mm				**429**

Where: Pi is the average rainfall between contour P_1 and P_2; $Pi = (P_1+P_2)/2$.
Ai is the sub area between the two contours.

The total recharge area of Al Auja is measured about 40.65 km^2, and the average depth of rainfall over the drainage basin during the period 1961-2004 is calculated about 429 mm/yr. Accordingly, the annual volume of rainfall over of the recharge area (P_V) will be about 17.42 MCM.

3.2.2 Surface Runoff :

Depending on the West Bank topography, runoff in the Eastern Basin (EB) which is characterized by steep slope and less rate of rainfall is mainly flow forward to the Jordan valley and then to Dead Sea.

The runoff in the EB depends on many factors such as: topography, rain intensity and its continuity, soil type, texture, porosity, and permeability, land use (plant cover, buildings,..) and the topography feature (elevation, slope, shape, ..).

Abed & Wishahi (1998) tabulated runoff for selective Wadis in the West Bank, the percentage of the average runoff in Al Auja area is found to be 11,43 % of the annual rainfall. Based on this percentage the amount of the surface runoff in Wadi Al Auja will be 53.7mm/yr (2.18 MCM/yr).

But based on applying Goldschmidt formula, the calculated runoff in Wadi Al Auja drainage basin is found to be 41.95 mm/yr where represent 9.8 % of the annual rainfall (1.74 MCM/yr).

3.2.3 Infiltration and Water Recharge:

The amount of water that infiltrates down into sub surface depends on many factors such as topography slope, soil type, the composition of the surface deposits and their porosity status, soil moisture, permeability, and rainfall continuity. The average annual infiltration in the West Bank was estimated by *Rofe and Raffety* in the year 1964/1965 within 24.6-26.8% of rainfall, and 9-27% according to *Shahab (1997)*. The infiltration in the NW of the West Bank is estimated within 20-30% *(Gvirtzman, 1994)*, and about 23.6% of the annual rainfall in the Eastern Basin *(Guttmann and Zuckerman 1995)*.

The effective recharge (the quantity of water that infiltrates and reach the water table) over Auja-Jericho drainage basin was estimated by *Black* & *Goldschmidt* (*1947*) with amount 22% of the annual rainfall. This value is agreed with *CDM* (*1998*) which reported average infiltration within 5-30 % of the total rainfall in semi arid zone “.

Based on *Thornthwaite* (*1931*) classification and the precipitation effectiveness index (Pe); the effective annual rainfall (P_e) for Wadi Al Auja is calculated about 4.2 inch (105.8 mm). By using Soil Conservation Service (SCS) method, the infiltration of the study area is calculated about 63.85 mm/yr (2.6 MCM/yr, 14.9% of the annual rainfall).

The method of chloride mass-balance (CMB) *(Eriksson and Khunakasem, 1969)* is used in order calculate the water recharge in al Auja spring. This method needs to know the chloride concentration in the spring water (41.12 mg/l), the chloride in the annual precipitation (6.5 mg/l), the average runoff (41.95 mm/yr), and the annual rainfall (429 mm/yr).

Based on the CMB method, the average water recharge in the study area of Wadi Al Auja is calculated 61.2 mm/yr (2.48 MCM/yr) which represents 14.3% of the annual rainfall.

3.3 Structural and Geological Setting

3.3.1 General :

The main fault in the West Bank is extended along the line of Aqaba-Dead Sea- Jordan Rift. The fault was transformed in the mid of Miocene period when a lateral strike-slip movement between African and Arabian plates took place (the Red Sea–Aqaba tectonic event). The main anticlines of the West Bank (Hebron, Ramallah, 'Anabta, Far'a, Al-ʻAuja ,Mar Saba and Um-Daraj) are formed since the Cretaceous (Turonian) - Eocene period when the south Syrian arc system folded up the shelf deposit N-S between the Mediterranean and the garben that contains the Jordan Valley and the Dead Sea *(Flexer et al. 1989).*

At the northern boundary of the study area of Al Jiftlic, Far'a fault is the main cause behind forming drain portion of Far'a valley that is used extensively for agriculture *(Hammad & Blankespoor, 2002)*. The Far'a anticline descends towards the Jordan Valley and the Dead Sea in a series of undulations to form secondary structures before buried beneath the Beidan or the Jordan Valley (dip about10-15 degrees) *(Begin, 1976).*

At the north of the Samia fault zone, rocks in the Auja-Fasayil area dip much steeper, between 20-40 degrees to the east. The hinge line of steeply- dipping structure is commonly referred to as the Auja-Fasayil monocline *(Figure 3.4)*. To the east of the Mar Saba anticlines, there is steeply-dipping syncline (Musa/ Jericho syncline) that plunges to the north-east and is cut off by the Jordan valley rift fault that runs N-S along the topographic escarpment near the Dead Sea and Jericho *(Scarpa, 1994; Guttman & Zukerman, 1998).*

The location of folding and faulting in the area some times show association with the groundwater wells availability; for example, all Ein Samia wells are located along the fault zone, these faults acts as barriers to groundwater wells flows where many faults in the West Bank acts as conduits. Beside that, many groundwater wells are adjacency to the Auja Keren Sartaba syncline (the east of Ein Far'a monocline) *(Kroituro, 1987; Tahal, 1995b).*

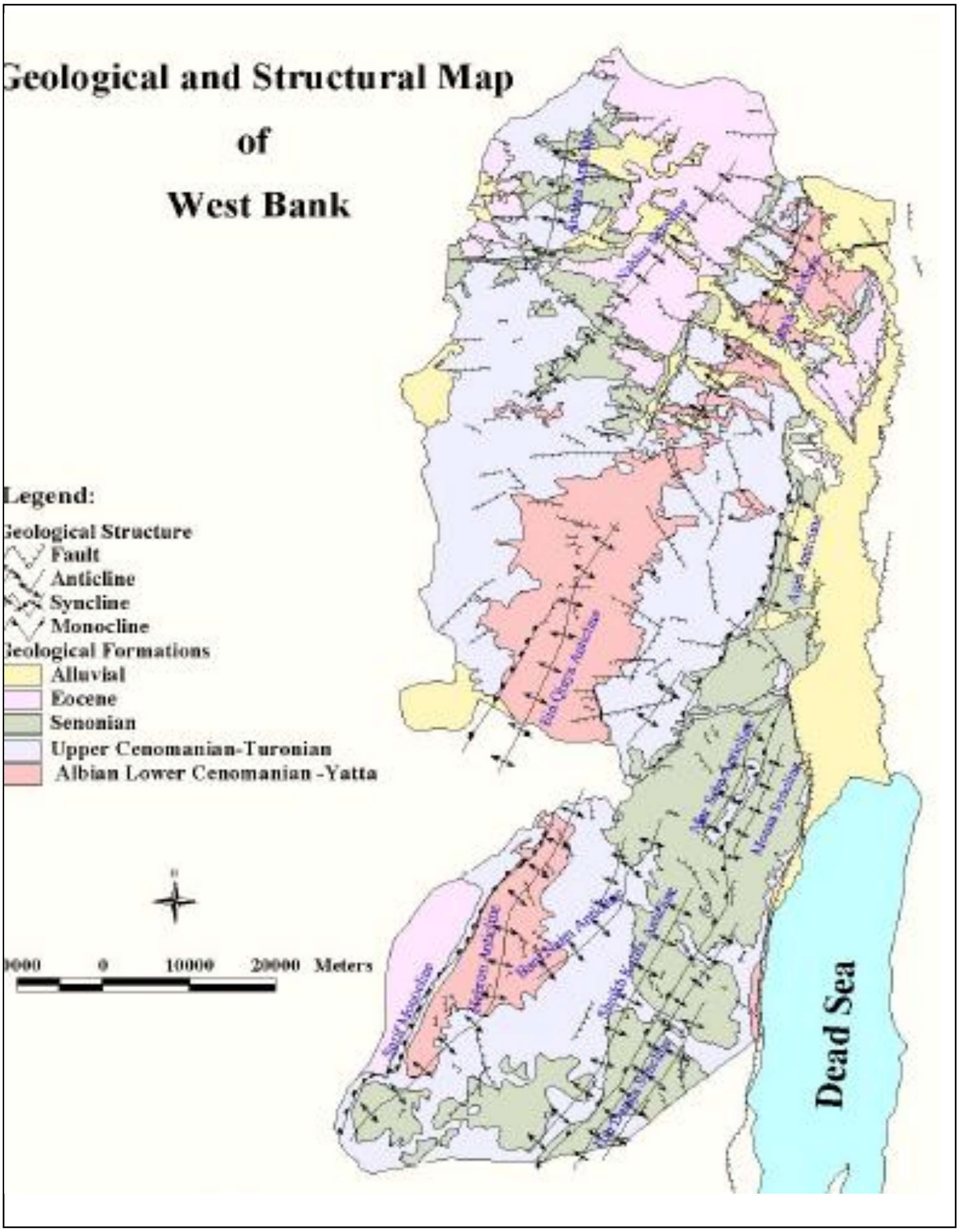


Figure 3.4: General geological and structural map of the West Bank (PHG, 2005).

3.3.2 Outcrops:

The Cenomanian and Turonian rocks exists along the eastern flanks axis (e.g. Mt Scopus Group) on the major anticlines, many of these Cenomanian and Turonian age rocks are forming a direct recharge source of rainfall to the main water-bearing formations within the eastern aquifer boundary *(CDM, 1998).*

Based on maps of geological outcrop areas (that modified from the Israeli geological survey, 1999), it shows that more than 90% of the outcrops within the Eastern Aquifer Basin are upper Cretaceous carbonate rocks of Cenomanian and Turonian, and Senonian age.

The study areas of Al Auja and Al Jiftlic are of unconsolidated Quaternary alluvial sediments. These formations overlie a wide area along the Jordan valley besides Wadis, and interior streams, while Pleistocene and Eocene formations are distributed in limited areas with average thick of 60m *(CH2M HILL , 2000).*

3.3.3 Stratigraphy:

The geologic sections *(Table 3.2)* describes the general stratigraphic sequence of the un/consolidated deposits of the study area in the Jericho area (Ein Samia, Auja, Fasayil, Jiftlic and Fruish Bait Dajan) and give general geological structure (including regional variation). The stratigraphic profile in the study area varies from the lower Cretaceous age to young formation Quaternary age. Much of the stratigraphic information presented herein is based on *Rofe and Raffety (1963, 1965), Begin (1976), CDM, (1998), Abed & Wishahi (1998), and Guttman (2000)* which are summarized in the following sections from the oldest to the youngest:

Table 3.2: General stratigraphical structure geology of the West Bank (After Qannam 2002; Guttman 2000; Guttman & Zuckerman 1995; Braun & Hirsch 1994; & Bartov et al. 1988).

Geological Time Scale				GROUP			FORMATION			LITHOLOGY	Thickness (m)	Hydrostratigraphy	Remarks
Era	System		Epoch	Palestinian		Israeli	Palestinian	Israeli					
CENOZOIC	Quaternary		Holocene	Recent		Karkar	Alluviam	Alluviam		Talus (marl&sand), alluvium, gravel.	1-120	Aquifer	The shallowest and the most productive aquifer
							Greavel	River Gravel				Aquifer	
			Pleistocene	Lisan		Dead Sea	Lisan	Lisan		Chalk, thinly laminated marl with gypsum bands and conglaminates.	200+	Aquifer	Pebble horizons serving as local good aquifers.
	Tertiary	Neogene	Pliocene/ Miocene	Bedia		Seqia	Beida	Bit Nir and Ziglag		Cemented Congllomerates & Limnic sometimes, limestone, marl and gravel.	100-200	Aquifer	Fms assist in forming good Aquifer.
		Paleogene	Eocene	Belqa	Jenin Sub Series	Avidat	Reef Nummulitic Limestone	Zor'a		Reef limestone, bedded limestone, chalke with limestone undifferentiated.	100-400	Aquifer in Limestone and Aquiqlude in Chalk	“good “ Aquifer
			Palaeocene			Mount Scopus	Nummulitic Limestone	Hatrurim	Taqiye	Marl, chalk and clay with Limonite.		Aquiclude	Thickness of Mt.Scopus varies from anticlinal margins to synclinal centre.
MESOZOIC	Senonian		Mastrichtian				Khan Al Ahmar and Zerqa		Ghareb	Yellowish chalk, Marl.		Aquiclude	
			Campanian				Abu Dis	Mishash		Chalk with back chert layers and marl.	50-200	Aquitard	
			Santonian				Amman	Menuha		White chalk & some calcerouse chalk.	30-120	Aquiclude	
	Upper Cretaceous		Turanian	Ajlun		Judea	Jerusalem	Bi'na	Derorim	Limestone, Dolomite with clay & marl.	15-65	Aquiclude	Considered as a continuous aquifer in the west bank.
									Shivata	Limestone with massive & cliff.	25-50	Aquifer	
									Netzer	Limestone & dolomite with marl/chalk.	70-150	Aquifer	
			Upper Cenomanian				Bethlehem	Weradim		Hard gray porouse dolomite.	25-100	Aquifer	
								Kefar Shaul		Chalky limestone, chalk and marl.	20-50	Aquitard	
							Hebron	‘Amminadav		Karistic limestone and dolomite.	110-140	Aquifer	
			Middle Cen.				Yatta	Ein Yorq e'am	Moza	Marl, clay and marly limestone.	10-30	Aquitard	Not always present
			Lower Cenomanian						Bet M'eir	Limestone, Chalky limestone & Dolomite.	40-150	Aquifer	Beit Meir tongue constitutes an aquiferous layer.
										Limestone, Marl & chert.		Aquitard	
							Upper Beit Kahil	Kesalon		Dolomite, chalky limestone, rich of fossils	20-35	Aquifer	Poor Aquifer due to small thickness.
								Soreq		Dolomite inter-bedded with marl.	110-170	Aquitard	Limestone and Dolomite horizons constitute an aquifer.
							Lower Beit Kahil	Giva't Yearim		Limestone, Dolomite.	40-90	Aquifer	
	Lower Cretaceous		Albian					Kefira		Limestone, dolomite, and marly limestone.	120-180	Aquifer	Profile at the base is marly.
				Kurunb			Kobar	Qatana		Marl and clay with some limestone.	50	Aquiclude	
								Ein Qinia		Marl and marly limestone.	60-70	Aquifer	
								Tammun		Limestone, Clay and marl.	80-150	Aquitard	
								Ein Al Asad		Limestone.		Aquifer	
			Aptian			Kurunb		Nabi Said		Limestone.		Aquifer	
			Neocomian				Ramali	Hatira		Sandstone.	150	Aquifer	
	Jurassic		Callovian/ Bajocian	Zerqa		“Arad	Upper Malih	Upper Malih		Marl interbedded with chalky limestone.	190	Aquitard	Excellent aquifer
							Lower Malih	Lower Malih		Dolomitic limestone, jointed and karastic.	55	Aquifer	

3.3.3.1 Cretaceous Age Sediments:

3.3.3.1.1 Lower Beit Kahil Formation (Albian/ lower Cenomanian):

The lower Beit Kahil formation begins with massively bedded at its base, becoming increasingly thin bedded, and clastic toward the top, at which it can exhibit karst features in some areas. The overall reported thickness of lower Bait Kahil Formation ranges from 120 meter to a bout 270 meter *(Rofe and Raffety (1995), Baida & Zuckerman. 1992)*. This aquifer represented in Wadi Al Auja and in Ein Samia areas. This formation divided into:

***The Lower part* (Albian):** This part consists of limestone, well-bedded, fine crystalline with occasional marl, shale, and dolomite. This part thickness ranges from 120 to 180m. This portion was penetrated about 148 m by Ein Samia well 3.

***The Upper part* (Lower Cenomanian):** This part is represented by dolomite, massively bedded fine-coarse crystalline. This part is highly fractured and karstic. Its thickness ranges from 40 to 90m *(Rofe and Raffety (1995), Baida & Zuckerman, 1992)*

3.3.3.1.2 Upper Beit Kahil Formation (lower Cenomanian):

The overall reported thickness of the upper Beit Kahil ranges from 60-200 m.
This formation is divided into:

The lower part :This part consists mainly of dolomite, fine-grained crystalline and other thin marly layers. This part thickness is between 60 and 130m. Ein Samia well 3 penetrate this aquifer with 113m thickness.

The upper part :This part is represented by dolomite, chalky limestone (massively bedded to cliff forming, usually coarse crystalline with abundant oysters and rudest). The thickness of the upper part of upper Beit Kahil is about 20 to 35m *(Rofe & Raffety, 1965; Baida & Zuckerman, 1992).*

3.3.3.1.3 Yatta Formation (lower and middle Cenomanian):

It’s exposed on both east and west of the Jerusalem anticline, mainly in the south of the area, but continuing NE as narrow strips along the steep limbs of Far’a anticline.
This formation can be divided into:

***The lower part* (Lower Cenomanian)** :This part composes of dolomite, chalky limestone and fine crystalline interbedded with marls. Thinly bedded, occasionally laminated with biomicrite and may contain chert nodules and thin chert bands. Lithology can vary significantly from one location to another. It's reported thickness ranges from 40 to 150 m.

***The upper part* (Middle Cenomanian)** :This part consists of marl, clay and marly limestone, usually highly enriched with fossilized fauna. Most aquifers confined with these layers are aquitard, it thickness ranged between 10-60 m *(Rofe & Raffety, 1965; Abed & Wishahi, 1998).*

3.3.3.1.4 Hebron Formation (Upper Cenomanian):

This formation is represented by dolomite and limestone, coarsely or poorly bedded, non fossiliferous. This formation shows a significant lithological variation over short distances, and well developed karst. Brecciation is common throughout limestone fragments embedded in dolomitic cement (This formation represented an excellent aquifer). Its reported thickness ranges from about 50m near Hebron to about 200m in the central and northern portion of the West Bank, this formation is represented in Ein Samia Well no.1 *(Rofe & Raffety, 1965; Braun and Hirsch, 1994).*

3.3.3.2 Tertiary Age Sediments:

3.3.3.2.1 Jenin Sub series (Paleocene and Eocene):

Eocene outcrop are represented in a small areas in the Jordan valley particularly in Marj Na'jah and Al Jiftlic. Most of the Eocene basin in the West Bank is a syncline. The rocks of this series are mainly of reef limestone, bedded nummulitic limestone, chalk with chert or limestone (nummulitic). Its thickness is unknown (the top is eroded out), but exceeds 300 meter and sometimes reach 500 meter thick *(Rofe & Raffety, 1965; CDM, 1998).*

3.3.3.2.2 Bedia Formation (Miocene-Pliocene) :

This formation consists of limestone, marl, sandstone-conglomeratic and limnic. Conglomerates are mostly cemented with calcium carbonate and show a bright red appearance. Marls typically contain nodular limestone. The formation rests unconformable on older rocks. Its full extent and thickness is unknown. It is present in sunken areas such as Wadi Far'a and Wadi Malih and may underlie alluvial areas, and may underlie other alluvial areas *(Rofe & Raffety, 1965; CDM, 1998).*

3.3.3.2.3 Samra Formation (Pliocene through Pleistocene):

This formation consists of conglomerates sandstones and silt sediments. Outcrops extent along the western part of the Jordan valley floor and forms the fertile soils of the agricultural areas near Jericho ,Al Auja, and Fasayil *(Rofe & Raffety, 1965, CDM, 1998).*

3.3.3.3 Quaternary Age Rocks:

3.3.3.3.1 Lisan Formation (Pleistocene):

This formation consists mainly of chalk, thinly laminated marl with gypsum bands. Limestone-interfingers with conglomerates of sandstones, cobbles and silt beds. Boulders of different sizes are separated by impermeable layers of saline marl of lacustrine deposits *(CH2M HILL, 2000; Guttman, 2000).*

Pleistocene-Lisan formation deposits cover a large part of the Jordan valley and many places enter the mouth of Wadis leading down from the western hills. The best exposures are found at the sides of the Jordan River flood plain where it has been exposed due to the rejuvenation and down cutting of the Jordan River. Lisan formation extends from Jericho to Al Jiftlic, Marj Na'ja, and Wadi Far'a in the north. Its full thickness is not known, but varies along the Jordan valley from 0 m to greater than 200m with an average thickness of 60 meters in the study area *(CH2M HILL, 2000; Guttman, 2000).*

3.3.3.3.2 Conglomerate (Neogene to Quaternary):

These sediments consist of conglomerate breccia-set in calcareous and hard cement. Overlie several older formations along Wadi Samia and form the hill tops near Jericho range from Neogene to Recent (*CDM, 1998).*

3.3.3.3.3 Alluvial Deposits (Quaternary):

As it's frequently difficult to separate the Lisan from Alluvial sands and gravels, recent and alluvial deposits are the youngest and shallowest materials. These sediments consist of talus (marl and sand), stream gravels, calcareous clays, soil-unconsolidated sediments along the valley floors. The alluvial deposits thickness is not documented but it’s laminated and found in large area of Al Auja *(CDM, 1998; CH2M HILL, 2000).*

3.4 Hydrogeology

3.4.1 Introduction :

The main mountain aquifer that feeds the majority of groundwater wells in the West Bank is located within the Albian-Turonian anticline to the south of Nablus and Eocene syncline to the north .The great thickness of this aquifer (up to 500 m) is the main reason standing behind high water capacity and productivity (*CDM, 1998).* The anticlinal structure of the Albian aquifer is consisting mainly of limestones and dolomites of the upper Beit Kahil Formation (upper perched aquifers) and lower Beit Kahil Formations (lower perched aquifer) *(Abed& Wishahi, 1998).* The crest of the mountain aquifer acts as a watershed for the groundwater flowing eastwards to the Jordan Valley and Dead Sea, or westwards flowing to the Mediterranean Sea *(Scarpa, 1994).* The directions of the hydraulic drainage of the mountain aquifers are divided mainly into three basins as shown in Figure 3.5.

3.4.2 Eastern Aquifer Basin (EAB) :

The Eastern Basin stretches from Far'a and Al-Jiftlic area in the north to the Dead Sea lisan peninsula that locates in the south. This basin is divided into six sub basins; Bardala, Maleh, Far'a, Fasayil-Auja, Jerusalem-Ramallah and Jerusalem semi arid *(Abed & Wishahi, 1998).* The main aquifer system in the Eastern Basin is presented by the calcareous aquifer, which consists of a thick section (approximately 700 meters) of permeable carbonate rocks (limestone's and dolomite interbedded with less permeable argillaceous units such as marls and clays).

The eastern aquifer formation is arranged from the oldest lower Bait Kahil to youngest Jerusalem Formation. This aquifer is divided into "lower" aquifer (Albian/lower Cenomanian age) and "upper aquifer" (upper Cenomanian/Turonian age) separated by the Yatta Formations (an aquitard) that confine the lower aquifer and controlled the ground water movement between the upper and the lower aquifers.

The flow of water direction in the EAB is toward the Jordan River and the Dead Sea to the east with estimated recharge area over 2200 km^2 *(Gvirtzman, 1994).* The potential yield of the area is estimated to be about 100 MCM/yr *(Gvirtzman, 1994)* to 172 MCM/yr *(Oslo 2 Accords, 1995).* The total Palestinian share 54 MCM/yr from the total potential yield distributed as 24 MCM/yr from wells and 30 MCM/yr from springs. On the other hand, Israeli dominates 118 MCM/yr from the total potential* (about 70% of the total water recharge).

These values may vary according to the annual fluctuation of precipitation and abstraction. *

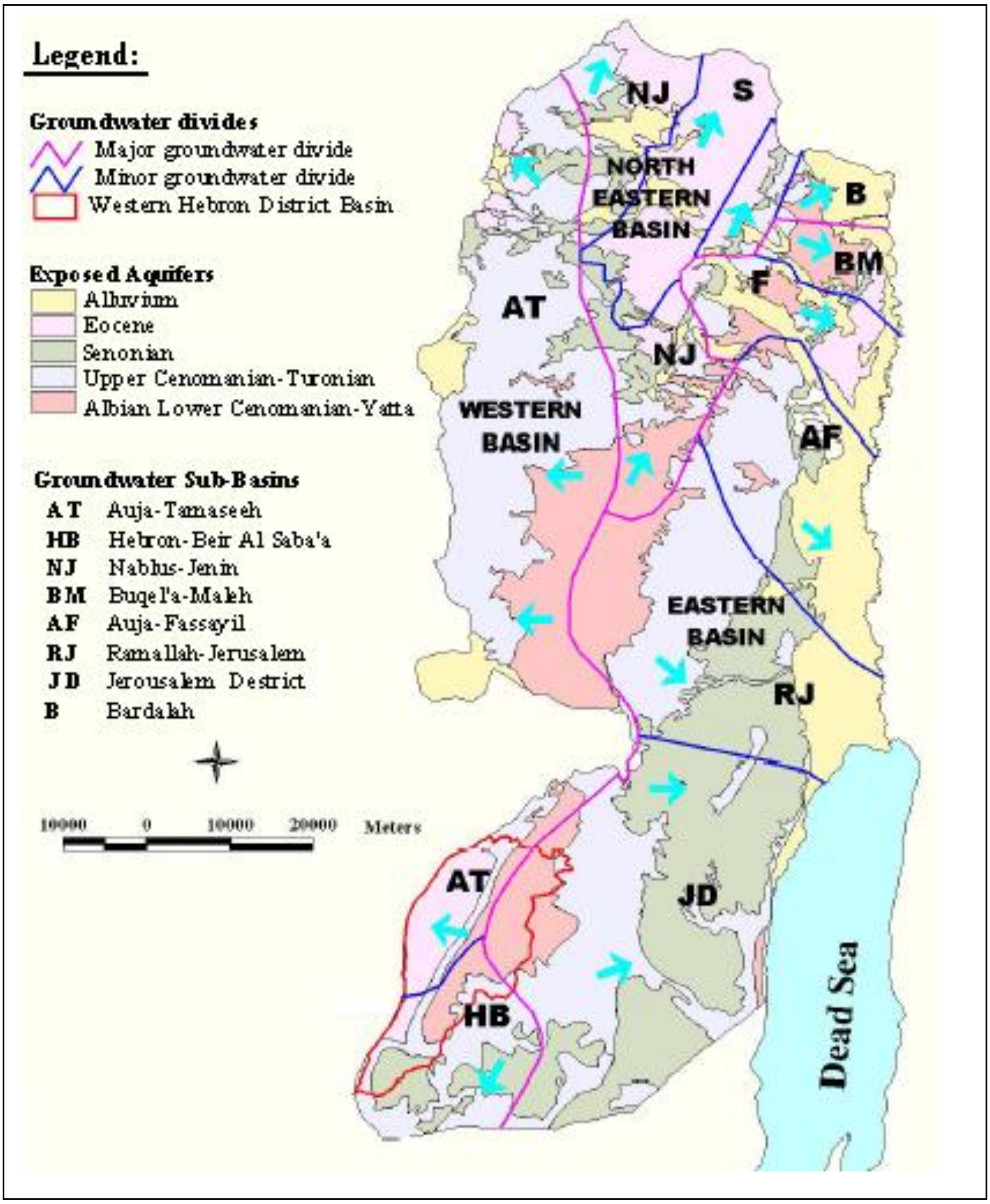


Figure 3.5: Ground water basins and exposed aquifers in the West Bank/Palestine (modified by PHG after ARIJ 2000).

3.4.2.1 Hydrogeological Characteristics of the EAB:

The permeable nature of the carbonate rocks of the mountain aquifer system is a result of what is called secondary porosity. Because of secondary porosity, the Cenomanian rocks (limestone and dolomite) have what is called karst characteristic that may increases the aquifer potential and its permeability *(Arkin, 1980).* Karst system may be interconnected vertically, thereby superimposing successive, ancient drainage pattern on the current groundwater flow system *(Rosenthal and Kronfeld, 1982).*

Abu Dis Formation (chalk and chert) and Yatta Formation (marly or clayey limestone) are the major aquitards which are associated with the mountain aquifer. These Formations tend to be relatively impermeable due to non fractured rocks thus reduce the capability of transmitting water. Water transmitting between the upper and lower aquifers is controlled also by the presence of thin layers/lenses of lower permeability units through these aquifers *(CDM, 1998).*

3.4.2.1.1 Upper Aquifer :

The upper aquifer considers as an important source of domestic water in the western aquifer basin. This aquifer consists mainly of interbedded dolomite and chalky limestone with total thickness ranges between few meters to 400 meters. An outcrop of the upper aquifer is located in the area characterized by relatively high rate of precipitation. The aquifer consists of three Formations; Jerusalem (Turonian), Bethlehem and Hebron Formations (upper Cenomanian) *(Tahal, 1997).* The upper aquifer is also overlain by relatively impermeable (aquitard) chalk and chert of the Abu Dis Formation of the Senonian age *(CDM, 1998).* In Ein Samia area, the groundwater well 18-15/001 receives water from the upper aquifer. The Hydrogeological properties of this well is illustrated in Appendix 3.3.

3.4.2.1.2 Lower aquifer :

The lower aquifer characterized by high water capacity and productivity according to the great thickness of dolomitic limestone’s and limestones (up to 400m) of the upper and lower Bait Kahil Formations and some of Yatta Formation. The aquifer represents the major regional source of drinking water in the West Bank and particularly in the EAB. The lower aquifer also contains thinner marl and clayey limestone intercalation that restrict vertical flow *(CDM, 1998).* In Ein Samia area, The groundwaters 18-15/004, 18-15/005, 18-15/006 feeds water from the lower aquifer. The Hydrogeological properties of these wells are illustrated in Appendix 3.3.

3.4.2.2 The Hydraulic Separation between the Upper and Lower Aquifer:

3.4.2.2.1 Yatta Aquitard :

While the upper and lower aquifers are probably hydraulically interconnected in some areas. The two parts are separated by the Yatta Formation that consists of marl, clay, and marly limestone intercalation. These compositions made Yatta formation to be low hydraulic conductivity *(MOPIC, 1996).* It acts locally as an aquitard; restrict the vertical water flow between the upper unconfined ”upper Cenomanian” and the lower confined sub-aquifer “ lower Cenomanian” and forms head difference typically 50-200 between them. The lithology and amount of secondary permeability in the Yatta Formation is critical to estimating the vertical leakage between two aquifers, whereas the upper part of the Yatta is generally an aquitard and the upper part of lower Yatta is more permeable *(CH2M HILL, 2000).*

3.4.2.2.2 Bethlehem Aquitard :

In some parts of EAB (e.g. west of Jericho), the lower part of Bethlehem Formation acts as confining unit that hydraulically separates the Hebron and Jerusalem Formations (Turonian) *(Guttman, 1998).* The groundwater flow from the Turonian aquifers expressed as series of perched springs, primary along Wadi Qilt and near Jericho (e.g Duyuk and Nuwei'ma springs) *(MEG, 2000).*

3.4.2.2.3 Pleistocene/Alluvium Aquifer :

The alluvial aquifer in the study area consists of unconsolidated beds of gravels and sands separated by impermeable layers of marl. Alluvial fan deposits are discontinuous; formed along the outlets of the major Wadis that flow eastward to the Jordan valley. Some times the alluvial deposits act as a transfer system conveying water from the mountain aquifer to the Jordan valley aquifer. Eastward, the sediments become marlier and the alluvium fans inter-finger with saline, and clay rich deposit; hence, groundwater wells in those areas represented by high salinity, this aquifer thickness ranges between 0-120m *(CDM, 1998; CH2M HILL HILL, 2000).*

3.4.2.3 Hydrogeology distribution of wells in the Eastern Aquifer Basin:

More than 100 shallow agricultural groundwater wells (generally less than 150m) of the Pleistocene/ alluvial aquifer within the EAB along the Jordan Valley (Table 3.3) shows m show local significance for agriculture with yields range from about 20-100 m^3/hr *(PWA, 2002).* The greatest concentration of wells is mainly in Jericho town and north of Al Auja (e.g. Fasayil, Al jiftlic, Marj Na'ja, Zubeidat, Marj Al Ghazal, Maleh …), most of these are located in unconsolidated deposits (about 81 groundwater wells).

Table 3.3: Hydrogeology distribution of the groundwater wells in the Eastern Aquifer Basin (Source: modified after PWA database, 2002).

Aquifer	**Hydrogeology**	**No. of Palestinian wells**	**No. of Israelis wells**
The Eastern	Pleistocene	100	
	Neogene	3	
	Eocene	11	
	Upper Turonian/ Cenomanian	10	
	Lower Cenomanian	6	
Total		**130**	**36**

3.4.2.4 Transmissivity :

The Transmissivity of the aquifers in the Eastern Basin is range from 4 to 5000 m^2/d in the ***lower aquifer*** (*Tahal, 1995a), and* from 100 m^2/d (i.e. Ein Samia well fields) to greater than 5000 m^2/d in the ***upper aquifer*** (*Tahal, 1998)*. The estimated Transmissivity in the ***alluvial aquifer*** (thickness 40-150 m) ranged from 10-80 m^2/day *(Guttman, 1998)*, and in the ***lisan aquifer*** about 20 m^2/d *(MEG, 2000)*. The reported Transmissivity value in the study area of ***Al Auja*** ranges between 4-15 m^2/day (lisan Aquifer) and from 193 - 990 m^2/d in the Jericho area *(MEG, 2000).*

3.5 HYDROCHEMISTRY

3.5.1 General :

This chapter provides a summary of surface and sub surface water chemistry as the first step before talking about the groundwater quality (acceptability of water for drinking and agricultural uses). Water chemistry differs from groundwater wells to another; this depends on the amount and the type of dissolved constituents through water contact with soils and rocks, contact with different types of pollutants, interaction with atmospheric gases, mixing processes, ion exchange, and precipitation of minerals *(WHO, 2005)*. Here, the water chemistry included results of the measured ions, and identification of the groundwater type.

3.5.2 Results :

These results include the measured physical parameters (Temp, pH, EC) and the analyzed chemical parameters of the major cations (Na^+, K^+, Ca^{2+}, Mg^{+2}) and anions (HCO_3^-, Cl^- , SO_4^{2-}, NO_3^-) of the groundwater wells of Ein Samia, Al Auja, and Al Jiftlic, beside one spring in Al Auja area (Appendices 3.4, 3.5, 3.6).

Table 3.4 represents the statistical parameters of 42 samples from the study areas which show high diversity in physical and chemical characteristics. The diversity in physical parameters represented as pH that ranges between 6.6 and 8.1, and EC that ranges between 460 µS/cm and 5310 µS/cm. The highest variation in cation values represented by sodium that ranges between 17.8 mg/L and 637 mg/L. The highest variation in anion results represented by Cl^- that ranges between 30 mg/L and 2057 mg/L (Table 3.4). According to this diversity, data are divided into three groups depending on the distribution of areas.

Table 3.4: Descriptive statistics of the main chemical and physical parameters of the studied groundwater wells in Ein Samia, Al Auja, and Al Jiftlic area.

Variable	Min	Max	Mean	St.dev	No. of Samples
Temp (ºC)	20.2	27.4	23.4	1.7	42
pH-value	6.6	8.1	7.1	0.3	42
EC (µS/cm)	460	5310	2090	1612	42
TDS (mg/L)	274	3469	1230	913	42
Ca^{2+} (mg/L)	46.09	366.70	149.06	96.58	42
Mg^{2+} (mg/L)	15.72	161.70	67.22	43.13	42
Na^+ (mg/L)	17.8	636.6	205.8	180.3	42
K^+ (mg/L)	1.2	55.2	18.2	15.4	42
HCO_3^- (mg/L)	135.6	585.8	371.6	101.3	42
Cl^- (mg/L)	30.4	2056.5	521	535	42
SO_4^{2-} (mg/L)	9.5	318.2	66.9	60.1	42
NO_3^- (mg/L)	9.9	114.9	31.1	21	42

3.5.2.1 Ein Samia Wells Group (ESWG):

Nine samples representing five groundwater wells used for domestic purposes were considered in this study; these groundwater wells are distributed in Ein Samia area east of Silwad in Ramallah district (Fig. 3.6)

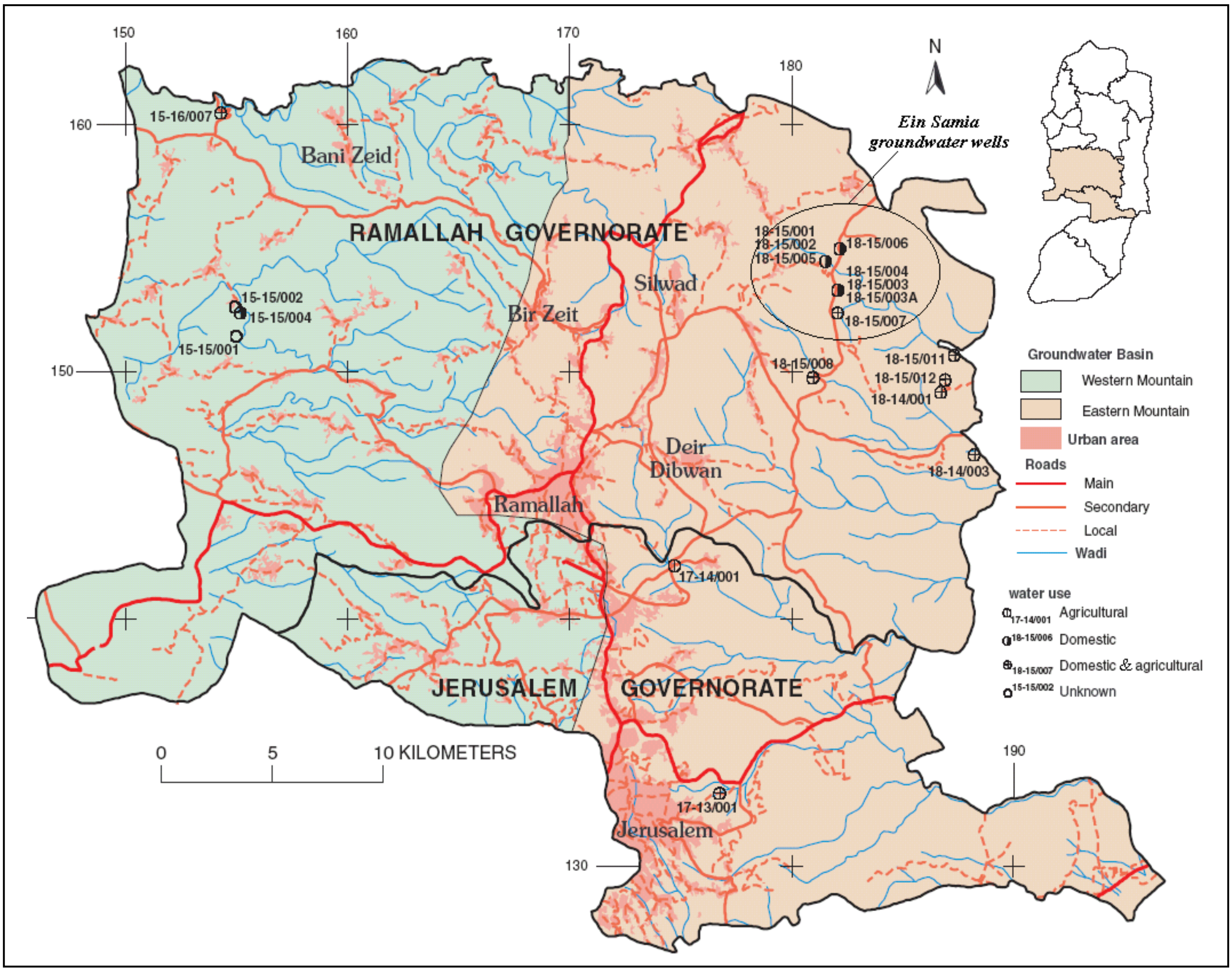


Figure 3.6: The groundwater wells distribution of Ein Samia in Ramallah district (PHG, 2000).

All shallow and deep groundwater wells of the Cenomanian rocks have EC within 460 μS/cm and 542 μS/cm. Based on *Carroll* classification *(1962)* all groundwater wells of Ein Samia represents fresh water according to the low range of TDS (274 -338 mg/L). The most dominant cation is found Ca^{2+} which range between 50 mg/L and 64 mg/L, and the most dominant anion is found HCO$_3^-$ which range between 225 mg/L and 330 mg/L (Appendices 3.4, Table 3.5).

TDS values didn’t show high variation in Ein Samia groundwater wells; this result is explained on the basis that the sampled groundwater wells share the same area of water recharge, and due to similar amount of dissolved constituents in the Cenomanian aquifers. The maximum TDS (338 mg/L) is found in the ESW4 that represent the deepest groundwater well (616m) in the Ein Samia area. This may be related to the percolation distance of water through the geological formations of the lower Cenomanian (dolomite & calcite rocks).

Table 3.5: Descriptive statistics of the main chemical and physical parameters of the groundwater wells in Ein Samia area.

Variable	Min	Max	Mean	St.dev	No. of Samples
Temp (ºC)	21.0	26.0	23.0	1.9	9
pH-value	7.1	7.8	7.4	0.3	9
EC (µS/cm)	460	542	503	30	9
TDS (mg/L)	274	338	298	24	9
Ca^{2+} (mg/L)	50.3	64.1	56.5	4.3	9
Mg^{2+} (mg/L)	15.7	32.0	25.4	5.1	9
Na^{+} (mg/L)	17.8	22.0	19.8	1.7	9
K^{+} (mg/L)	1.2	4.5	2.2	1.0	9
HCO_3^{-} (mg/L)	225.8	329.5	260.1	37.9	9
Cl^{-} (mg/L)	30.4	37.8	35.0	2.0	9
SO_4^{2-} (mg/L)	9.5	17.0	13.7	2.2	9
NO_3^{-} (mg/L)	11.7	25.6	17.3	5.2	9

The HCO_3^- shows very high significance correlation with TDS and EC. The groundwater wells of the Ein Samia area generally show the following arrangement of ions:

$$Ca^{2+} > Mg^{2+} > Na^{+} > K^{+}$$

$$HCO_3^{-} > Cl^{-} > SO_4^{2-} > NO_3^{-}$$

$$HCO_3^{-} > Ca^{2+}$$

3.5.2.2 Al Auja Group:

Nine samples representing five water resources in Al Auja area are included in this study, these groundwater wells are distributed in Fig. 3.7.

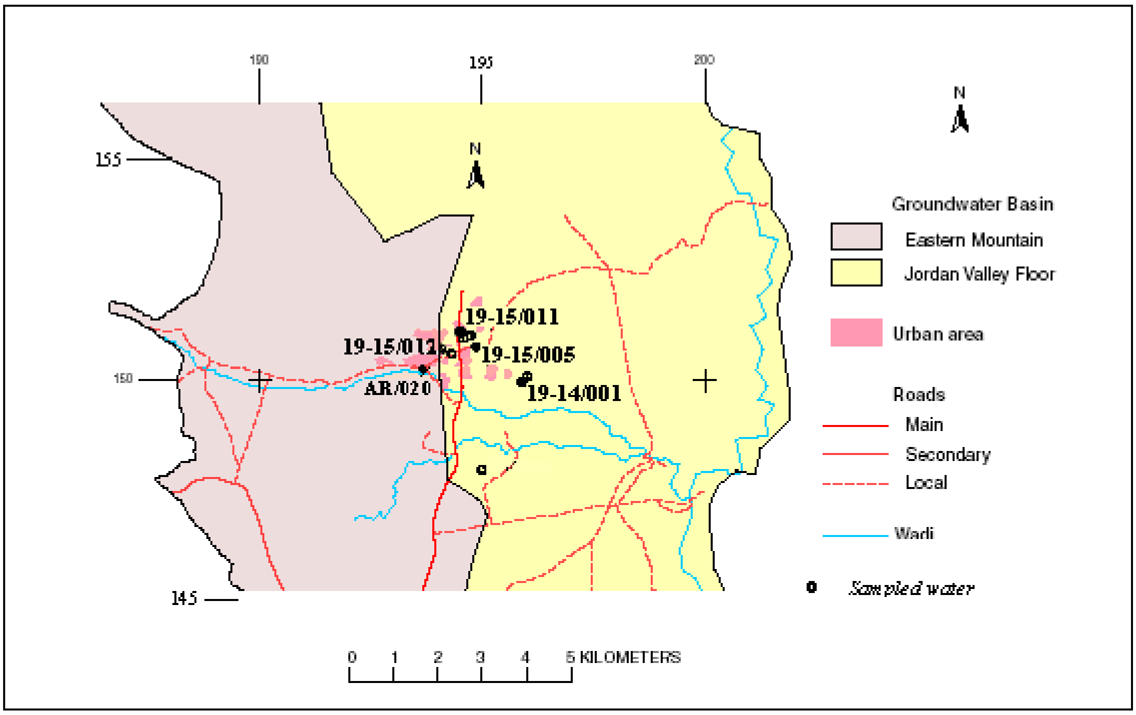


Fig. 3.7: The groundwater wells distribution of Al Auja area (North of Jericho), (PHG, 2000).

In the study area, EC varies from 527µS/cm (medium salinity) in the spring water AR/020 to 2310 µS/cm (high salinity) in the ground well 18-14/001, sodium ions varies from 24 -315 mg/L, and chloride from 32-500 mg/L (Table 3.6).

The sampled water of Al Auja are characterized by low TDS in the west (i.e. spring AR/020), moderate in the center (i.e. ground wells 19-15/ (005,011,012)), and highest in the east of the study area (i.e. ground well 18-14/001). The important notice is that HCO_3^- of spring AR/020 represents 75% of the total anions, while this percent is decreased toward the east conjugated with the increases of Na^+, Cl^-, and SO_4^{2-}. These results refer that salinity increases as we go forward the east in the study area.

The parameters of Ca^{2+}, Na^+, and Cl^- show very high significance correlations with TDS and EC. The water of the groundwells in Al Auja area generally shows the following arrangement of ions:

$$Na^+ > Ca^{2+} > Mg^{2+} > K^+$$

$$Cl^- > HCO_3^- > SO_4^{2-} > NO_3^-$$

$$Cl^- > Na^+$$

Table 3.6: Descriptive statistics of the main chemical and physical parameters of the sampled water in Al Auja.

Variable	Min	Max	Mean	St.dev	No. of Samples
Temp (ºC)	20.2	24.4	22.4	1.5	9
pH-value	6.8	8.1	7.3	0.4	9
EC (μS/cm)	527	3469	1267	1128	9
TDS (mg/L)	310	1526	709	410	9
Ca^{2+} (mg/L)	46.1	144.3	91.3	33.7	9
Mg^{2+} (mg/L)	25.8	51.1	37.0	9.3	9
Na^{+} (mg/L)	23.9	315.1	111.8	98.7	9
K^{+} (mg/L)	2.0	34.7	19.0	13.7	9
HCO_3^{-} (mg/L)	292.9	585.8	435.1	116.6	9
Cl^{-} (mg/L)	32.0	500.2	162.3	157.3	9
SO_4^{2-} (mg/L)	11.0	178.4	67.8	54.8	9
NO_3^{-} (mg/L)	9.9	42.2	17.2	10.6	9

3.5.2.3 Al Jiftlic Group :

Twenty four samples representing thirteenth groundwater wells used for domestic and agricultural purposes were considered in this study of Al Jiftlic area. Figure 3.8 shows the distribution of sampled groundwater wells in Al jiftlic area.

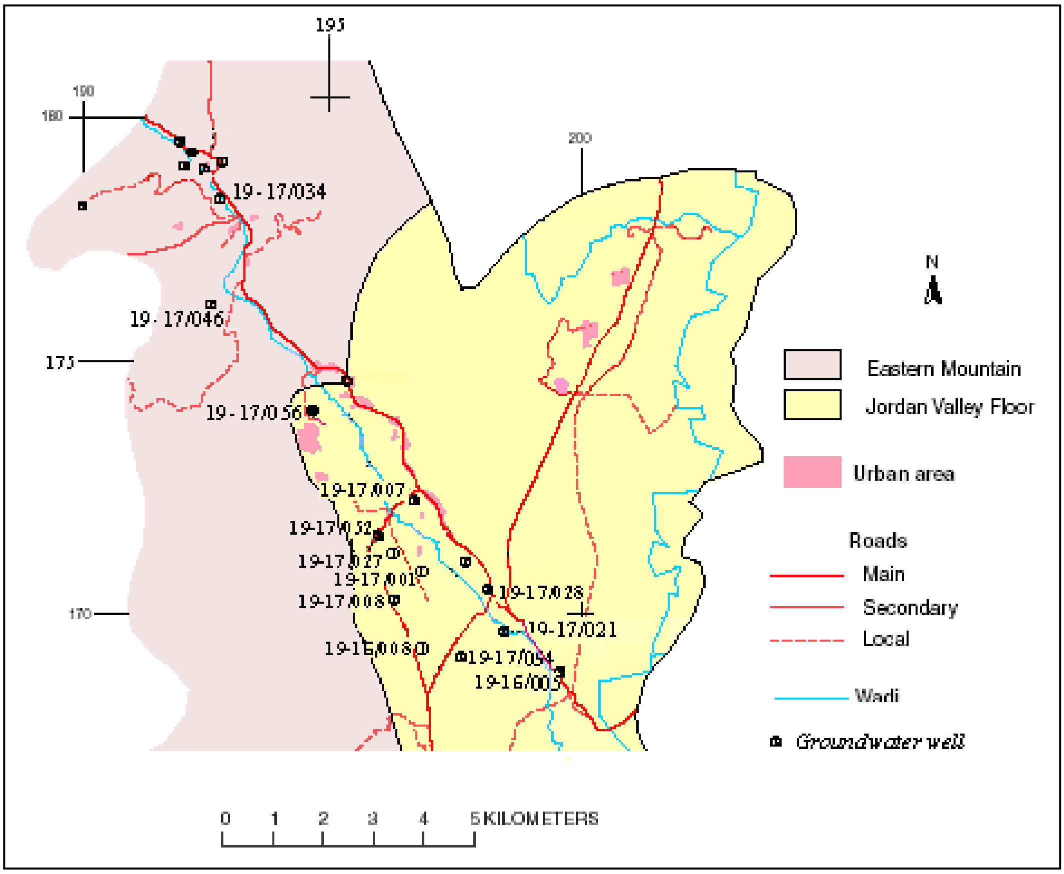


Fig 3.8: The distribution of the groundwater wells in Al jiftlic area (PHG, 2000).

The groundwater wells of Al Jiftlic ranges in their EC from 752 to 5310 µS/cm, sodium ranges from 58 to 637 mg/L, and chloride from 79 to 2057 mg/L (Appendix 3.6, Table 3.7).

Table 3.7: Descriptive statistics of the main chemical and physical parameters of the groundwater wells in Al Jiftlic.

Variable	Min	Max	Mean	St.dev	No. of Samples
Temp (ºC)	20.6	27.4	24.0	1.6	24
Ph-value	6.6	7.5	6.9	0.2	24
EC (µS/cm)	752	5310	3056	1468	24
TDS (mg/L)	521	3469	1775	819	24
Ca^{2+} (mg/L)	84.2	366.7	205.4	90.8	24
Mg^{2+} (mg/L)	27.7	161.7	94.2	38.4	24
Na^{+} (mg/L)	58.2	636.6	310.8	161.3	24
K^{+} (mg/L)	1.6	55.2	23.9	14.9	24
HCO_3^- (mg/L)	135.6	510.0	389.6	79.3	24
Cl^- (mg/L)	79.0	2056.5	837.8	504.6	24
SO_4^{2-} (mg/L)	12.5	318.2	86.6	62.2	24
NO_3^- (mg/L)	15.8	114.9	41.9	21.8	24

A linear correlation among the various parameters was performed (chapter 3, section 9). The study showed very high significance correlation between Mg^{2+}, Na^{+}, and Cl^{-}, where these ions are very high correlated with TDS, and TDS is very high correlated with EC.

According to the TDS, the groundwater wells of Al Jiftlic are divided into three groups:

The first group (i.e. 19-16/008 that locate in the Alluvium aquifer and 19-17/034 in the upper Cenomanian aquifers) represents the lowest TDS average in the study area (Table 3.8). TDS ranges between 500 mg/L and 600 mg/L (fresh water). This group represents the lowest groundwaters salinity where EC average is 780 µS/cm. Ca^{2+} represents the main dominant cation (86 mg/L), and HCO_3^- is the dominant anion (334 mg/L) in water. The ions of the first group show the following arrangement:

$$Ca^{2+} > Mg^{2+} > Na^{+} > K^{+}$$

$$HCO_3^- > Cl^- > SO_4^{2-} > NO_3^-$$

$$HCO_3^- > Ca^{2+}$$

The second group represents groundwater wells of TDS range between 1200 mg/L and 2300 mg/L (groundwater wells 19-17/027, 19-17/056, 19-17/046, 19-17/001, 19-17/007, 19-17/021, 19-17/008, and 19-17/054. The main lithologies of these aquifers (Eocene- Alluvium) are marl, dolomitic / chalky limestone, and gypsum. (Table 3.8).

The third group represents the groundwater wells which have relatively high concentration of TDS (2600-3300 mg/L). This group includes the groundwater wells 19-16/001, 19-17/028 and 19-16/005 which are located in the Alluvium and Eocene aquifers. This group represents the highest groundwater salinity relative to the other groups (EC avg. ≈ 5000 µS/cm) (Table 3.8).

It was found that the second and the third groups share the following characteristics:

- Na^+ is the main dominant cation and Cl^- is the main dominant anion.
- The salinity-controlling has very high significant correlation with Na^+, and Cl^- that represents the main dominant anion in water.
- The ions arrangement are generally:

$$Na^+ > Mg^{2+} > Ca^{2+} > K^+$$

$$Cl^- > HCO_3^- > SO_4^{2-} > NO_3^-$$

$$Cl^- > Na^+$$

Table 3.8 : The total dissolved solids average in Al Jiftlic ground wells during 2003/2004.

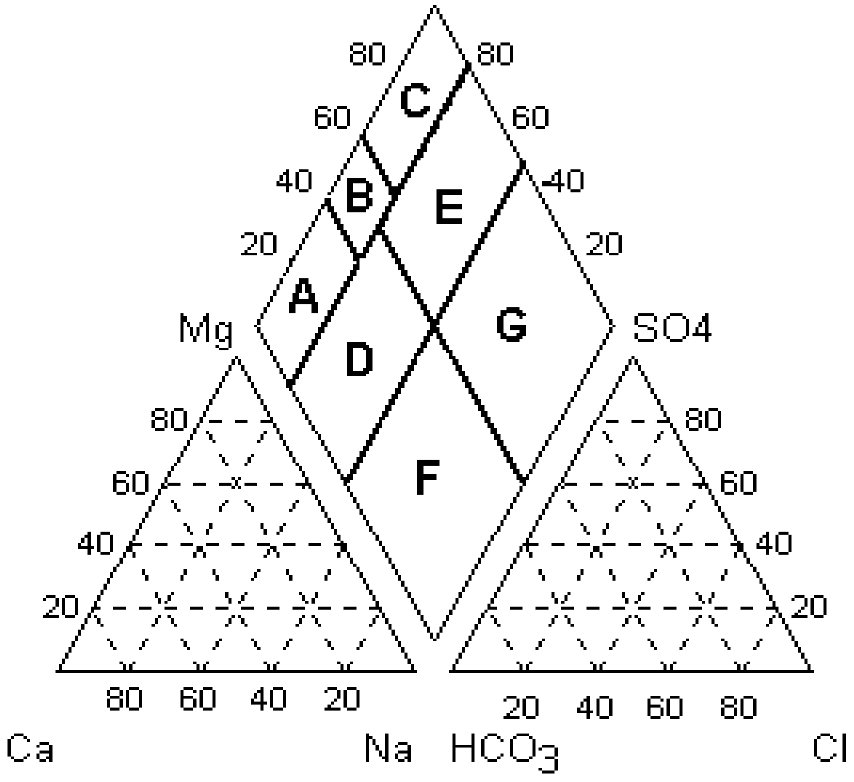
Group No.	**TDS (mg/L)**	**TDS $_{Av.}$ (mg/L)**	**Cl Av. (mg/L)**	**Wells Code**	**Aquifer Fm & Wells Depth Av. (m)**
Group(1)	500-600	750	100	19-16/008, 19-17/034	Alluvium (70) & Upper Cenomanian (150)
Group(2)	1200-2300	1600	700	19-17/027, 19-17/056, 19-17/046, 19-17/001, 19-17/007, 19-17/021, 19-17/008, 19-17/054	Alluvium (70), Eocene (115), Neogene (147).
Group(3)	2600-3300	2950	1200	19-16/001, 19-17/028, 19-16/005	Alluvium +Eocene (150)

In general, the study showed that all shallow and deep groundwater wells within the Cenomanian aquifers contain lower amount of TDS than the other groundwells of the Eocene-Alluvium aquifers. All groundwater wells of Eocene-Alluvial are found located at far distance from the recharge area than the other groundwater wells of Cenomanian aquifers. Salinity in the groundwater wells is found increased forward the SE in Al Jiftlic and forward the east in Al Auja which indicating that increases in TDS is conjugated with the farness of water flow. Thus, chemical evaluation gave a simple basic idea about the water flow pattern as “water flow in al Auja is from the western mountains toward the east, while water flow in Al Jiftlic is recharged from the NW to SE direction”.

As EC is good estimator of salinity, 75% of the sampled water shows simple increasing in the EC in the year 2004 relative to 2003, while 5% didn’t show clear change, and 20% of the groundwater wells show a decease. The increasing in the water pumping rate for compliance the domestic and agricultural water demands, and the decreases in water flow that feeds groundwater wells and springs in the eastern basin will lead to serious drawdown in the water level and thus increasing salinity.

3.5.3 Classification of the Groundwater's Type (Piper diagram) :

Water type in the study is determined using AQUACHEM software program ver 3.7 and using GWW software program (United Nations, 1995). The result is in the form of triangular plot (Piper diagram) that gives geo-chemical interpretation for understanding water chemistry. Two triangular fields plotted separately, each corner express the concentration percentage of major cations (Ca^{2+}, Mg^{2+}, Na^{+}, and K^{+}), and the anions (HCO_3^{-} , SO_4^{2-} and Cl^{-}) in meq/L. The general characteristic of the water is represented on the diamond shape between the two triangles of the Piper shape, Piper classified the water into seven types on the diamond according to Langguth (1966) as shown in Figure 3.9.



Water type:

Normal earth alkaline water:

A: with prevailing bicarbonate.
B: with prevailing bicarbonate and sulphate (or chloride).
C: with prevailing sulphate (or chloride).

Earth alkaline water with increased portion of alkalis:

D: with prevailing bicarbonate.
E: with prevailing sulphate and chloride.

Alkaline water:

F: with prevailing bicarbonate.
G: with prevailing sulphate - chloride.

Figure 3.9: Piper trainer diagram and water type classification-according Langguth (1966).

3.5.3.1 Ein Samia Group :

According to Langguth (1966), Figure 3.10 shows the water type of the all deep and shallow ground wells of Ein Samia area is located in the earth alkaline water with prevailing bicarbonate (Ca-Mg-HCO_3). The existence of Ca^{2+} as the main dominant cation and HCO_3^- as the main dominant anion is due to recharging water in limestone and dolomitic limestone of the Cenomanian aquifers *(Lloyd & Heathcoat, 1985)*. In general, all aquifers in the study area share in normal contents of TDS (300 mg/L), chloride (35 mg/L), and nitrate (<17 mg/L) concentrations.

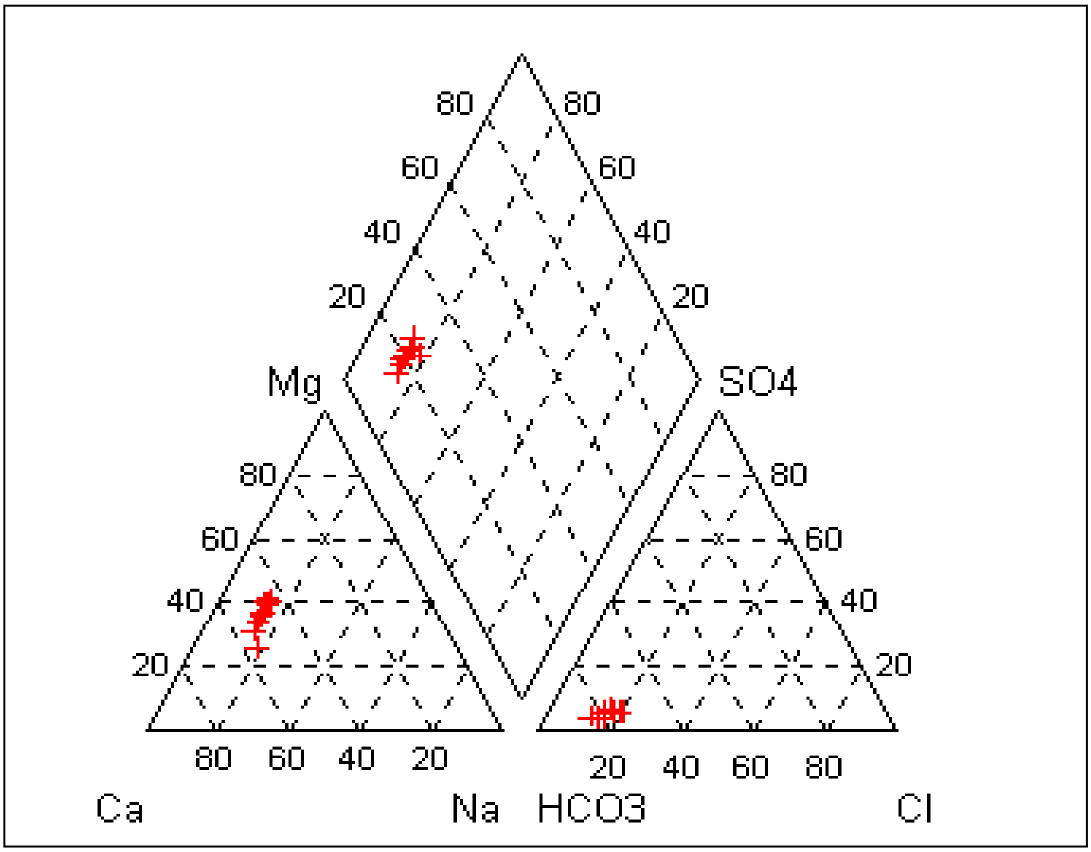


Figure 3.10: Piper diagram showing chemical results of Ein Samia groundwater wells.

3.5.3.2 Al Auja Group :

Based on the Piper diagram (Fig. 3.11), the water in Al Auja district is generally classified into three types:

1- Al-Auja spring water is of earth alkaline water with prevailing bicarbonate (Fig. 3.11). Ca^{+2} in water represents the main cation and HCO_3^- exist as the main anions which indicate water chemistry is typical of carbonate aquifer. All measurements show the spring contains lower salinity whereas TDS average is about 340 mg/L. The spring contain nitrate in normal concentration suggests that nitrate is the natural level (14.8 mg/L) in carbonate aquifers. Low TDS and relatively high bicarbonate concentrations suggest that AR/020 water represent recent recharge *(Chebotarev, 1955; Back, 1961; Mifflin, 1968).*

2- The second water type is the earth alkaline water with increased portion of alkalis and prevailing bicarbonate (Fig. 3.11). This water type is presented in the Alluvium/Lisan aquifers (≤100m depth) in the center of Al Auja (as well 19-15/005, 19-15/011, and 19-15/012). The water of this group is characterized by medium averages of TDS (681 mg/L), where Ca^{2+} (97 mg/L) and HCO_3^- (462 mg/L) are the main ions dominant.

3- The third groundwater type is the earth alkaline water with increased portion of alkalis with prevailing chloride and sulphate (Fig. 3.11). This water type is represented in the well 18-14/001 that locates to the eastern part of Al Auja center. The high average concentrations of sodium (272.5 mg/L) and chloride (241 mg/L) is expected due to presence of Alluvium formation of the Holocene epoch, which consist of marl and Alluvium inter-fingering with saline deposits which contributes in increasing salinity. This groundwater well contains also high average value of sulfate (~146 mg/L). This relate to the fact that the utilized aquifer penetrates also the lisan formation of Pleistocene that is characterized by the presence of gypsum rocks.

The hydrogeochemical history of this groundwater well shows that water type was of the earth alkaline water with increased portion of alkalis and prevailing bicarbonate *(PWA, 2002).* This study showed water is of earth alkaline water with increased portion of alkalis and prevailing chloride and sulphate. This water type is uncommon in shallow Alluvium aquifer (depth $_{avg.}$ ≈ 59m). The shifting process of the water type may occurred as a result of aggression of saline water or due to high dissolution of evaporite mineral dominantly gypsum (calcium-sulphate) and saline deposits in the aquifer that contributed in increasing alkali ions with time. This aquifer represents the highest value of dissolved minerals in the area where TDS is 1358 mg/L. The groundwater well is contained nitrate in normal concentration; this is a sign that the groundwater not faces danger pollution with wastewater.

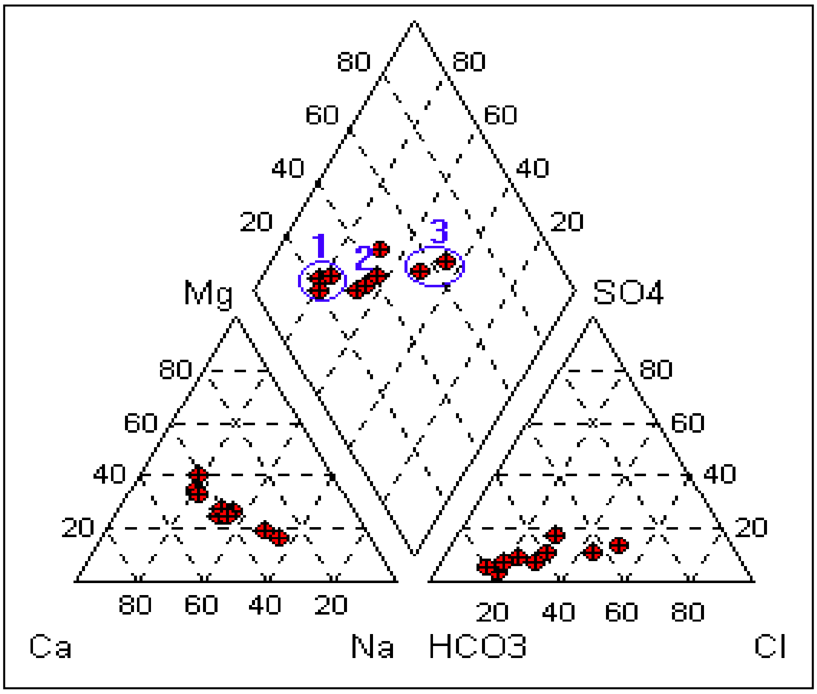


Figure 3.11: Piper diagram showing chemical results of Al Auja groundwater wells and spring.

3.5.3.3 Al Jiftlic Group :

The waters of the groundwater wells of Al Jiftlic area are classified into two groups according to the water type:

1- The earth alkaline water with increased portion of alkalis, and prevailing of bicarbonate (Fig 3.12). Inorganic water constituents are arranged according to their concentration as Ca-Mg-Na-HCO_3-Cl. This water type is found in the upper Cenomanian aquifer (depth $_{Av.}$ ≈150m, e.g. 19-17/034 NW of the Al Jiftlic), and in the shallow Alluvium aquifers (depth $_{Av.}$ ≈ 66m, i.e. 19-16/008 at the center of Al Jiftlic). This water chemistry is similar to Beida aquifer (Neogene) indicating that the water of the both aquifers is resulted from similar processes during the carbonates weathering. This group has an average TDS of 690 mg/L where calcium (86.3 mg/L) and bicarbonate (334 mg/L) are the main ions dominant. The average chloride in this group is about 100 mg/L while the average nitrate is 40 mg/L.

2- The earth alkaline water with increased portion of alkalis with prevailing of sulphate and chloride (Fig 3.12). Sodium represents the main dominant cation (500 mg/L) and chloride is the main dominant anion (1420 mg/L) in groundwater wells (e.g. 19-16/005, 19-17/008, 19-17/021, 19-17/054, 19-16/001, 19-17/001, 19-17/028, and 19-17/046). The aquifer of these groundwater wells is usually of Alluvium, but some times extended to Eocene. These aquifers are characterized by higher salinity which associated with evaporite minerals mainly gypsum and halite. Similar groundwater chemistry between Alluvium and Eocene aquifers in this area is a sign of that these aquifers share a common water flow path which may originated from the same recharge area (chapter 3, section 8.8.3).

All historical data of chloride concentration show increasing from 50 mg/L beginning from Bathan area to approximately 1000 mg/L in the study area of Al Jiftlic. High salinity in Al Jiftlic is explained due to far water recharge toward downstream through the unconfined Alluvium aquifer system in Wadi Far’a (which consists of highly permeable Alluvial sand and gravel) to the east-southwards (Al Jiftlic area) and infiltrates into these sands and gravel’s, then forming the source of groundwater wells (chapter 3, section 8.8.3).

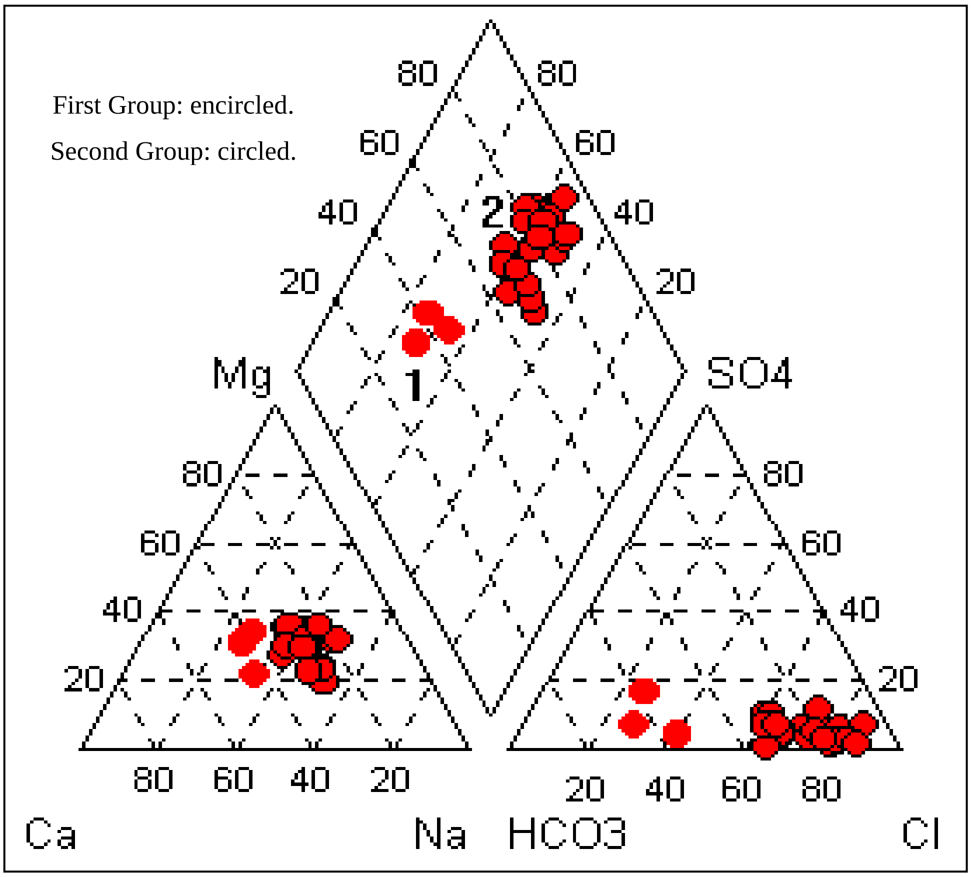


Fig. 3.12: Piper diagram showing chemical results of Al Jiftlic groundwater wells and spring.

Table 3.9: The summery of the water type in the study area of the eastern basin.

Water type	Area	(%) of collected sample
Alkaline water with prevailing bicarbonate.	Ein Samia 19-15/(001,002a,004,005,006), Auja springs (AR/020)	26%
Earth alkaline water with increased portion of alkalis and prevailing bicarbonate.	Auja 19-15/(005,011,012). Al Jiftlic (19-16/008, 19-17/034).	22%
Earth alkaline water with increased portion of alkalis and prevailing sulphate and chloride.	East Auja (18-14/001). Al Jiftlic19-16/(001,005), 19-17/(001,007,008,021,027,028,046,054,056).	52%

3.5.4 Seasonal Variation in Chemical Constituents :

Winter precipitation is the main source of water recharge of the groundwater wells in the study area, the concentration of these ions may be changed due to several environmental processes such as gaseous loss, absorption by plants, mixing with another water type, mineral precipitation, ion exchange (absorption, adsorption, and substitution), and mineral dissolution.

The concentrations of K^+, Na^+, Cl^-, SO_4^{2-}, and NO_3^- as well as EC are measured in winter higher than summer for the majority groundwater wells of Al Auja and Al Jiftlic area (Figure 3.13). This indicates possible occurrence of simple mixing during water recharge to the aquifers. The increased of these ions mainly Na^+, and Cl^- concentrations in winter represents a natural result of flushing the soil salinity that formed at the soil zone due to agricultural activity and high evaporation of water from the surface during summer. The increasing of NO_3^- concentration in winter is a natural phenomenon of nitrogen oxidation that increased in winter. The decreases of NO_3^- in summer return to ammonia volatilization and denitrification processes (nitrogen loss “N_2, N_2O, NO”) which are activated in hot temperature at pH between 6 and 8 *(Puel and Clark 1989)*. In addition to waste water mixing, high concentration of SO_4^{2-}, Na^+, Cl^-, and K^+ may also came from some mineral dissolution such as gypsum, halite, sylvite,..... .

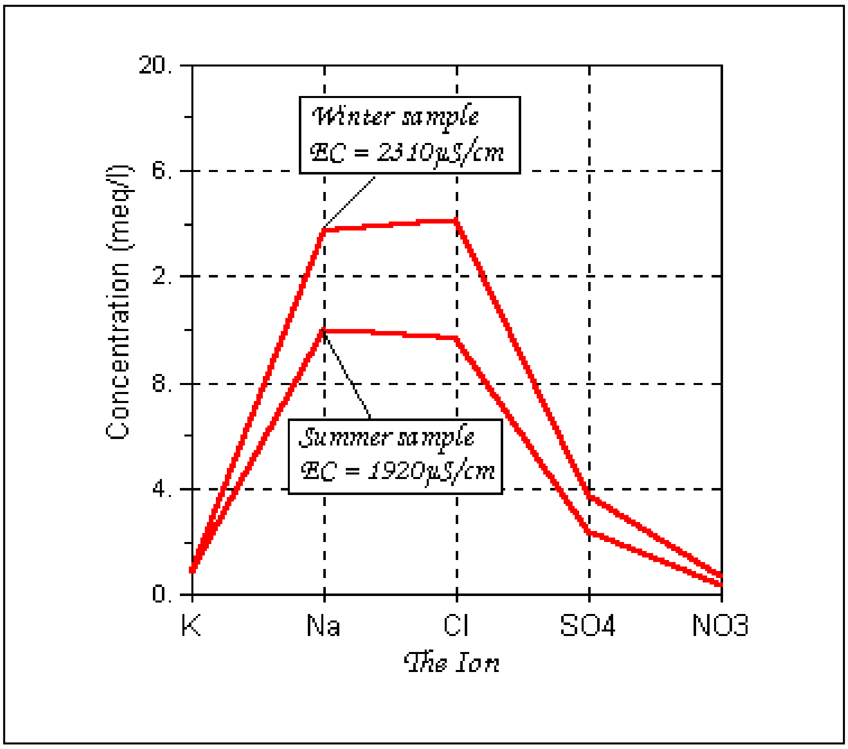


Figure 3.13: Schoeller diagram plot for the samples collected in winter and summer from 19-14/001 at Al Auja.

3.6 WATER QUALITY

3.6.1 General :

Human activities (sewage contamination, agricultural activities…), and natural environmental processes (sea water mixing, mineral dissolution between soils and water, ion exchange processes...) are the main possible causes of decline in chemical, biological, and physical characteristic of water which lead to poor water quality.

The evaluation of water quality (suitability for domestic and irrigation uses) involves the type and the amount of dissolved constituents in groundwater. Herein, the evaluation is based on a comparison of the physical and chemical parameters of the sampled water against the water guidelines of the Word Health Organization *(WHO, 2005)* and *Palestinian drinking standard (PWA,2005).*

3.6.2 Water Quality for Domestic Purposes :

When talks about domestic water, it means drinking, cleaning, cooking, bathing uses …etc. The primary purpose of the guidelines for drinking-water quality is the protection of public health. In general water is potable when physical, biological and chemical parameters are below the permissible limits of the local and international guidelines and standards without expected negative health effect over the lifetime of consumption *(WHO, 2005).* Deficit in the health balance depends on the amount, the period, and the type of dissolved constituents. For example, the continuous consumption of water that contain high dissolved constituents is likely to increase unstable health balance which usually represented in symptoms of dysentery, kidney, and cardiovascular diseases, as well as development of gynecological and pregnancy-related pathology *(Bellissari, 1994).*

3.6.3 Chemical and Physical Quality Evaluation :

Chemical water quality is determined after the determination of the main cations (Ca^{2+}, Mg^{2+}, Na^{+}, and K^{+}), and anions (HCO_3^-, Cl^-, SO_4^{2-}, and NO_3^-) as well as some minor ions (NH_4^+, F^-, and PO_4^{2-}). The physical parameters (EC, pH, Temp, water hardness, turbidity, color, taste, and odor) may also important for identify the level of water quality. The basis of water quality is evaluated by the *Palestinian drinking standard (PWA,2005),* and the *WHO (2005)* in Table 3.10.

Water hardness is the capacity of water to precipitate soap as solid soap residue when the divalent metallic cation e.g. (Ca^{2+}, Mg^{2+}, Fe^{2+}, Ba^{2+}, and Sr^{2+}) reacts with sodium soap to produce insoluble residue with soap *(WHO, 2005)* . There are two types of Hardness: temporary hardness (the calcium and magnesium carbonate) that would be removed by boiling and leaving a precipitation of $CaCO_3$, and permanent hardness (the calcium and magnesium that would exist as sulfates or chlorides) which would not be removed by boiling). The total hardness (TH) is calculated in the term of carbonate as the following equation:

$$\text{TH (mg/L as } CaCO_3) = 2.5\ Ca^{2+} + 4.12\ Mg^{2+}$$ *(Todd, 1980)*

Table 3.10: World Health Organization (WHO, 2005) & Palestinian standards (2005) guidelines for potable water.

Parameter	**WHO guidelines**	**Palestinian standers**		**Source of cause**	**Consumer impact**
		Basic	**Conditional**		
Temp. °C	12-25	8-25	12-25		Aesthetic: should be acceptable .
pH- Value	6.5-8.5	6.5-8.5	9.5		Aesthetic: Low pH: corrosion. High pH: taste & soapy feeling (pH >12).
Ca^{2+}(mg/L)	75	75	100	Dissolution & weathering of rocks and soils, specially limestone, dolomite and gypsum.	Aesthetic: Water hardness
Mg^{2+}(mg/L)	125	50	120	Dissolution & weathering of rocks, specially carbonates.	Aesthetic: Water hardness, high $MgSO_4$ cause bitter taste and diarrhea.
Na^+(mg/L)	200	200	400	Leaching from rocks & soils, dissolution & weathering of minerals, fertilizers, mixing with seawater & sewage.	Aesthetic: taste, high Na^+ may harmful infants, hypertension patients, people with heart problem.
K^+(mg/L)	12	10	12	Rocks, wastewater agriculture, mixing with seawater.	Aesthetic:
NH_4^+(mg/L)	1.5-35			Metabolic, agricultural, and industrial process.	Aesthetic: taste and odor (indicator of sewage & waste pollution)
HCO_3^-(mg/L)	125-350	100	500	Carbonate rocks & soils, ancient brines and seawater, sewage, CO_2 from atmosphere.	Aesthetic, white deposit on fruit and leaves by using sprinkler.
Cl^-(mg/L)	250	250	600	Rocks soils, sewage, brines & seawater.	Aesthetic: taste & corrosion.
SO_4^{2-}(mg/L)	250	200	400	Rocks and soils containing ores Sulphides or Sulphur compounds, fertilizers, sewage.	Aesthetic: taste & corrosion.
NO_3^-(mg/L)	50	50	70	Agricultural land (fertilizers, legume plants...), sewage, decaying organic matter, fuel combustion, N_2 fixation, & NH_3 oxidation.	Health significance: infant methahemoglobin, carcinogenic when combined with amines & amides.
F^-(mg/L)	1.5	0.61	1.5	Rocks & soils (e.g. phlourspar).	Health significance: dental and skeletal deformities.
PO_4^-(mg/L)		<1.0		Dissolution & weathering of minerals, organic decay, fertilizers, and agriculture return flow.	Environmental problem: Eutrophication.
TDS (mg/L)	500-1000	1000	1500	Mainly from the major anions and cations.	Aesthetic: objectionable to consumers.
Hardness (mg/L)	500	500	500	Deposition of Ca^{2+} and Mg^{2+} in water.	Aesthetic: High hardness: scale deposition, scum formation. Low Hardness: possible corrosion.

The water type is classified as *Sawyer and McCarty (1967)* as illustrated in Table 3.11. Using water of total hardness greater than 80 mg/L as $CaCO_3$ for domestic purposes is the main reason standing behind coagulates of soup lather. Depending on the water quality guideline of WHO (2005), the maximum permissible limit of water hardness for domestic purpose is limited by 500 mg/L as $CaCO_3$ (Table 3.10).

Table 3.11: Water classification as Sawyer and McCarty (1967), based on hardness.

Hardness (mg/L) $CaCO_3$	**Water Class**
0-75	Soft
75-150	Moderately hard
150-300	Hard
Over 300	Very hardness

At pH between 7 and 8, bicarbonate is main carbonate species dominant (95-98%) *(Fetter,1994)* thus alkalinity ≈ HCO_3^- mg/L as $CaCO_3$[*]. If alkalinity is less than the total hardness, then temporary hardness will equal alkalinity, and permanent hardness will equal total hardness minus temporary hardness. If alkalinity is more than total hardness then all hardness is temporary *(Hounslow, 1995).*

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[*] Alkalinity in the term of mg $CaCO_3$ = ((HCO_3/Eq. Wt.HCO_3) *Eq.Wt. of $CaCO_3$), or HCO_3* 0.82

3.6.3.1 Ein Samia Group :

All groundwater wells of Ein Samia area uses for supplying consumer in Ramallah area with domestic or potable water. In general, these groundwater wells are far away from agricultural activity or human contamination, and water is pumped with modern pumpage.

Based on the total water hardness (210-277 mg/L as $CaCO_3$); the groundwater wells of this group is classified as "hard" water (as *Sawyer and McCarty classification, 1967*). The second samples of the groundwater wells ESW1, and ESW2a showed increase in the total hardness as a sign of additional amount of carbonate dissolution over precipitations. The groundwater pH ranges between 7.1-7.8. Within this range, HCO_3^- (mg/L as $CaCO_3$) is the only carbonate species present. While total hardness in all groundwater wells of Ein Samia is more than alkalinity [HCO_3^-] therefore water hardness in Ein Samia groundwater wells s is classified as temporary (188-266 mg/L) and permanent (10-50 mg/L) hardness as shown in Table 3.12.

Table 3.12: The average temporary and permanent hardness of Ein Samia groundwater wells (2003/2004).

Well code	Well Depth (m)	Total Hardness mg/L as $CaCO_3$	Temporary Hardness mg/L as $CaCO_3$	Permanent Hardness mg/L as $CaCO_3$
18-15/001	60.3	248.3	197.9	50.4
18-15/002a	252	249.2	205.2	44.1
18-15/004	616	276.9	266.3	10.6
15-18/005	526	240.0	205.5	34.5
15-18/006	172	212.6	187.6	25.0

All groundwater wells show similar range of TDS (274-338 mg/L), EC (460-542 µS/cm), cations, and anions parameters. The water of this group contains acceptable average values of Ca^{2+} (56 mg/L), Mg^{2+}(25.5 mg/L), HCO_3^- (260 mg/L), Cl^- (35 mg/L), Na^+ (20 mg/L), K^+ (2.2 mg/L), and NO_3^- (17 mg/L) concentrations. All groundwater wells constituents are less than *Word Health Organization (WHO, 2005)* and *Palestinian drinking standard (PWA, 2005)*. Therefore, chemically, Ein Samia groundwaters are potable water.

3.6.3.2 Al Auja Group :

Most shallow groundwater wells of al Auja are located in the agricultural area. Some times the pumping water showed red color due to Fe (II) oxidation of the internal iron tube of the old pumping machine such as the groundwater wells 19-15/005, and 19-14/001.

The groundwater wells are classified according to hardness as "very hard" water (370-548 mg/L), while the spring water (AR/020) is classified as "hard" water (241 mg/L). The highest value of hardness is represented in well 19-14/001, where temporary hardness (477 mg/L) is higher than permanent hardness (71 mg/L). The spring water AR/020 is characterized by minimum hardness where the total hardness is temporary (241 mg/L as $CaCO_3$) (Table 3.13).

Table 3.13: The average temporary and permanent hardness of Al Auja groundwater wells (2003/2004).

Well code	***Total Hardness*** ***mg/L as $CaCO_3$***	***Temporary Hardness*** ***mg/L as $CaCO_3$***	***Permanent Hardness*** ***mg/L as $CaCO_3$***
19-14/001	547.8	476.9	70.9
19-15/005	419.3	410	9.3
19-15/011	377.2	315.2	62
19-15/012	390.7	380.3	10.4
AR/020	241.2	241.2	---

The groundwater well 19-14/001 that is located in the eastern part relative to the other groundwater wells has higher EC (2115µS/cm) and TDS (1358 mg/L) average due to higher concentration of the major ions such as Ca^{2+}(137 mg/L), Na^+ (272 mg/L), and Cl^- (421 mg/L) relative to the other wells. The ionic concentration of Ca^{2+}, Na^+, K^+, HCO_3^-, and Cl^- exceeds the guidelines of *WHO (2005)* and *Palestinian drinking standard (PWA,2005)*. Therefore and accordingly to those results, the water of the ground well 19-14/001 is absolutely unsuitable for drinking with some cautions for using groundwater well 19-15/005. The spring water (AR/020) show the lowest values of EC (531µS/cm) and TDS (331 mg/L), and contain ions concentration less than *Palestinian and WHO standards(2005).*

3.6.3.3 Al Jiftlic Group :

Most of pumping machines in the area are old, and working mechanically using petroleum energy. The metallic rust on the old tubes is noticed (i.e. 19-16/005, 19-16/008, 19-17/001, and 19-17/54) due to long time of stop pumping in winter where those machines are usually activated in the beginning of summer.

The water of the groundwells of Al jiftlic area can be divided according to their total harness into three groups (Table 3.14):

The water hardness of the first group is classified as “hard” water with an average of 230 mg/L as $CaCO_3$, while the second and third groups are of “very hard “water. The minimum total hardness and TDS is measured in the well 19-16/008 with an average of 180mg/L, and the maximum hardness is found in the well 19-16/005 with an average of 1470 mg/L as $CaCO_3$. The water hardness in the first group is temporary, while the second and the third group show mixed of temporary and permanent hardness, in the second group the temporary hardness is over permanent, while in the third group permanent water hardness is higher than temporary. The study showed that increasing in permanent hardness over temporary is related to salinity increasing.

Table 3.14: The summery of the total hardness of Al Jiftlic groundwater wells (2003/2004).

Group Number	**T.H Avg. (mg/L as $CaCO_3$)**	**Temporary. Hardness (mg/L $CaCO_3$)**	**Permanent. Hardness (mg/L $CaCO_3$)**	**Well Code**
Group (1)	230	150-300	---	19-16/008, 19-17/034
Group (2)	495	290-370	32-233	19-17/001, 19-17/046, 19-17/056, 19-17/007, 19-17/027, 19-17/021, 19-17/054
Group (3)	895	275-418	441-658	19-16/001, 19-17/028, 19-17/008, 19-16/005

All physical parameters (EC, pH, TDS), and the majority of cations and anions concentration (mainly Na^+, K^+, Cl^-) of the first group (Table 3.15) are lower than the limits of *Palestinian and WHO standards of drinking (2005)*. This group represents 15% of the total samples, from the chemically point of view the groundwater wells of the first group are suitable for drinking.

The majority of physical and chemical parameters (TDS, Ca^{2+}, Na^+, K^+, HCO_3^-, Cl^-, and NO_3^-) of the second group represent higher values than *Palestinian and WHO standard limits (2005)*. In the second group, the groundwater well 19-17/056 shows the maximum TDS (2079 mg/L), Cl^- (1099 mg/L), and Na^+ (338 mg/L) concentrations, and the well 19-17/046 contain the maximum concentration of SO_4^{2-} (98.5 mg/L), and NO_3^- (67.5 mg/L).

The third groundwater wells group represents more brackish water due to higher amount of TDS (Table 3.15). The study showed that the groundwater well 19-17/028 contains the maximum amount of TDS (3469 mg/L), Na^+ (637 mg/L), K^+ (55 mg/L), and Cl^- (2057 mg/L), and the groundwater well 19-16/005 contains the maximum amount of Mg^{2+} (222 mg/L), HCO_3^- (610 mg/L), SO_4^{2-} (318 mg/L), and NO_3^- (73 mg/L).

The statistical data of 24 samples shows that the second and the third group of the sampled groundwaters wells (85% of the total samples) of Al Jiftlic are within poor water quality and can't be used for drinking

Table 3.15: The average measured parameters for each group of Al Jiftlic groundwater wells.

Group	**EC** (µS/cm)	**TDS** (mg/L)	**pH**	**Ca^{2+}** (mg/L)	**Mg^{2+}** (mg/L)	**Na^+** (mg/L)	**K^+** (mg/L)	**HCO_3^-** (mg/L)	**Cl^-** (mg/L)	**SO_4^{2-}** (mg/L)	**NO_3^-** (mg/L)	**F^-** (mg/L)
(1)	788.7	545	7.3	86.3	36.9	68.4	2.8	334.1	104.6	42.5	39.0	0.14
(2)	2464.6	1248	6.8	165.5	96.0	251.8	21.3	402.2	649.2	68.1	45.1	0.5
(3)	4866.3	2736	6.8	315	185.0	497.7	36.0	390.1	1419.2	133.1	38.2	0.1

3.6.4 Water Quality for Agriculture Purposes :

Type and concentration of dissolved ions in water, soil type and its characteristics, and plant type that will be irrigated are important points for evaluating the suitability of water for irrigation. The high presence of salts in irrigation water is the main reason for causing physical, chemical and physiological effects on plants. Physical effects is divided into two types:- the direct *physical effect* that result from decreasing the water uptake limit; due to changing the osmotic condition in the root zone, the second type is the *indirect physical effect* where represent the effects on the plants growth when salts in irrigation water changing the soil structure, permeability or aeration *(Todd, 1980)*. Plants may be effected *chemically* (metabolic reactions) when exposed to some toxic ions (i.e. boron) through irrigation. High level of salinity could influence the crop *physiologically;* such as cells enlargement and division, the production of proteins and nucleic acids, and the rate of increase in plant mass *(Ayers et al. 1985).*

3.6.4.1 Salinity (Total Dissolved Solids / Electrical Conductivity) :

Salinity increasing is proportional with the total dissolved solids (TDS) that is linked to the measured electrical conductivity according to the following equation:

$$TDS\ (mg/L) \approx EC\ (\mu s/cm) * (0.55\text{-}0.76).$$

One of the major consequences of the soil salinity increasing in the root zone is reducing the energy of plants growth. Some crops show visible injuries of leaf burn symptoms which are normally occur as a result of high salinity. High evapotranspiration on the leaves surface could attribute in build up salts in the root zone by taking up the fresh water and leave the salt behind in the soil.

Based on EC and TDS parameters; the United State salinity laboratory (USSL) classified irrigation water into low, medium, high and very high salinity *(Richard, 1954)* as shown in Table (3.16).

Table 3.16: The irrigation water in the groups according to EC and TDS (Richard, 1954).

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

3.6.4.2 Sodium Adsorption Ratio (SAR) :

SAR measures the degree of sodium hazard where sodium in irrigation water replaces the adsorbed Ca^{2+} and Mg^{2+} in the soil clays. The main hazard of high SAR represents in deterioration the physical soil structure such as reducing infiltration and permeability which contributes in deflocculation of tilth *(Karanth, 1987)*. SAR is calculated according to the following equation:

$$SAR = \frac{Na^+}{\sqrt{\frac{Ca^{2+} + Mg^{2+}}{2}}}$$ (Al concentrations are in meq/l unit)

The classification of irrigation water that based on SAR is shown in see Table 3.17.

Table 3.17: Classification of irrigation water based on SAR values (Wilcox, 1955).

SAR range	Water Class	Comments
< 10	S1	***Low sodium***: can be used for irrigation on almost all soils with little danger.
10-18	S2	***Medium sodium:*** 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:*** may produce harmful levels of exchangeable sodium in most soils.
> 26	S4	***Very high sodium:*** unsatisfactory for irrigation purposes, except for waters with low and medium salinity.

3.6.4.3 Soluble Sodium Percentage (SSP) :

In addition to the evaluation of SAR, the sodium hazard of irrigation water can be expressed in the term of the Soluble Sodium Percentage (SSP). The SSP express the sodium percentage to the total values of cations, which is expressed as the following formula:

$$SSP = ((Na^+ + K^+)/(Ca^{2+} + Mg^{2+} + Na^+ + K^+))*100$$ (All ionic concentrations are in meq/l)

Table 3.18: Classification of irrigation water based on SSP (Todd, 1980).

Water Class	SSP	EC µs/cm
Excellent	<20	>250
Good	20-40	250-750
Permissible	40-60	750-2000
Doubtful	60-80	2000-3000
Unsuitable	>80	>3000

3.6.4.4 Residual Sodium Carbonate (RSC) :

The anions HCO_3^- and CO_3^- in the irrigation water tend to precipitate calcium and magnesium ions in the soil resulting in an increase in the proportion of the sodium ions. For this reason, RSC was considered to be indicative of the salinity hazard of water.

Eaton (1950) suggested that Residual Sodium Carbonate (RSC) is defined by the formula:

$$RSC = (CO_3^- + HCO_3^-) - (Ca^{++} + Mg^{++}) \quad \text{(All ionic concentrations are in meq/l)}$$

Table 3.19: Classification of irrigation water based on RSC values (College of Agricultural Science, 2002).

RSC	Hazard
<0	Non
0-1.25	Low, with some removal of calcium and magnesium from irrigation water.
1.25-2.5	Medium, with appreciable removal of calcium and magnesium from irrigation water.
>2.5	High, with most calcium and magnesium removed leaving sodium to accumulate.

3.6.5 Evaluation the Irrigation Water Quality :

To give a judgment, whether the water is proper for irrigation or not, irrigation waters are classified in terms of salinity hazard (EC/TDS), Sodium Adsorption Ratio (SAR), Soluble Sodium Percentage (SSP), and Residual Sodium Carbonate (RSC)....

3.6.5.1 Ein Samia Study Area :

To determine the groundwater quality for irrigation, the measured, analyzed, calculated, and plotted results are illustrated in Table 3.20, and Figure 3.14.

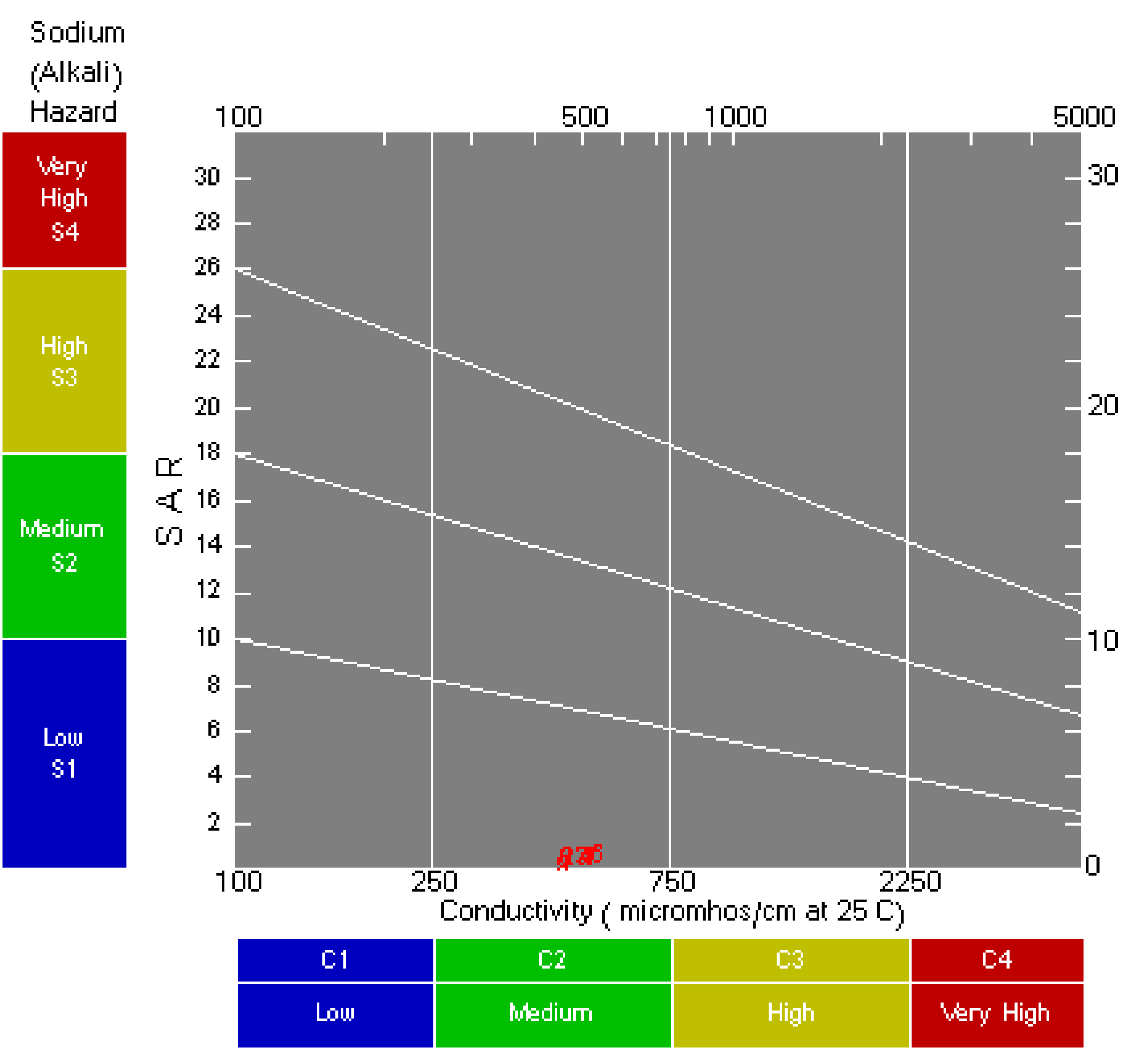
Based on United State Salinity Laboratory (USSL) *(Richard, 1954)* and EC-SAR *(Wilcox, 1955)*; all groundwaters are of low sodium - medium salinity hazard (S1-C2) with an average SAR of 0.55 (Figure 3.14). Therefore, water can be used to irrigate plants of moderate salt tolerance without serious hazards. Lower sodium concentration in the irrigated water means low hazard on soil structure.

Based on the low average of soluble sodium percentage (SSP) *(Todd 1980)* which is about 15.8 at EC 503 µS/cm; the water quality of Ein Samia groundwater wells are classified as “Excellent” for irrigation “lower salinity and higher water quality”.

According to residual sodium carbonate parameters (RSC), all RSC results are a negative value (with average of –0.65) which indicates no hazards of irrigation water on the soil aggregation.

Table 3.20: The average measured, analyzed, and calculated results for determining water quality for irrigation in Ein Samia groundwater wells..

Well code	PH	EC (µS/cm)	SSP %	SAR	RSC	K^+ (mg/L)	Cl^- (mg/L)	NO_3^- (mg/L)
18-15/001	7.69	489.8	14.82	0.52	-0.25	1.83	36.83	19.18
18-15/002a	7.35	515.5	15.48	0.55	-0.24	1.75	35.06	21.39
18-15/004	7.11	541	15.39	0.58	-0.28	1.90	34.68	12.35
15-18/005	7.20	507	14.69	0.51	-0.26	1.65	30.43	30.43
15-18/006	7.40	464	18.07	0.58	-0.18	3.45	35.53	18.39



Keys:

2, 3: 18-15/001.	7: 18-15/005.
1, 4: 18-15/02a.	8, 9: 18-15/006.

Figure 3.14: The EC-SAR water classes (UN, 1995) in Ein Samia study area.

3.6.5.2 Al Auja Study Area :

☐ **Group1** *(i.e. groundwater wells code 19-15/(005,011,012))*

Based on EC-SAR values *(Richard, 1954; Wilcox, 1955)*; the majority of the irrigation water is classified into low sodium hazard - high salinity hazard (S1-C3) (Figure 3.15). The average SSP (36.7) at EC of 1010 µS/cm (Table 3.21) indicating that the waters classify as "permissible" to irrigate the moderate salt tolerance crops. These groundwater wells are not recommended to be used to irrigate plants of low sensitive salt tolerant (Appendix 3.7). Depending on the average SAR (2.04), and RSC (0.01), the irrigation water hazard on soil structure will be very low.

☐ **Group2** *(i.e. groundwater well code 18-14/001)*

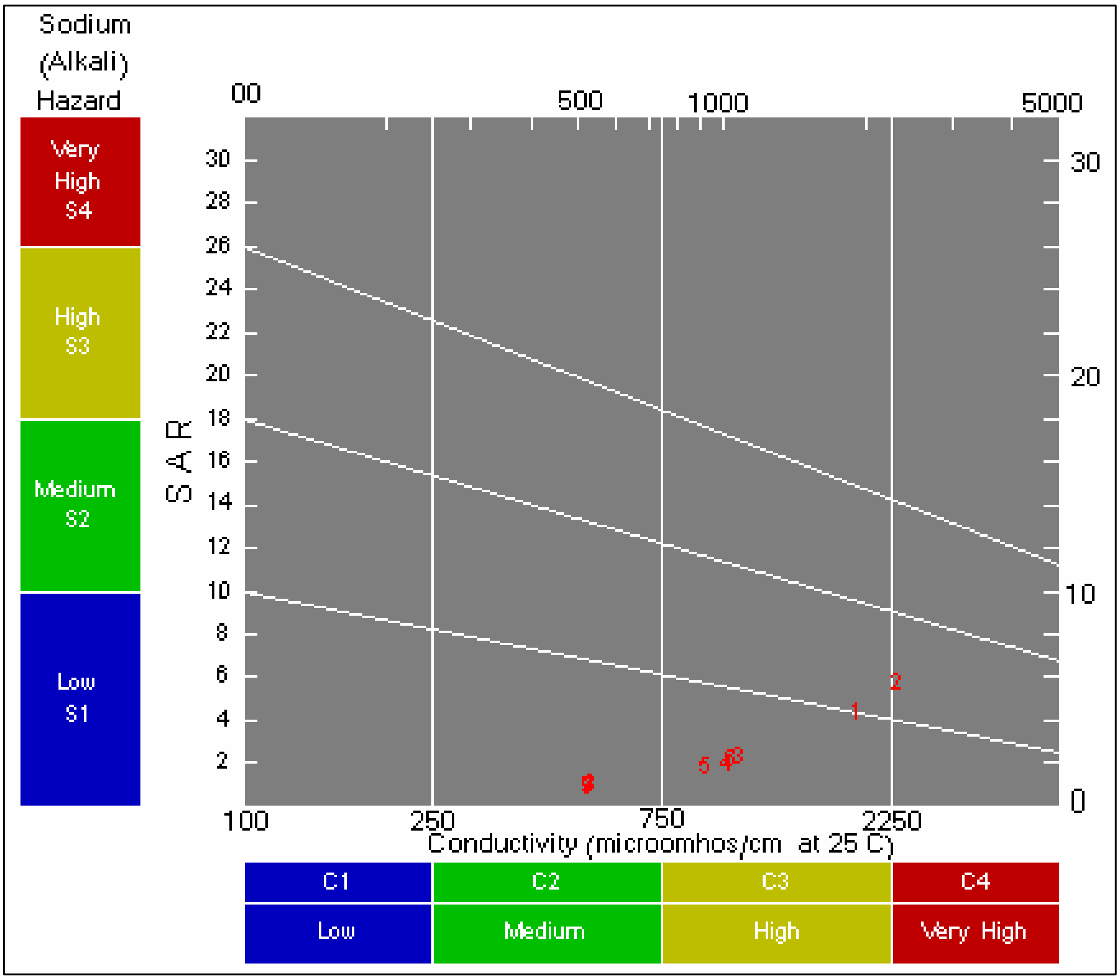
Based on EC-SAR, the groundwater well 18-14/001 is classified into low/medium sodium hazard - high salinity hazard (S2-C3) (Figure 3.15). The average SSP (53.7) at EC of 2115 µS/cm indicates that irrigation water locate in "doubtful" water quality. This water may cause medium implications on the sensitive crops due to moderate concentration of specific sodium and chloride ion toxicity. In general, the groundwater well *18-14/001* can be used for irrigate selected salt-tolerant plants under special conditions such as careful irrigation, good drainage and leaching. According to the calculated average SAR (5.1) and RSC (0.02) (Table 3.21); irrigation with the groundwater well 19-14/001 can be used on almost soils with little danger.

☐ **Group3** *(spring code (AR/020))*

The average SAR of Al Auja spring is given by 0.79 at 531 µS/cm of EC. The classification of irrigation water is of low sodium hazard–medium salinity hazard (S1-C2). The SSP of the spring water is about 21.5; therefore the irrigation water quality is considered "Good". Low values of RSC, SAR, and SSP (Table 3.21) indicate water is suitable to irrigate plants of moderate sensitive salt tolerance without any expected effect on the soil permeability.

Table 3.21: The average measured, analyzed, and calculated results to determining water quality for irrigation of Al Auja water resources.

Well code	*pH*	*EC (µS/cm)*	*SSP %*	*SAR*	*RSC*	*K^+ (mg/L)*	*Cl^- (mg/L)*	*NO_3^- (mg/L)*
19-15/011	7.25	923	34.3	1.82	0	15.78	124.5	12.95
19-15/012	7.01	1054	39.1	2.09	0.01	34.74	123.5	11.21
19-15/005	7.08	1058.5	36.7	2.13	0.01	19.94	123.5	10.8
19-14/001	6.83	2115	53.6	5.06	0.02	34.73	421.3	32.35
AR/020	7.76	531	21.5	0.79	0	3.77	41.12	14.8



Key:

1, 2: 18-14/001.
3, 4: 18-15/005.
5: 19-15/011.
6: 19-15/012.

7, 8, 9: AR/020.

Figure 3.15: The EC-SAR water class (UN, 1995) in Al Auja study area.

3.6.5.3 Al Jiftlic Study Area :

☐ **Group 1** (groundwater wells 19-17/034, and 19-16/008)

This group represents the lowest groundwater salinity in Al jiftlic area. Based on EC-SAR classification, this water type is of low sodium hazard - medium/high salinity hazard (S1-C2/C3) (Figure 3.16). Based on the low average of both SSP ratio (29.3 %), and sodium & chloride ion toxicity, the groundwaters quality of the group-1 are classified "good "water for surface irrigation. Based on the low average values of EC (588 µS/cm), and SAR (1.6), the irrigation water effect on the soil structure will be low due to slow ion exchange of calcium and magnesium of the soil with sodium in the irrigation water.

☐ **Group 2** (groundwater wells 19-17/ (007,021,001,027,046,056))

The majority groundwater wells are concentrated at the edge of low/medium sodium hazard - high/very high salinity hazard (Figure 3.16). The average SSP ratio of this group is 43.6 at 2465 µS/cm of EC. This leads that water quality is only "permissible" to irrigate plant of high and very high salt tolerant. The concentration of sodium (245 mg/L) and chloride (616 mg/L) ions in irrigated water are able to cause medium/sever effects on the sensitive salt tolerant plants. Based on the SAR (4.13), the sodium content in irrigation water is not sufficient to cause danger damage on the soil structure.

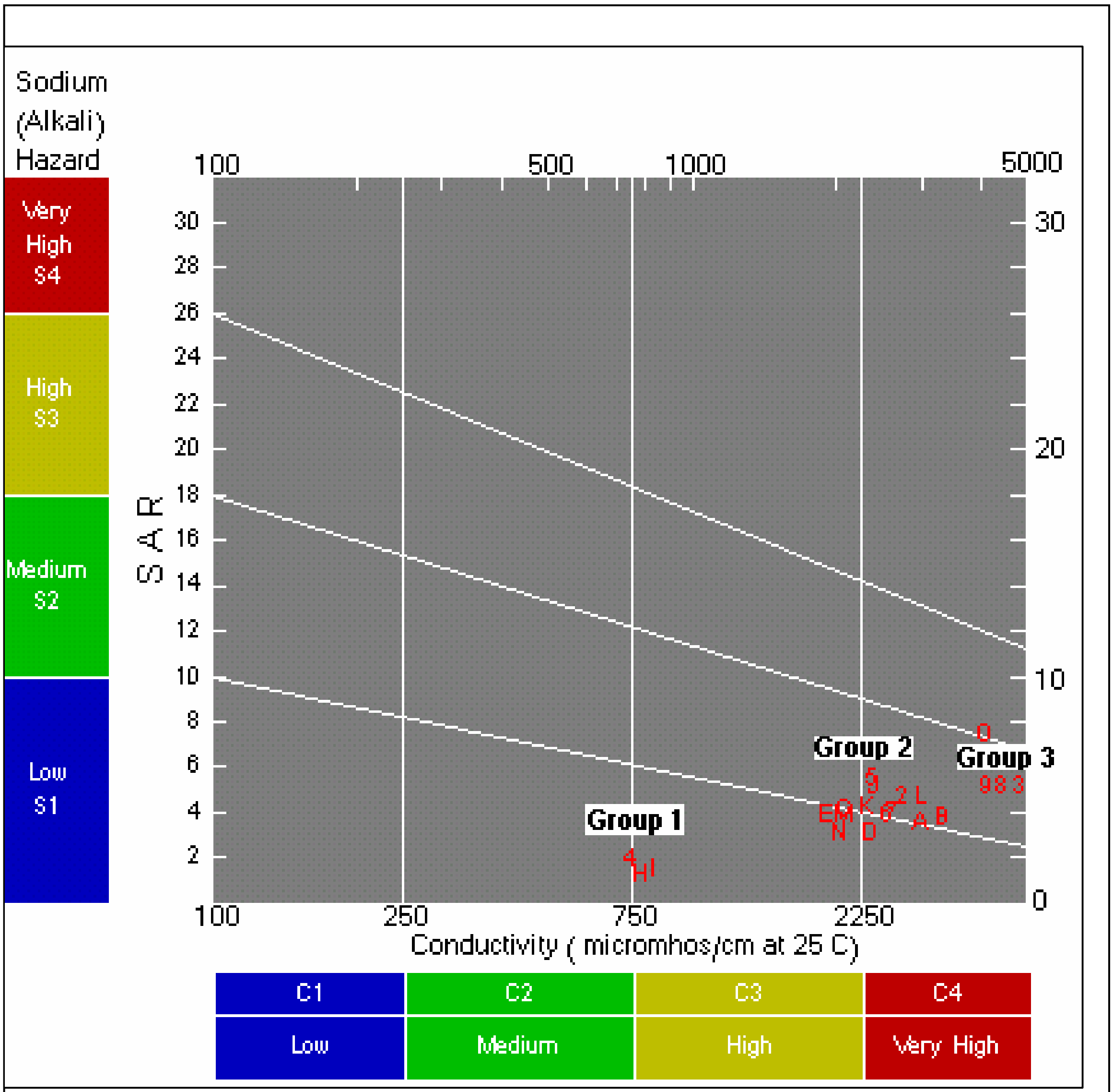
☐ **Group 3** (groundwater wells 19-17/ (054, 008,028, 001), 19-16/(001, 005)

This group represents the highest salinity in Al jiftlic study area. The irrigation water of this group is classified into medium sodium hazard - very high salinity hazard (S2-C4) (Figure 3.16). This water is not suitable for irrigation under ordinary conditions, but it can be used for special plant types which are tolerant with high salt (Appendices 3.7). The irrigated soil should be characterized by high permeability (such as coarse-textured soils) to avoid accumulate salts in the root zone.

The groundwater wells of this group contain the highest average of chloride (1420 mg/L), and sodium (500 mg/L) ions. These ions can cause medium/severe consequence on irrigation and may produce harmful level on the soil pores. Uses this water that contain high content of bicarbonate (420 mg/L) can also cause undesirable white deposits on fruit or vegetables.

Table 3.22: The average measured, analyzed, and calculated results to determining water quality for irrigation of Al Jiftlic groundwater wells.

Well code	*PH*	*EC*	*SSP*	*SAR*	*K^+*	*Cl^-*	*NO_3^-*
		(µS/cm)			*(mg/L)*	*(mg/L)*	*(mg/L)*
19-17/034	7.29	807	27.08	1.41	3.44	81.69	38.7
19-16/008	7.47	752	33.86	1.87	1.58	150.3	39.5
19-17/056	6.91	2050	40.75	3.5	12.75	537.15	58.1
19-17/027	6.4	2113	41.9	3.67	16.41	518.78	19.9
19-17/046	6.98	2370	49.1	4.7	8.82	554.33	90.15
19-17/001	6.88	2380	53.5	5.4	20.52	570.4	26.15
19-17/007	7.18	2595	44.75	3.9	41.06	665.04	37.85
19-17/021	6.77	3150	36.5	3.6	22.7	850.49	34.75
19-17/054	6.84	2990	44.6	4.7	36.3	1099.2	33.9
19-17/008	6.9	4265	44.6	5.15	32.69	1140.3	25.05
19-16/005	6.57	4820	40.2	5.2	30	1397	73
19-17/028	6.77	5040	48.2	6.7	46.04	1688.56	35.2
19-16/001	6.75	5230	44.2	5.85	27.08	1305.2	38.45



Key:

1	19-16/001	7	19-17/007	D	19-17/027	J	19-17/046
2	19-16/001	8	19-17/008	E	19-17/027	K	19-17/046
3	19-16/005	9	19-17/008	F	19-17/028	L	19-17/056
4	19-16/008	A	19-17/021	G	19-17/028	M	19-17/056
5	19-17/001	B	19-17/021	H	19-17/034	N	19-17/056
6	19-17007	C	19-17/027	I	19-17/034	O	19-17/028

Figure 3.16: Salinity grouping of groundwater wells in Al Jiftlic area (Wilcox, 1955).

3.7 WATER GENESIS

3.7.1 General :

Interactions between water and surrounding host rocks are the main processes that controlling the water type, and its genesis. Rock-water interactions usually occur during weathering, dissolution, precipitation and ion exchange between water and clay minerals. Furthermore, water mixing with seawater, agricultural returned flow, waste water, or deep brine water is also affect the groundwater genesis.

Determination of such processes requires description of the main mineral assemblage of the rocks in which water is found, and identification of chemical reaction that responsible for the geochemical evolution of groundwater.

3.7.2 Saturation Indices (SI) :

Despite groundwater chemistry is affect by interaction between rocks and soil with water during metioric water percolation or aquifer storage; this interaction is controlled by the saturation indices of groundwater with respect to various mineral phases. The saturation indices of the concerned minerals (Table 3.23) are an indicator for showing the tendency of water for precipitation or dissolution at the particular mineral phase. This process is controlled by the solubility product of each mineral phase in the term of the activity ratios (on log scale) of the ion in groundwater *(Kramer, 1968; Helgeson et al., 1969; Paces, 1972, Fritz, 1975).* The thermodynamic calculation of each SI was computed by using PHREEQC software program *(Parkurst and Appelo 2001)* based on the following equation:

$$SI = \text{Log}\ (K_{IAP} / K_{SP})$$

Where:

K_{IAP} is the ion activity product which equals the product of the measured activities, and K_{sp} is the solubility product of the mineral. To determine the mineral equilibrium reaction in natural water K_{IAP} is compared with K_{sp} into three cases:

- ☐ **Case1:** $K_{IAP} = K_{sat}$ or $SI = 0$; water is just saturated with the mineral phase.
- ☐ **Case2:** $K_{IAP} > K_{sat}$ or $SI > 0$; water is over saturated with respect to the mineral phase (tend to precipitation).
- ☐ **Case3:** $K_{IAP} < K_{sat}$ or $SI < 0$; water is under saturated with respect to the mineral phase (tend to dissolve more of the mineral if it is available).

Table 3.23: The mineral phases considered in the thermodynamic calculations of SI.

Phase	**Master Species**	**K_{sp}**
Anhydrite	$CaSO_4 \rightarrow Ca^{2+} + SO_4^{2-}$	4.68×10^{-5}
Gypsum	$CaSO_4.2H_2O \rightarrow Ca^{2+} + SO_4^{2-} + 2H_2O$	2.49×10^{-5}
Aragonite	$CaCO_3 \rightarrow Ca^{2+} + CO_3^{2-}$	4.94×10^{-9}
Calcite	$CaCO_3 \rightarrow Ca^{2+} + CO_3^{2-}$	3.52×10^{-9}
Dolomite	$CaMg(CO_3)_2 \rightarrow Ca^{2+} + Mg^{2+} + 2\ CO_3^{2-}$	1.07×10^{-17}
Magnesite	$MgCO_3 \rightarrow Mg^{2+} + CO_3^{2-}$	6.87×10^{-9}
Fluorite	$CaF_2 \rightarrow Ca^{2+} + 2F^{-}$	$1\times10^{-10.4}$

3.7.3 Durov Classification of Groundwater :

The Durov classification of groundwater is applied using AQUACHEM program Ver. 3.7 in order to display the possible geochemical process to determine the water genesis *(Lloyd and Heathcoat, 1985)*. In general, Durov is similar to piper diagram in that analyses are plotted on separated anion and cation triangle. The Durov diagram is based on the percentage of each major ion (meq/L) to the total cations and anions which represented 100% (meq/L). The result is a square plot divided into nine areas, each characteristic of different water type (Figure 3.17).

Lloyd and Heathcoat (1985) summary the interpretation of each square field in the Durov diagram as the following:

Field 1: HCO_3^- and Ca^{2+} dominant frequently indicates recharging waters in limestone, sandstone, and many other aquifers.

Field 2: This water type is dominant by Ca^{2+} and HCO_3^- ions. Association with dolomite is presumed if Mg^{2+} is significant. However, in those samples in which Na^+ is dominant under certain circumstance.

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 circumstance.

Field 4: SO_4^{2-} dominant or anion discriminant and Ca^{2+} dominant, Ca^{2+} and SO_4^{2-} dominant, frequently indicates a recharge water is lava and gypsiferous deposits; alternatively, a mixed water or water exhibiting simple dissolution may be indicated.

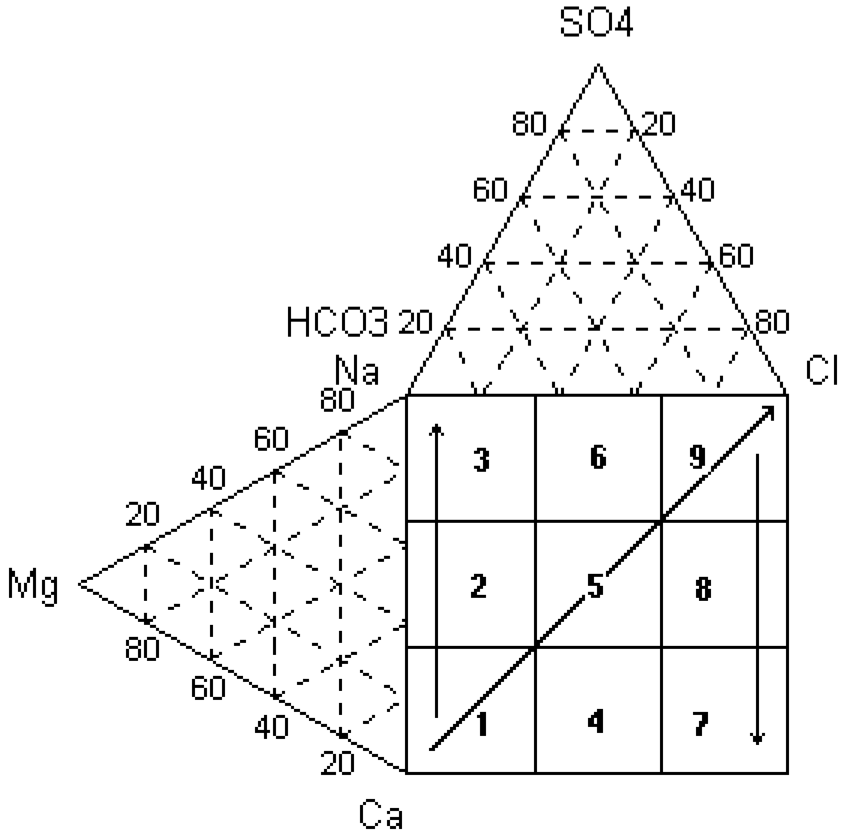
Field 5: No dominant anion or cation indicates water exhibiting simple dissolution or mixing.

Field 6: SO_4^{2-} dominant or anion discriminant and Na^+ dominant is a water type not frequently encountered and indicates probable mixing influences.

Field 7: Cl^- and Na^+ dominant cation is frequently encountered unless cement pollution is present. Alternatively, the water may result from reverse ion exchange of Na-Cl water.

Field 8: Cl^- dominant anion and Na^+ dominant cation indicate that the groundwater may be related to reverse ion exchange of Na-Cl waters.

Field 9: Cl^- and Na^+ dominant frequently indicate end-point water.



Classification of hydrogeochemical processes as Lloyd and Heathcoat (1985):

Upper line (1-3): ion exchange.
Diagonal line (1-9): dissolution or mixing.
Lower line (9-7): reverse ion exchange.

Figure 3.17: Durov diagram showing the expected hydrogeochemical processes.

3.7.4 Interpretation of Water Genesis :

The sampled groundwater genesis is identified based on the amount and the type of dissolved minerals, the values of saturation indices, and the plots of Durov diagram.

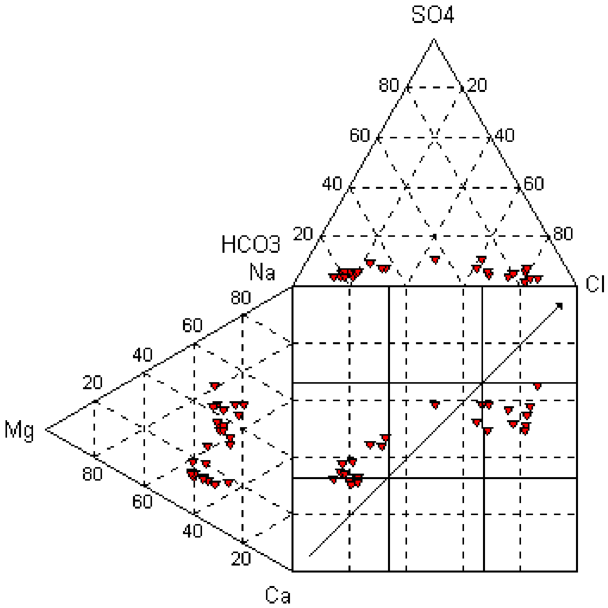


Figure 3.18: Durov diagram for the samples collected in summer.

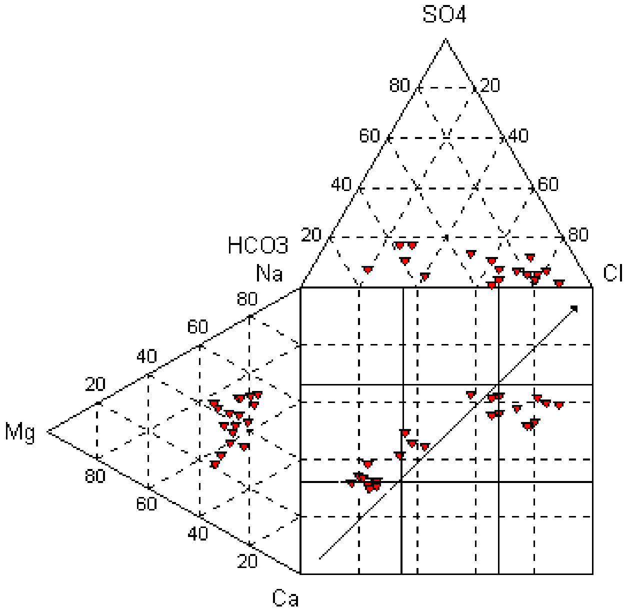


Figure 3.19: Durov diagram for the samples collected in winter

In general, the water of the study area is unsaturated with respect to anhydrate and gypsum, 80% of the samples are saturated with respect to dolomite, and calcite (Tables 3.24, 3.25 and 3.26).
The majority of study waters plot in field (2) and field (8) on Durov diagram along the mixing-dissolution line. Based on Durov diagram (Fig. 3.18, and 3.19), no variation in water characteristic between summer and winter in Ein Samia groundwater wells, while many groundwater wells of Auja, and Jiftlic are exposed to simple dissolution or mixing in winter rather than summer. To simplify the study, the water genesis is discussed in groups according to similar characteristic for each study area:

3.7.4.1 Ein Samia Group :

The majority groundwater wells of this group show the concentration of earth alkalis (Ca^{2+}, Mg^{2+}) over alkalis (Na^{+}, K^{+}). By comparing the ratio of Ca^{2+}/Mg^{2+} in the sampled groundwater well (1.1 to 1.75) with the natural ratio in limestone and dolomite aquifers (1.11-2.0) *(as Schoeller, 1956; Hsu, 1963; and Rosenthal 1987)*, the water chemistry is typical of carbonate weathering, where dolomite and calcite are the main dominant dissolved minerals.

The Na/Cl ratio of Ein Samia groundwaters (0.88 to 0.98) are within the ratio of precipitation (0.86-1) (*Hsu, 1963)*. This ratio is an indicator that precipitation is the main source of Ein Samia groundwater wells without occurrence of significant mixing with waste water or deep saline water.

Based on the saturation indices in Table 3.24; all the deep groundwater wells are under saturated with respect to the dissolved minerals of calcite, aragonite, dolomite, gypsum, anhydrate, and fluorite, while the shallow groundwater well 18-15/001 (ESW1) is over saturation with respect to calcite, dolomite, and aragonite minerals.

Table 3.24: The average saturation indices Ein Samia groundwater wells (2003/2004).

WELL-ID	**Well depth (m)**	**Calcite ($CaCO_3$)**	**Aragonite ($CaCO_3$)**	**Dolomite ($CaMg(CO_3)_2$)**	**Gypsum ($CaSO_4.2H_2O$)**	**Anhydrite ($CaSO_4$)**	**Fluorite CaF_2**
ESW1	60.3	0.30	0.16	0.56	-2.50	-2.73	-2.76
ESW2a	252	-0.01	-0.14	-0.04	-2.51	-2.74	-2.90
ESW4	172	-0.07	-0.22	-0.10	-2.59	-2.80	-2.89
ESW5	526	-0.20	-0.35	-0.35	-2.75	-2.98	
ESW6	616	-0.01	-0.14	-0.09	-2.56	-2.79	-3.03

Based on Durov diagram (Fig. 3.20), all groundwater types are on the edge line of field 1 and field 2 where Ca-Mg-HCO_3 are dominant ions as a result of simple dissolution of dolomite and limestone rocks. Despite the difference in aquifers type, all water samples of Ein Samia area are resembled in their chemical characteristics between summer and winter, and in there water type. The low variation in chemical parameters is a sign of that the Albian-Cenomanian aquifers of Ein Samia feed water from common recharge areas and/or evidence on the existence of interconnection between the Cenomanian aquifers due to the presence of Ein Samia major faults.

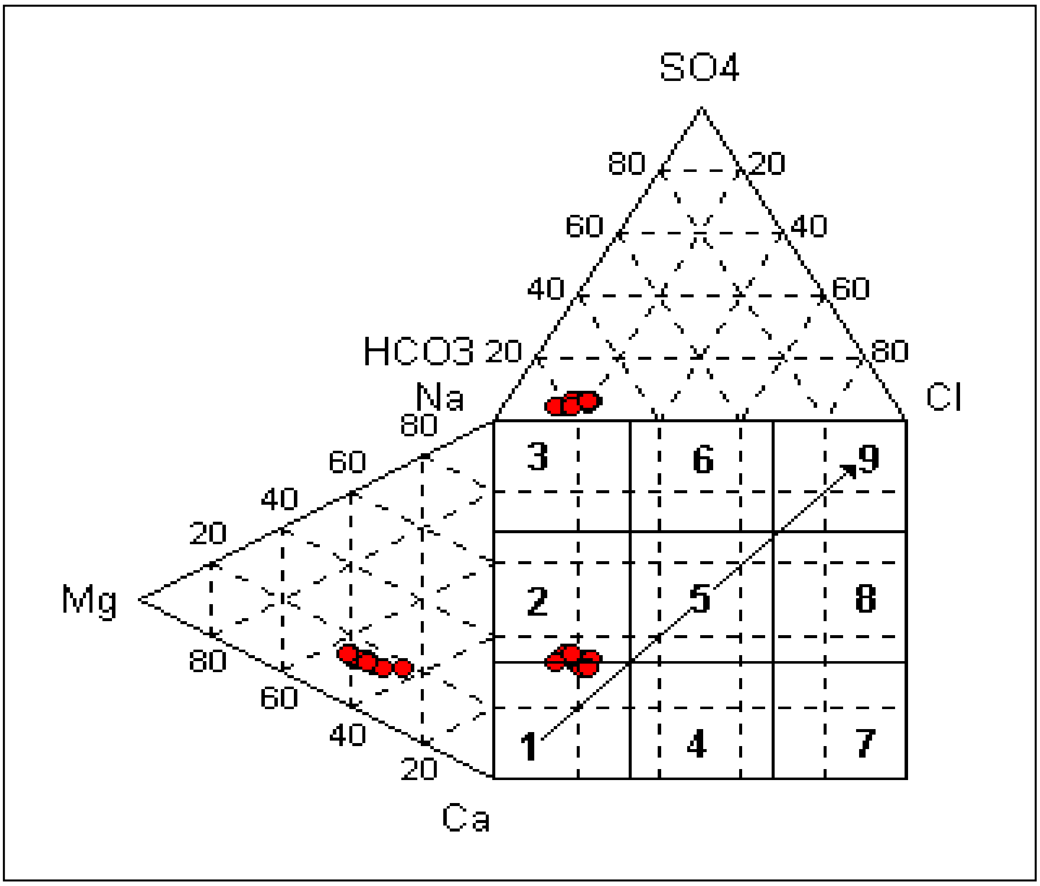


Figure 3.20: Durov diagram showing the hydrogeochemical processes in Ein Samia aquifers.

3.7.4.2 Al Auja Group :

In this group, the highest water salinity is represented in the groundwater well 19-14/001 that locate within the Pleistocene aquifer. Despite the ratios of Cl^-/Σ anions (~0.28), HCO_3^-/Σ anions (~0.41), and Na/Cl (~1) indicate to carbonate weathering, and halite mineral dissolution; the low ratio of Ca^{2+}/Mg^{2+} (~0.6) in the groundwater well 19-14/001 relative to the normal ratio in carbonate aquifer *(Hem, 1992),* and the high ratio of Na^+/Ca^{2+} (~5.8) point toward the following process:

- Decreases in calcium concentration as a result of calcium precipitation on the form of calcite where the saturation indices of calcite is oversaturation.
- Natural softening process due to simple rate of calcium and magnesium ion exchange with sodium and potassium (Ca^{2+} + 2Na-Clay ----- $2Na^+$+ Ca-Clay) *(Hounslow, 1995).*

Based on the saturation indices (Table 3.25), the surface/ground waters of Al Auja are under saturated with respect to the dissolved minerals of anhydrite, gypsum, and fluorite, and over saturation with respect to calcite and dolomite due to far recharging water along recharge area of carbonate rocks of Ein Samia Wadi.

Table 3.25: The average saturation indices of Al Auja surface and subsurface water (2003/2004).

WELL-ID	Calcite ($CaCO_3$)	Aragonite ($CaCO_3$)	Dolomite ($CaMg(CO_3)_2$)	Gypsum ($CaSO_4.2H_2O$)	Anhydrite ($CaSO_4$)	Fluorite CaF_2
19-14/001	0.08	-0.08	0.05	-1.43	-1.66	-2.06
19-15/005	0.20	0.06	0.35	-1.79	-2.02	-3.54
19-15/011	0.19	0.05	0.31	-1.62	-1.85	
19-15/012	0.09	-0.05	0.1	-1.98	-2.21	-2.15
AR/020	0.41	0.27	0.83	-2.52	-2.75	-2.63

The Durov diagram (Figure 3.21) illustrates that Al-Auja spring (AR/020) plots in the square field 2 where its water type is dominant with Ca-Mg-HCO_3. This type presumes simple dissolution of dolomitic limestone bedrock that is located near the top hills at the west (Wadi Al Auja). The karst development implication may occur as a result of carbonate dissolution.

Durov diagram (Figure 3.21) shows that, the sampled groundwater well of 19-14/001 in summer 2003 plots on the edge Field (6). In winter 2004 it shifted toward the dissolution or mixing line (cross circle). The simple increasing in water salinity in winter is explained due to simple mixing of water recharge with wastewater or agricultural returned flow mainly at the surface zone (Figure 3.22). The main source of high availability of SO_4^{2-} is from gypsum dissolution in the Lisan formation and from anthropogenic mixing.. This water type (dominant with SO_4^{2-}, and discriminates with Na^+) is not frequently in Al Auja but encountered east of the study area due to the presence of evaporite and saline soil. High concentration of nitrate, potassium and sulfate are often from agricultural activity in the area or from water mixing with agriculture returned flow.

The transition of 19-14/001 toward the dissolution line is rather than the other groundwater wells that located to the west (i.e. 19-15/005, 19/15/011, and 19-15/012), and the spring water AR/020 because the spring water is much closed to the recharge area relative to the groundwells. This result indicating that water recharge in Al Auja area is from the western mountains toward the eastern decline (Figure 3.21).

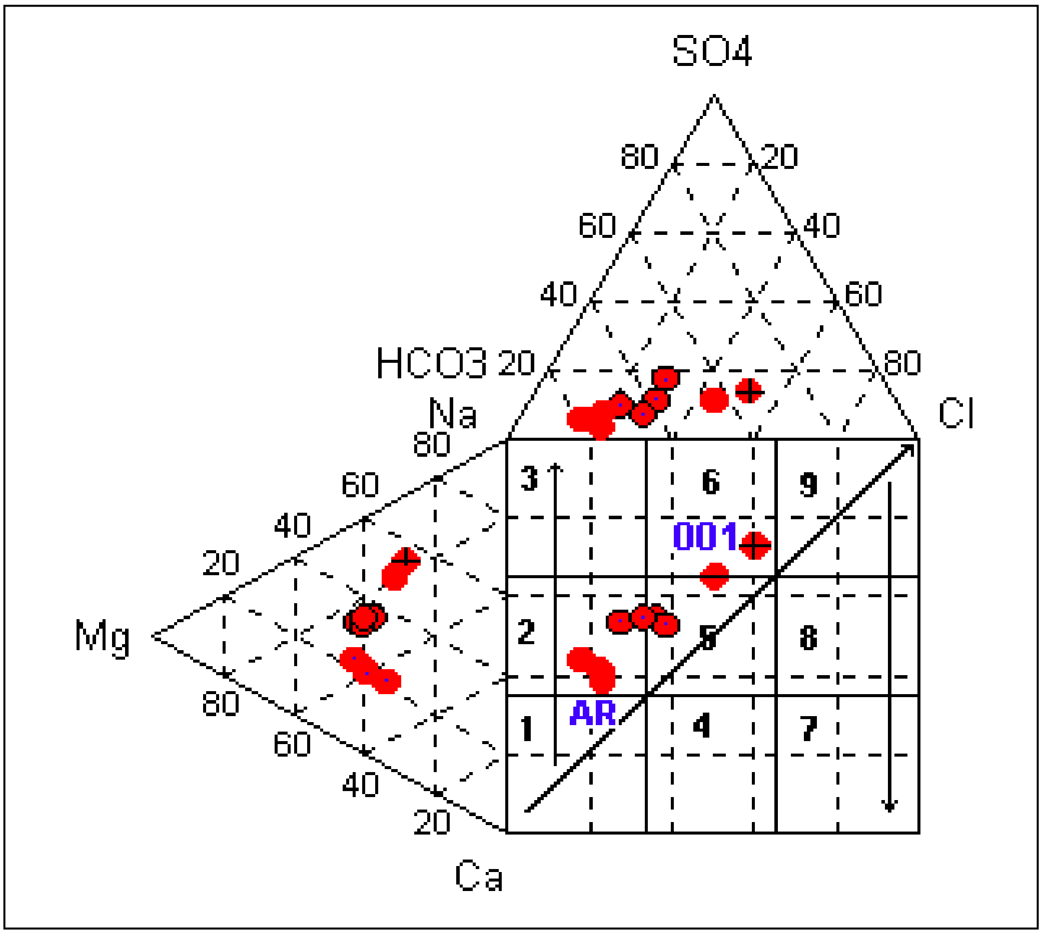
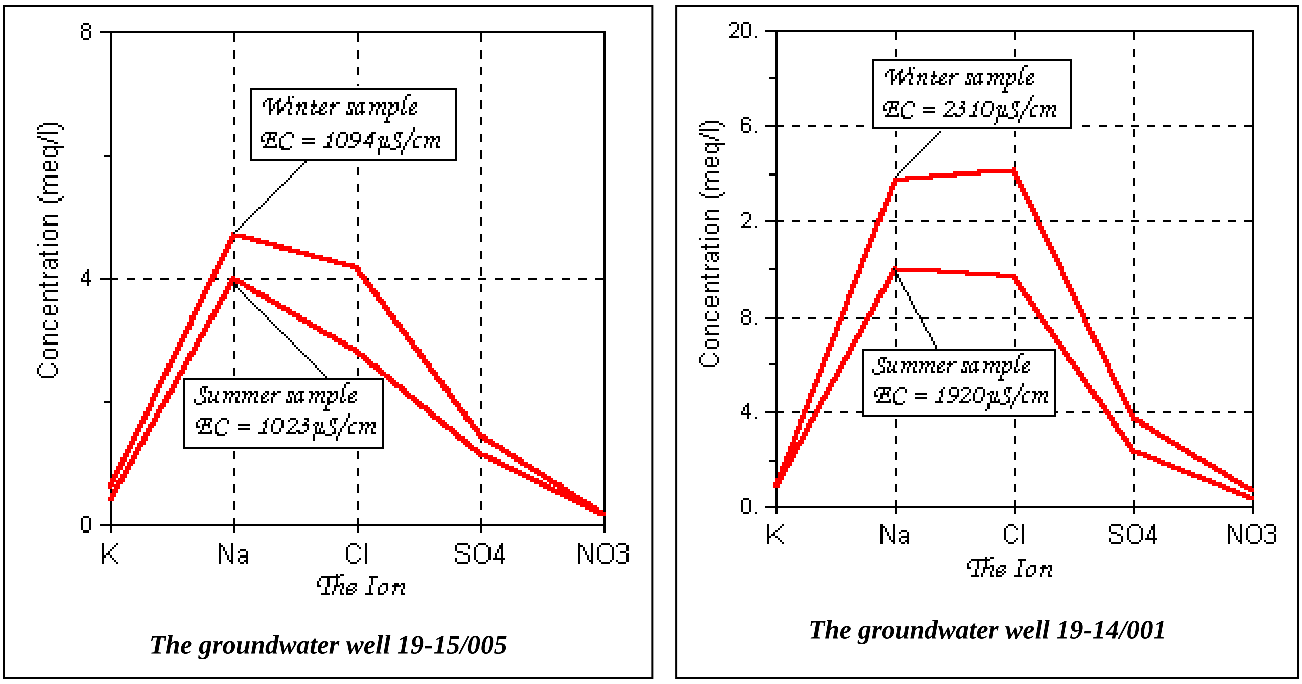


Figure 3.21: plot of the wells studied in Al Auja district in Durov diagram.



The groundwater well 19-15/005

The groundwater well 19-14/001

Figure 3.22: Schoeller diagram plot for samples collected in winter and summer from Al Auja.

3.7.4.3 Al Jiftlic Group :

The groundwells of Al Jiftlic are divided into the following groups:

❑ **First Group**

The groundwells 19-16/008 and 19-17/034 that located northwest of Al Jiftlic area are characterize by lower salinity and lower ratios of Na/Ca relative to the other groundwells of the second & third group. The ratio of Na/Cl (0.81- 1.1) in those groundwells are found to be within the precipitation ratio. These ratios indicate to low evaporites dissolution due to shorter distance of water recharge. This result agrees with Durov diagram (Fig 3.23) where these groundwater wells plot between the fields 2 & field 5 along the dissolution and mixing line (low dissolution relative to other groundwater wells).

In general, the waters of the first group wells are under saturated with respect to anhydrite, gypsum and fluorite while over saturated with respect to dolomite and calcite (Table 3.26).

This water type is dominated by Ca^{2+}, Mg^{2+}, and HCO_3^- ions. This water chemistry is typical of dolomitic limestone bedrock's where Ca/Mg ratio is within 1.24 -1.98. The over saturation of calcite and dolomite minerals take place as a result of limestone-dolomite weathering during water recharge from Al Far'a area.

❑ **The Second /Third Group :**

The groundwaters of this group are characterized by higher dissolution of minerals than the first group. These groundwaters are over saturated with respect to dolomite, and under saturated with respect to gypsum, anhydrate, and fluorite (Table 3.26).

The majority groundwater wells of electrical conductivity more than 2500 µS/cm characterize by low ratios of Ca^{2+}/Mg^{2+} (~ 0.88) relative to the natural range in the carbonate aquifer as *Hsu (1963)*. Beside that those groundwater wells are have low ratios of $(Ca^{2+} + Mg^{2+})/(Na^+ + K^+)$ (0.43-0.83) and high ratios of Na^+/Ca^{2+} (2.18-5.5). All these ratios are indicators of calcium precipitation (dedolomitization) and/or the natural process of ionic exchange in the aquifers or during long distance of water contact with clays.

The low values of HCO_3^-/Cl^- (0.12-0.52) is significant ratio of high salinity water. The lower ratios of Cl^-/Σ anions (0.35-0.53) and Na^+/Cl^- (0.45-.83) than the hydrological cycle of precipitation indicate the main sources of salinity in Al Jiftlic groundwater wells are from:

- Halite rock dissolution during Lisan-Alluvium formations.
- Mixing with agricultural and wastewater during water recharge along Wadi Al Far'a.
- And possible mixing with deep brine water.

Based on Durov diagram, the majority groundwaters of the second group plot between field 5 & 8 (Figure 3.23), while all groundwaters of the third group plot on field 8 (19-17/008, 19-16/005, 19-17/028, 19-16/001) where Na^+ is the main dominant cations and Cl^- is the most dominant anion (Figure 3.23). This mean that the waters of the third group which are located to the SE of the second and the first group waters exhibit more dissolution or mixing than the second and the first group. Here we can get a conclusion that the main water recharge in Al Jiftlic area is forward SE. In winter these groundwater wells show simple shift toward the dissolution or mixing line relative to summer (no water dilution in winter, (Figure 3.24).

Table 3.26: The saturation indices average for each well of Al Jiftlic study area (2003/2004).

Group	**WELL-ID**	**Calcite ($CaCO_3$)**	**Aragonite ($CaCO_3$)**	**Dolomite ($CaMg(CO_3)_2$)**	**Gypsum ($CaSO_4.2H_2O$)**	**Anhydrite ($CaSO_4$)**	**Fluorite CaF_2**
(1)	19-17/034	0.14	0.00	0.28	-1.94	-2.18	-1.74
	19-16/008	0.39	0.24	0.56	-2.19	-2.42	
(2)	19-17/056	0.02	-0.12	0.16	-1.69	-1.90	-3.76
	19-17/027	0.14	0.00	0.52	-2.11	-2.33	-2.76
	19-17/046	0.08	-0.07	0.21	-1.52	-1.74	-2.83
	19-17/007	0.19	0.05	0.57	-1.84	-2.07	-2.90
	19-17/001	0.03	-0.11	0.03	-1.96	-2.19	
	19-17/054	-0.08	-0.22	0.22	-1.89	-2.11	
	19-17/021	-0.08	-0.23	0.04	-1.89	-2.11	-1.51
(3)	19-17/008	-0.24	0.38	-0.15	-1.50	-1.72	-2.62
	19-16/005	0.36	0.22	1.00	-1.07	-1.28	
	19-17/028	-0.01	-0.15	0.31	-1.76	-1.98	-3.04
	19-16/001	0.23	0.08	0.53	-1.36	-1.59	-3.10

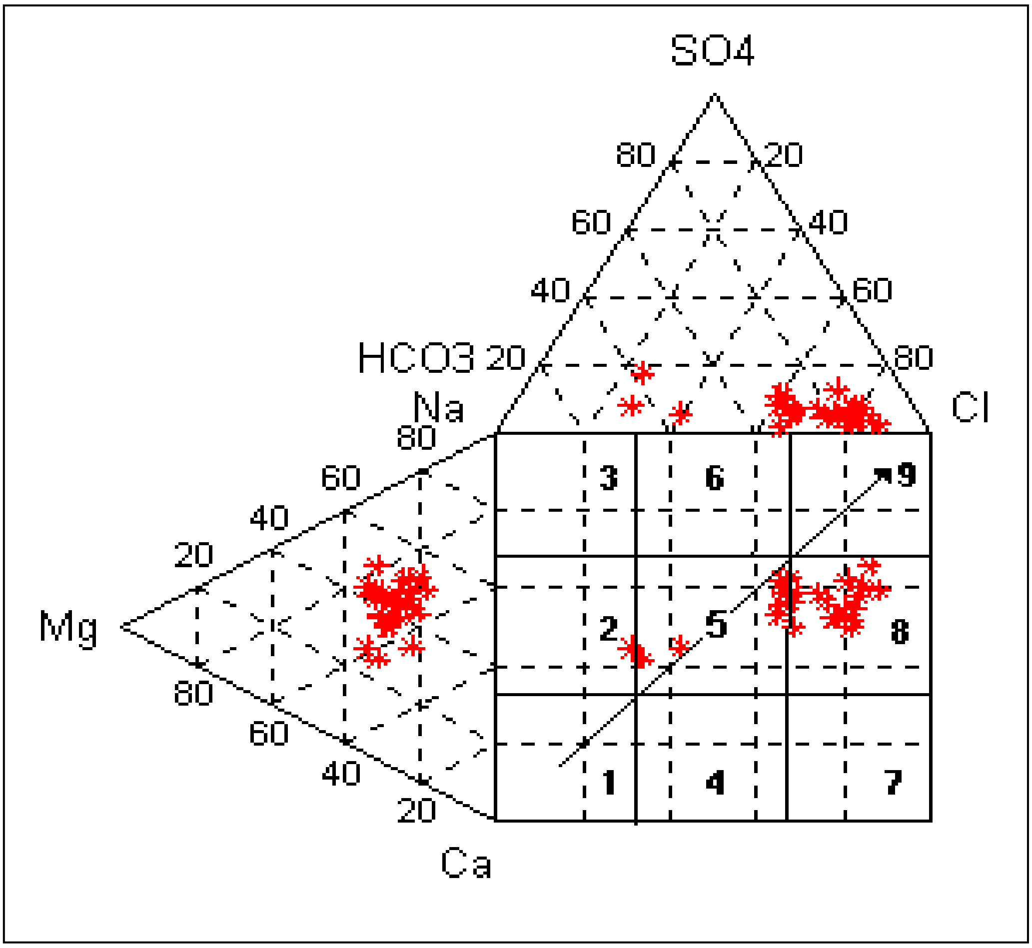
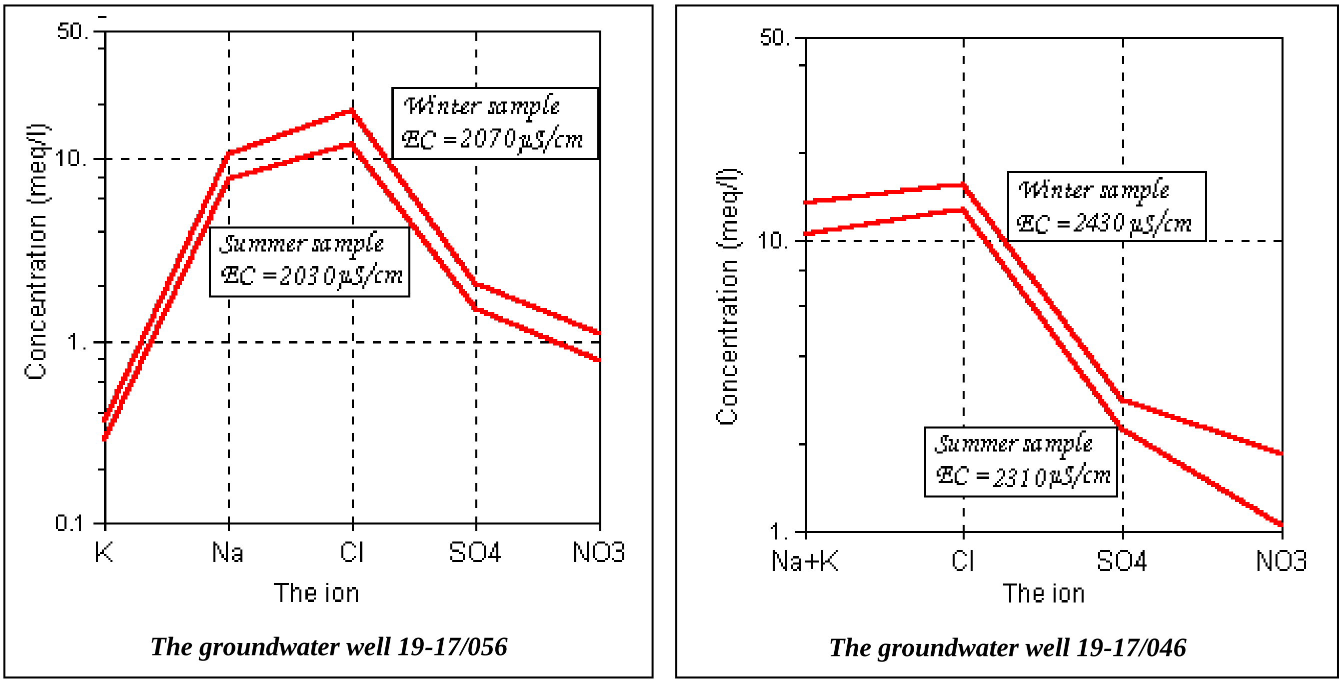


Figure 3.23: Durov diagram showing the hydrogeochemical processes at al Jiftlic aquifers.



The groundwater well 19-17/056

The groundwater well 19-17/046

Figure 3.24: Schoeller diagram plot for samples collected in winter and summer from Al Jiftlic.

3.8 ENVIRONMENTAL ISOTOPES COMPOSITION

3.8.1 Introduction:

Isotopes are nuclides with the same atomic number (proton number) but with different mass number (numbers of neutrons). Naturally, water contains about 25 stable nuclides and 1675 unstable (radioactive) isotopes commonly referred to as environmental isotopes *(Walker et al., 1989)*. Unstable isotopes have always nuclides in which the atomic number is greater than 82 (radioactive) and decay spontaneously due to spontaneous emission of nuclear particles until they achieve a stable nuclear configuration. Globally distribution of isotopes is produced from anthropogenic sources, such as aboveground nuclear detonation testing and emissions from nuclear reactors.

The uses of environmental isotopes are a modern scientific hydrogeologic application. It is set as a powerful natural tracer of the most hydraulic processes; moreover these isotopes behave as carriers that can describe physiochemical changes. Usually, an isotopic technique is used to achieve multiple purposes summarized in the following points *(Sidle, 1997)*:

- Estimation of residence times of water and the subsequent histories.
- Identification of groundwater well s origin.
- Conservative tracers of groundwater flow-paths.
- Estimation of flow rates.
- Identification of aquifer recharges areas.
- Estimation of solute exchange among phases in system.
- Determination of extent of chemical reactions in subsurface.
- Calibration of flow models

In case of the low atomic number or ‘light’ isotopes, fractionation may occur during evaporation of water from the ocean and open water surfaces. The processes of evaporation, condensation and rain formation are responsible for enrichment or depletion *(Clark and Fritz 1997)*. The degree of enrichment depends on climatic conditions including mean annual temperature, relative humidity, precipitation, and evaporation rates.

The main isotope composition that is used in the study analysis was oxygen-18 (^{18}O), hydrogen isotopes as deuterium (^{2}H), and tritium (^{3}H). These isotopes are ideal tracers of water sources and movement because they are constituents of water molecules and can not dissolve in water like other tracers of ‘water’ such as Cl^-, or dyes so its still widely used as a tracer.

3.8.2 Sampling and Analysis:

Isotope analysis of oxygen-18 and deuterium together with tritium was carried out by Umwelt Foerschung Zentrum (UFZ) institution in Leipzig in Germany on the light of scientific cooperation with Al Quds University. Nine water samples were collected from both shallow and deep groundwater wells which located in the Alluvium (Al Auja, and Al Jiftlic area), and Cenomanian aquifers (Ein Samia area), in addition to one sample of spring water (Wadi Al Auja). All samples were collected in the period extended from July 2003 to October 2004. One groundwater well was sampled twice; once in summer and once in winter (July/2003, January/2004). Each sample was collected in 50 ml polyethylene bottle for ^{18}O and ^{2}H, and in 500 ml bottle for ^{3}H analyses.

The isotopes composition (^{18}O and ^{2}H) were determined by using gas source mass spectrometry with detection error of ±0.2 ‰ for ^{2}H and ^{18}O, while ^{3}H was determined by using electrolytic enrichment with a detection error range between ± 0.3-0.5 TU. The detection error for each isotope content is added to or subtracted from the item value.

Stable isotope ratios are reported relative to the Standard Mean Ocean Water (SMOW) as deviation (δ) values expressed as the following equations in units of parts per thousand per mil and written as "‰".

$$\delta\, ^{18}O = [\, ((^{18}O/^{16}O)\text{sample} / (\, ^{18}O/^{16}O)_{\text{SMOW}}\,) - 1] *1000$$

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

Tritium concentration in water is expressed as absolute concentrations, using tritium units (TU). The TU represents- the ratio of ^{3}H atoms to ^{1}H atoms, where $^{3}H/^{1}H = 10^{-18}$ is defined as 1 tritium unit (1TU) *(Mazor, 1991).*

3.8.3 Deuterium-Oxygen18 Relationship:

The isotopic composition of the sampled groundwater well is plotted on $\delta\, ^{18}O$-$\delta\, ^{2}H$ diagram (Fig 3.25) which shows the standard relationship between $\delta^{18}O$ and $\delta^{2}H$ weighted mean values of the global scale which is sampled from many rivers, lakes and precipitation from various countries. The plotted line that correlates $\delta^{18}O$ on the X axis against $\delta\, ^{2}H$ on the Y axis is called the meteoric isotope line. The best-fit of the "global" meteoric line is expressed as:

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

The meteoric line facilitates knowing groundwater well origin and tracing its recharge movements. But due to different climates (as precipitation, evaporation, melting, and condensation), and geographic factors in different areas, the best-fit line in the West Bank represents the Mediterranean or the Middle East Meteoric Line (MMWL) which given by the relation:

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

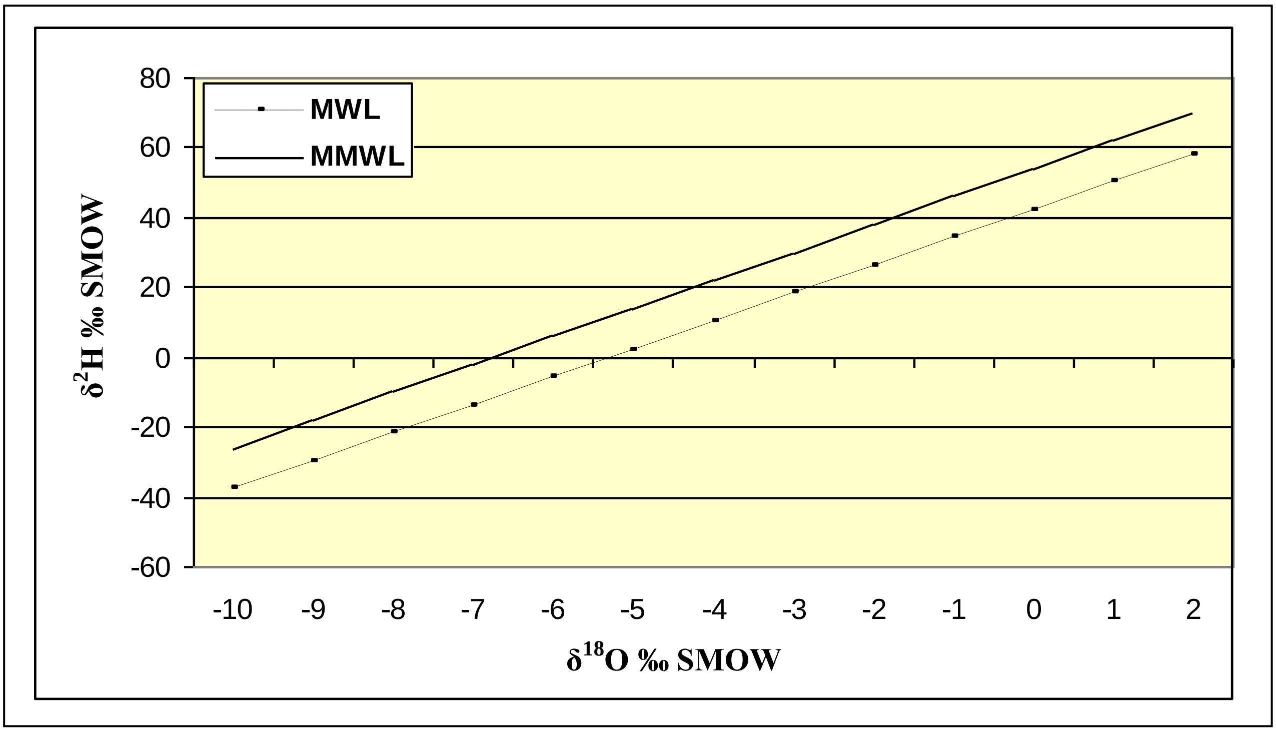


Figure 3.25: The plot graph of ^{2}H against ^{18}O isotope of precipitation and surface water in the Eastern Mediterranean region compared to the global meteoric line.

The term which shows the lower or higher approach of intercept between δ^{2}H and δ^{18}O is expressed by deuterium excess (d-excess) *(Clark and Fritz, 1997)*. The equation which measures the enrichment of deuterium is given by:

$$\text{D-excess} = \delta^{2}\text{H} - 8\,\delta\,^{18}\text{O} \text{ (Craig, 1961).}$$

The deuterium excess value depends on several factors such as altitude, distance from the coast and storm trajectory paths *(Mazor, 1991)*. D-excess is estimated by *Craig (1961)* for global meteoric waters, it always show significantly values higher than 10‰. However, the highest deuterium excess values (d>19‰) are found for those stations that have higher altitudes.

Here, d- excess is classified into three cases:

1. High d-excess values (i.e. d-excess ~22) may be attributed to the effect of isotopic exchange with the moisture originating from the Mediterranean Sea. This moisture is generally characterized by low relative humidity conditions or rapid primary evaporation (natural evaporation after precipitation) of isotope composition before or during there infiltration *(Nir 1967; Dincer and Payne 1971; Yurtesever and Gat 1981).*

2. Low d-excess (positive values) indicates samples are located closely to meteoric line, which suggests groundwater derived from direct infiltration of the local precipitation.

3. Low d-excess (negative values) suggests secondary evaporation during rainfall in hot or dry air *(Clark and Fritz 1997 and Clark 2002).*

3.8.4 The ^{2}H and ^{18}O Composition of Precipitation:

The isotope composition of rainwater is a result of interaction between humid marine air mass and dry continental air mass *(Gat and Carmi 1970).* Some modification of precipitation composition may occur before it infiltrates into the aquifer due to secondary processes, such as isotope exchange with aquifer rocks or fractional evaporation prior infiltration. Stable isotope composition of rainfall within the study area is enriched in heavy stable isotope in both δ^{18}O and δ^{2}H. The range of the isotopic composition during the whole rainy season (2001-2003) varies from -6.42 to 0.41‰ for δ^{18}O and -29.7 to -25.9 ‰ for $\delta\ ^{2}$H with d-excess within 17.7 to 22.62 ‰. These variations in rainfall isotopic concentration may relate to the amount of event rainfall and evaporation process.

3.8.5 Water Isotope Hydrology:

Natural water molecules have nine different isotopic configurations, its return to the fact that oxygen has three stable isotopes and hydrogen has two stable isotopes. Different water molecule composition has different characteristic for example, the light isotopic species of water ${}^{1}H_{2}{}^{16}O$ has a higher vapor pressure than the heavy species ${}^{1}H_{2}{}^{18}O$ or ${}^{1}H^{2}H^{18}O$ which are fractionated preferentially during evaporation *(Sidle, 1997).*

It is common to refer for the heavy isotopic species of water being enriched, having a positive δ value relative to the international standard. The degree of enrichment depends on climatic conditions, including mean annual temperature, relative humidity, precipitation, and evaporation rates *(Mazor, 1991; Sidle, 1997).*

3.8.6 ^{18}O and ^{2}H Interpretation of the Study Area:

The isotopic results accurately ^{18}O and ^{2}H in the sampled water that were collected from the study area in July/2003 and January/2004 are illustrated in Table 3.27 and the relation between δ^{18}O and δ^{2}H of those samples are plotted on Figure 3.26.

The stable isotopes composition of the sampled groundwater wells show relatively lower values than MMWL varying from $^{-}$4.9 to $^{-}$6.0‰ with an average of (–5.5 ± 0.0008) ‰ for δ^{18}O and from -21.8 to -26.7 ‰ with an average of (-3.96 ± 0.037) ‰ for δ^{2}H. Based on these results the groundwater well s are enriched in ^{18}O, and ^{2}H and represent recent water recharge where D-Excess of the meteoric water line is over 18 *(Craig, 1961).* Based on the data in Table 3.27, the isotopic composition (δ^{18}O) of the sampled ground water of the study areas are arranged as:

"D-Excess of Ein Samia groundwells > Al Auja > Al Jiftlic"

Accordingly, the groundwater wells of Ein Samia and Al Auja feed water from higher watershed than Al Jiftlic groundwater wells. The steadiness in δ^{18}O values through the first and the second sampling in the groundwater well 19-14/001 (2003/2004) is an indicator of similar climatic regime through the few previous years.

Table 3.27: The ^{18}O and ^{2}H composition of the samples collected from the eastern drainage basin (2003/2004).

Well code	Location	Date	EC	$\delta\ ^{18}O$	$\delta\ ^{2}H$	D-excess
18-15/001	'Ein Samia	28/07/03	475	-6	-26.3	21.74
18-15/005	'Ein Samia	28/07/03	507	-5.77	-25.9	20.25
18-15/006	'Ein Samia	28/07/03	468	-5.74	-25.3	20.63
19-15/005	Al 'Auja	04/08/03	1094	-5.57	-24.3	20.31
19-14/001	Al 'Auja	11/01/04	1920	-5.34	-23.4	19.29
19-14/001	Al 'Auja	4/08/03	2310	-5.3	-22.8	19.61
19-17/027	Al jiftlic	04/08/03	2090	-5.08	-21.8	18.91
19-17/007	Al jiftlic	04/08/03	2630	-4.9	-20.9	18.31
Spring AR/020	Al-Auja	28/07/03	727	-5.82	-25	21.56

Ein Samia groundwater well (19-15/001) and the surface spring water AR/020 are located at the MMWL (Figure 3.26) which suggested both waters are recharged from the local precipitation without significant mixing that sign the shallow aquifers. Majority of the sampled water of Al Auja and Al Jiftlic groundwells contain $\delta^{2}H$ lie below Mediterranean metioric line and over the global meteoric line (Figure 3.26). The higher values of isotopic composition ($\delta^{18}O$, and $\delta^{2}H$) of Al Jiftlic groundwater wells (lower D-Excess) is appoint to that those water are older than Ein Samia groundwater wells.

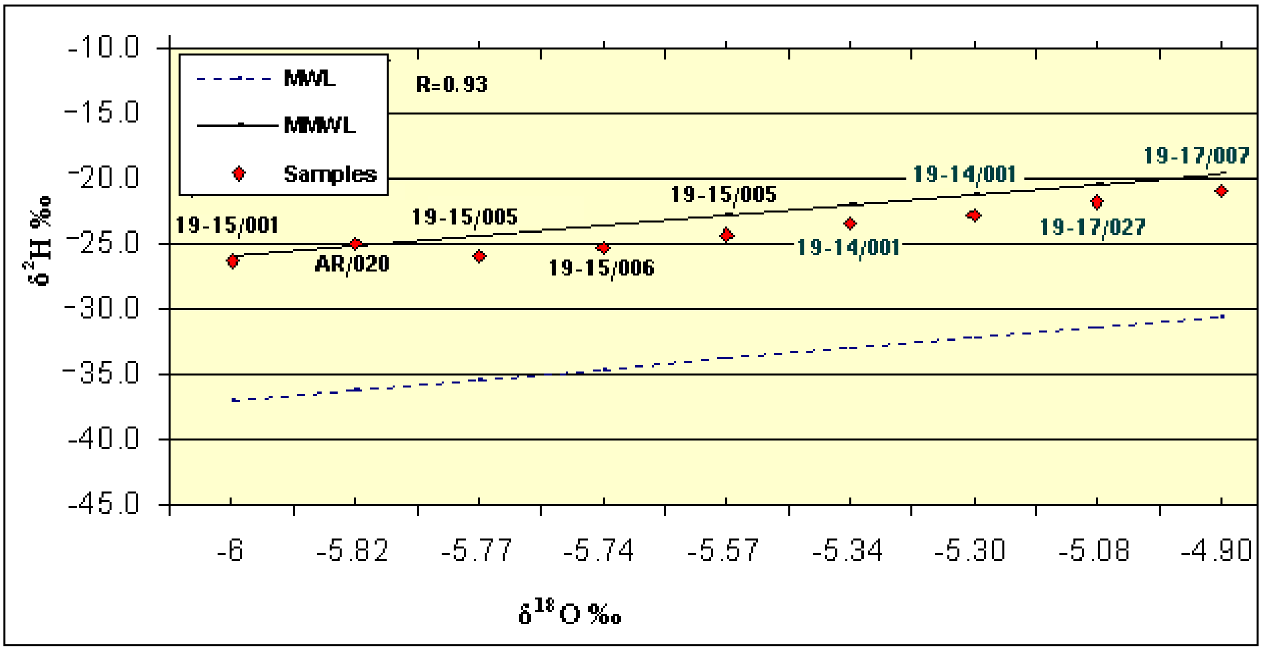


Figure 3.26: The relation of $\delta^{2}H$ versus $\delta^{18}O$ of the samples, which were collected from shallow/deep groundwells, and surface water of the eastern basin compared to MWL and MMWL.

The study found direct relation between water salinity (EC), and isotopic composition ($\delta^{18}O$ & $\delta^{2}H$) for the different areas. For example the groundwater well 19-17/007 contains higher EC and higher $\delta^{18}O$ relative to the groundwells due to long distance of chemical reaction of recharging water with carbonate rocks interbedded with salts (marine salts) represented by dissolved calcium and magnesium salts in water [$MgCl_2$, $CaCl_2$, $MgSO_4$, $CaSO_4$] , the statistical process in chapter 3, section 9 represents strong correlations between those parameters.

The water samples points on the conventional $\delta^{18}O$-$\delta^{2}H$ diagram (Figure 3.27). The relationship between those variables was found to fit the following equation:

$$\delta^{2}H = 5.48\ \delta^{18}O + 6$$

The slope 5.48 of the line that represented between $\delta^{18}O$ & $\delta^{2}H$ indicates to a direct condensation from atmospheric moisture *(Gat and Issar, 1974)*. The strong correlation between $\delta^{18}O$ and $\delta^{2}H$ is due to natural fractionation of water molecule through evaporation during winter precipitation.

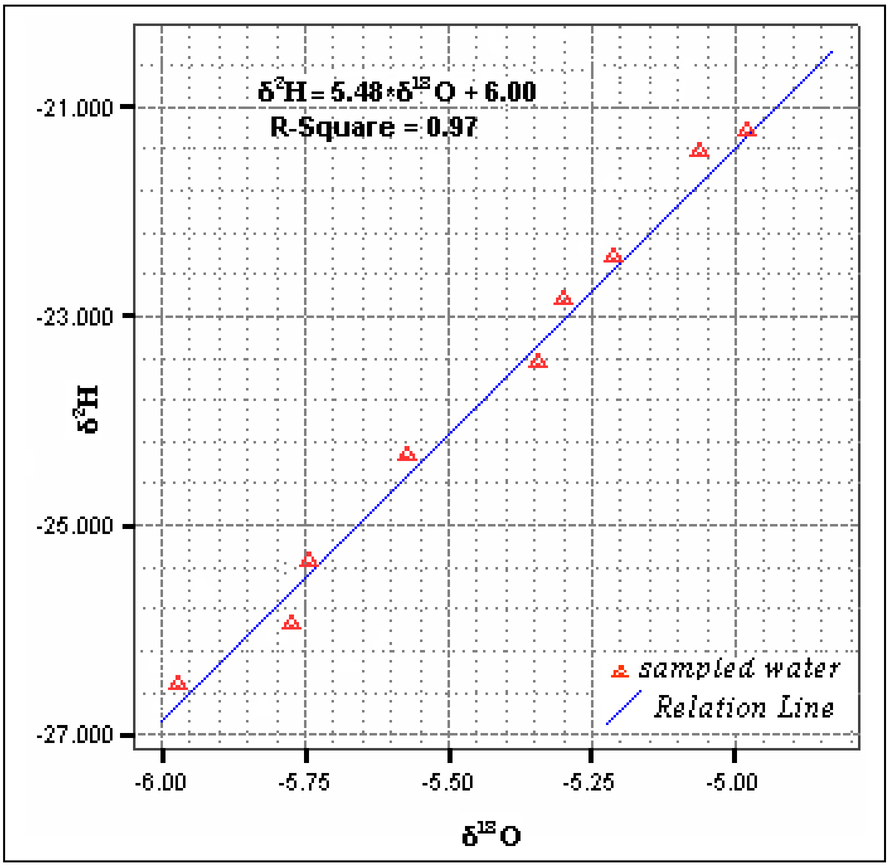


Figure 3.27: The evaporation line represents the relation between $\delta^{18}O$ and $\delta^{2}H$ of the sampled water.

3.8.7 Ground Water Dating:

Tritium is the most used isotope tracers for dating groundwater well, quantifies mixing, and providing information about the flow rates of the homogeneous aquifers. The age of the sampled groundwater well is the length of time when sample was isolated from the atmosphere and travailing through distance by recharging until being discharged from the well pumpage for testing. Tritium method alone can’t give accurate date for groundwater well due to complicated mixing processes between aquifers, and spatial and temporal variation in the fallout concentration *(Davisson et al. 1998)* but it can set as identifier for event marker.

For example, tritium in precipitation and groundwaters had continuously increased during the period of atmospheric nuclear testing (1952–1963) *(Daniels et al. 1991)* from 5 TU in 1952 *(Kaufman and Libby, 1954)* until reach maximum of 803 TU in 1963. After 1963 tritium concentration decreased due to limitation in the surface nuclear explosion activities.

According to piston flow or well-mixed reservoir end member models (mainly in a confined groundwater wells), low tritium concentration is available at deep layers indicate to the oldest water age while higher tritium concentration is available at the upper layer as assign of recent water recharge *(Davisson et al. 1998).*

3.8.8 Tritium Interpretation:

Here, the water age is estimated by comparing the available ^{3}H concentration in the sampled water with the expected remaining ^{3}H-concentration after the initial decay through precipitation (Appendices 3.8). For example if the remained tritium in the sampled groundwater well in 2004 is more than 0.24 and less than 2.35 TU then the water date is expected back to the late of 1950 to 1960.

3.8.8.1 Ein Samia Area:

Table 3.28 illustrate that the sampled groundwater of Ein Samia wells (2003/2004) containing tritium concentration within 0.4 – 5.4 TU referring that water dating is return to the recent years (after 1950). The tritium concentrations of the sampled groundwater wells of Ein Samia in 13/10/2004 are found to contain 5.4 TU in 19-15/001 (60m depth), 3.3 TU in 19-15/006 (172m depth), 2.8 TU in 19-15/002a (252m depth), and 0.4 TU in 18-15/004 (616m depth).

According to the tritium concentration (Table 3.28); the deeper groundwater of Ein Samia wells contains older water than the groundwater wells of less water thickness. Depending on that the groundwater ages of the Ein Samia wells can be arranged as the following sequence:

[The groundwater age of 18-15/004 >19-15/002a > 19-15/006 > 18-15/001]

As conclusion, the deepest groundwater wells of Ein Samia have the lowest tritium concentration (the oldest water) due to long distance of water infiltration after precipitation to the deep aquifer, while the shallowest groundwater wells have the highest tritium concentrations (recent water) due to shorter distance of water infiltration after precipitation.

Table 3.28: Tritium concentrations of the samples of Ein Samia groundwater wells (2003-2004).

Well-ID	**Date**	**Well Elev. (a.s.l)**	**Well depth**	**Water depth**	**Sub-Aquifer**	**^{3}H (TU)**	**^{3}H Error**
18-15/001	28/07/2003	446	60m	23m	Tur/ up. Cen.	5	±0.5
18-15/001	03/04/2004	446	60m	23m	Tur/ up. Cen.	5.4	±0.5
18-15/001	**13/10/2004**	**446**	**60m**	**23m**	**Tur/ up. Cen.**	**5.4**	±0.5
18-15/006	28/07/2003	432	172m	29m	Upper. Cen.	3.6	±0.4
18-15/006	05/04/2004	432	172m	29m	Upper. Cen.	3.4	±0.4
18-15/006	**13/10/2004**	**432**	**172m**	**29m**	**Upper. Cen.**	**3.3**	±0.3
18-15/002a	28/07/2003	417	252m	80m	Mid. Cen.	4.2	±0.4
18-15/002a	03/04/2004	417	252m	80m	Mid. Cen.	3.5	±0.4
18-15/002a	**13/10/2004**	**417**	**252m**	**80m**	**Mid. Cen.**	**2.8**	±0.3
18-15/004	05/04/2004	432	616m	272m	Low. Cen.	0.4	±0.3
18-15/004	**13/10/2004**	**432**	**616m**	**272m**	Low. Cen.	**0.4**	±0.3

3.8.8.2 Al Auja Area:

The groundwater wells that were sampled in 4/08/2003 (19-14/001 and 19-15/005) are found containing tritium concentrations of 3.6 TU (Table 3.29). This means that the groundwater well of 19-14/001 and 19-15/005 are dating to the same age (before 45 years ago) when the initial concentration was 45 TU in the initial precipitation before decaying along water recharge from the western mountains.

The study considered the flow rate in the alluvium formation in Al Auja is about 0.056 m^3/hr^*; accordingly the maximum recharged area of the western hills will be far away approximately 22 Km from the sampled groundwater wells.

Table 3.29: Tritium concentration of the sampled groundwater wells of Al Auja (2003-2004).

Well-ID	**Date**	**Well Elev. (a.s.l)**	**Well depth**	**Water depth**	**Sub-Aquifer**	**^{3}H (TU)**	**^{3}H Error**
19-14/001	04/08/2003	-268	59	---	Alluvium	3.6	±0.4
19-14/001	11/01/2004	-268	59	---	Alluvium	3.3	±0.4
19-15/005	04/08/2003	-265.4	65	---	Alluvium/Pleistocene	3.6	±0.4

---

[*] Based on the estimated flow rate thought the Alluvium formation in Al Jiftlic area.

3.8.8.3 Al Jiftlic Area:

Here, the determination of the groundwater source is based on tritium decay with time after precipitation, and following the increases in chloride concentration that results from evaporite minerals dissolution and/or water mixing along the traveling distance of water recharge. In general, this technique suggests that the flow water path begins from Al-Badhan mountains to the upper aquifers of Al Fari'a garben then water recharges to Fruish Beit Dajan and then extend to Al jiftlic area before finally seepage forward the eastern valley (Figure 3.28).

According to the topographic contours, the slope of the precipitation flow on the hills and Wadis of Al-Fari'a garben is toward the SE where feeds most aquifers in Fruish Al jiftlic included the upper Cenomanian aquifer (i.e. groundwell 19-17/034). Based on Table 3.30, the highest tritium concentration (1.5 TU), and the lowest chloride concentration (82 mg/L) is recorded in 19-17/034 relative to the other groundwater wells in this group. This supports the idea that the groundwell 19-17/034 feeds water from shorter distance of recharge area relative to the eastern groundwells of Al jiftlic. This groundwater age is estimated backed to ~52 years when the initial tritium is ~28 TU in the year 1953; accordingly the recharge distance will be ~22.8 Km, considerable that the average flow rate of infiltrated water is ~0.05 m^3/hr. Based on the topographic map, the estimated distance is coincided with the measured length (22-24 Km) from the highest flanking mountains (750 m a.s.l).

The recharged water continues in its path toward the SE direction where feeds the groundwell 19-17/046 (Neogene aquifer) and the groundwell 19-17/056 (Neogene aquifers) that has lower ^{3}H value (0.9 TU), higher chloride (640 mg/L), and lower elevation point at the same direction comparative with the previous points (Table 3.30, & Fig. 3.28). Based on the estimated time (~9.09 year) that needs for traveling water from 19-17/034 until arrives the groundwell 19-17/056 (5.2 Km); the average flow rate will be ~ 0.065 m^3/hr, where the average gradient is 50-60m.

According to this technique, the flow water is recharging downward the Eocene/Alluvium to the south-east where feeds the groundwells 19-17/007 and 19-17/021 (Fig 3.28), and 19-17/028 that has lower ^{3}H values (0.7 TU), lower elevation (-268 m b.s.l), and higher chloride concentration (1500 mg/L) due high dissolution of evaporite minerals (mainly halite and gypsum) along the wide area of lisan formation. The average flow rate of water is estimated about 0.098 m/hr along the distance between the groundwell 19-17/056 and 19-17/028 that far 4.8 Km where the hydraulic gradient ranged within 60-70m.

Higher tritium (0.9 TU), lower chloride (1300 mg/L), and higher elevation (-260m b.s.l) in 19-16/001 relative to 19-17/028 refer to presence of secondary flow path of lower water salinity from the western mountains toward 19-17/028. The decreases in both chloride and tritium concentration in the groundwater well 19-17/054 (1100 mg/L, 0.6 TU) consolidate the idea of secondary flow path of low salinity water from the western area where low salinity water is recorded in the groundwater well 19-16/008 that characterize by higher ^{3}H (1.1 TU) and lower chloride (150 mg/L). The groundwater 19-16/008 is the only well that contain fresh water in Al Jiftlic area . The study suggest that this groundwater well didn't expose to mixing with saline water that recharge and seepage along the main flow path of Wadi Al Far'a.

Table 3.30: The main and secondary flow path toward the groundwater wells of Al jiftlic area.

The main flow Path					
Well ID	**Well Depth (m)**	**Well elev. (m.a.s.l)**	**Cl^- (mg/L)**	**^3H (TU)**	**Sub aquifer**
19-17/034	150	-149	82	1.5	U.Cen.
19-17/046	81	-167	550	N.D	Neogene
19-17/056	147	-205	640	0.9	Eocene
19-17/007	74	-244	660	N.D	Alluvium
19-17/021	81	-256	850	N.D	Eocene
19-17/028	72	-268	1500	0.7	Alluv+Eoce
19-17/054	75	-273	1100	0.6	Alluvium
19-16/005	68	-290	1400	N.D	Alluvium
19-16/001	68	-260	1300	0.9	U.Cen.
19-16/008	66	-243	150	1.1	Alluvium

The secondary flow path						
Well ID	**Well Depth (m)**	**Well elev. (m.a.s.l)**	**Cl^- (mg/L)**	**^3H (TU)**	**Sub aquifer**	**Notes**
19-16/001	68	-260	1300	0.9	U.Cen.	Mixing
19-16/008	66	-243	150	1.1	Alluvium	mixing

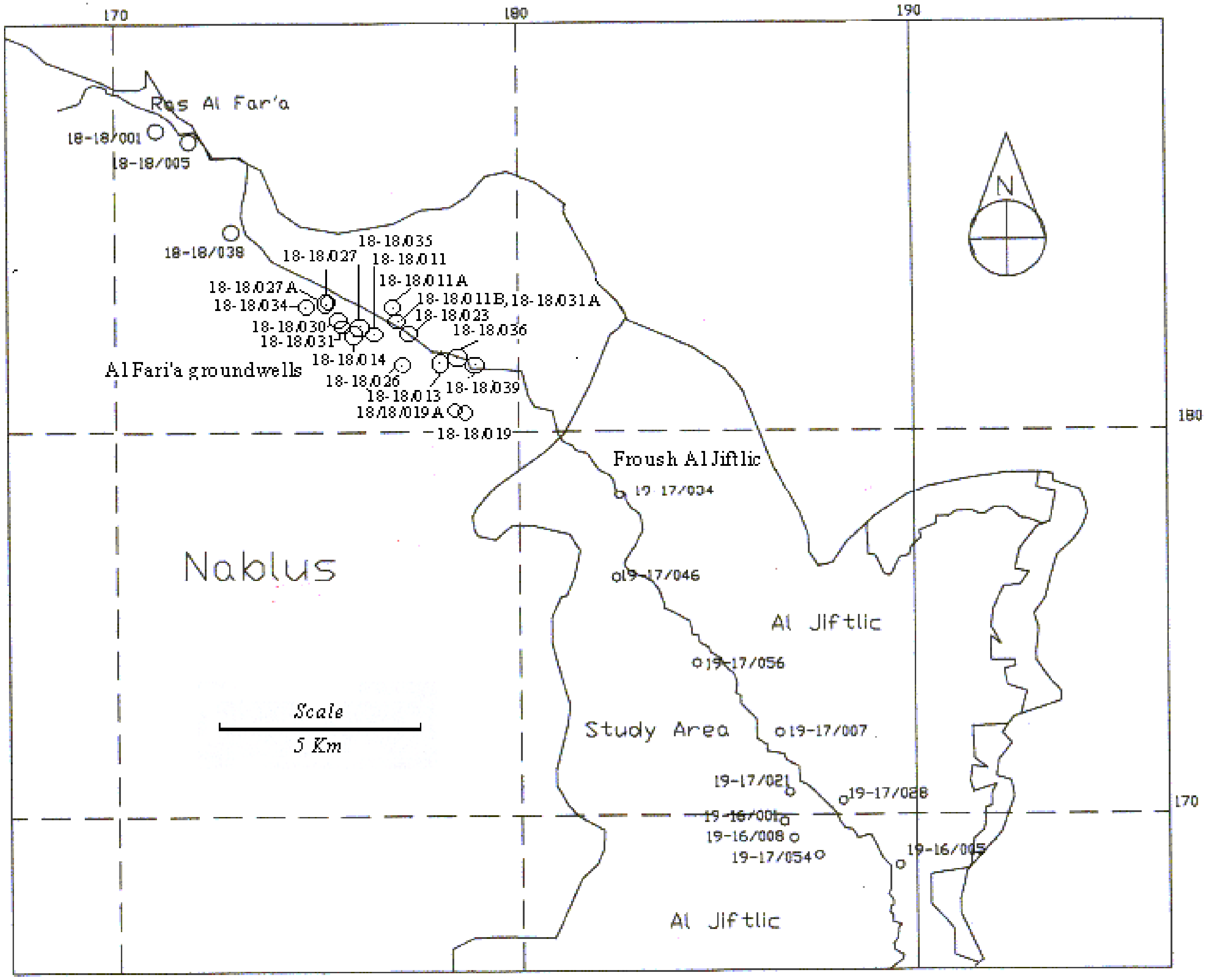


Figure 3.28: The groundwater wells distribution along Wadi Al Far'a.

3.9 STATISTICAL ANALYSIS

3.9.1 Introduction :

The software SPSS version 10 was used for the statistical analysis of the chemical results. The output is in the form of descriptive statistics (minimum, maximum, mean and standard deviation), clusters, correlation coefficients using Pearson rank, and the mathematical equations which represent linear relations between selected parameters of very high correlation coefficients ($R \geq 0.9$).

3.9.2 Parameters Interrelationships :

Based on the correlation matrix in Appendix 3.9, the very high correlation coefficients between different parameters of the sampled water are tabulated in Table 3.31:

Table 3.31: The very high correlated parameters of sampled water within the study area.

Parameters	**Correlation coefficient**
TDS- EC	0.99
TH- EC	0.96
Ca- EC	0.97
Mg- EC	0.98
Na- EC	0.97
Cl- EC	0.99
Ca/HCO_3- EC	0.94
TH-TDS	0.95
Ca -TDS	0.99
Mg- TDS	0.97
Ca/HCO_3- TDS	0.94

Parameters	**Correlation coefficient**
Na- TDS	0.98
Cl -TDS	0.99
Na-Cl	0.97
Mg-Cl	0.96
Mg-Na	0.92
Na-Ca/HCO_3	0.91
Ca-Mg	0.96
Mg-Ca/HCO_3	0.92
Ca-Na	0.96
Ca-Cl	0.98
Cl-Ca/HCO_3	0.96

The mathematical equations of the very high correlated parameters plot on the form of linear relationship according the general equation Y = aX + b, where X and Y are concentration variables (ionic parameters unit is mg/L), a is the slope of the relation line, and b is the Y axis intercept.

The relationship between those ions and EC were found to fit the following equations:

$Ca^{2+}(mg/L) = 0.05 \times EC + 26.25$ R= 0.97
$Mg^{2+}(mg/L) = 0.03 \times EC + 10.27$ R= 0.98
$Na^{+}(mg/L) = 0.09 \times EC - 5.34$ R= 0.97
$Cl^{-}(mg/L) = 0.31 \times EC - 145.42$ R= 0.99
$TDS(mg/L) = 0.54 \times EC + 72.03$ R= 0.99
$TH(mg/L) = 0.26 \times EC + 110.14$ R= 0.96

All sampled water show positive link between EC and TDS, where the average slope represents 0.55 units (Figure 3.29).

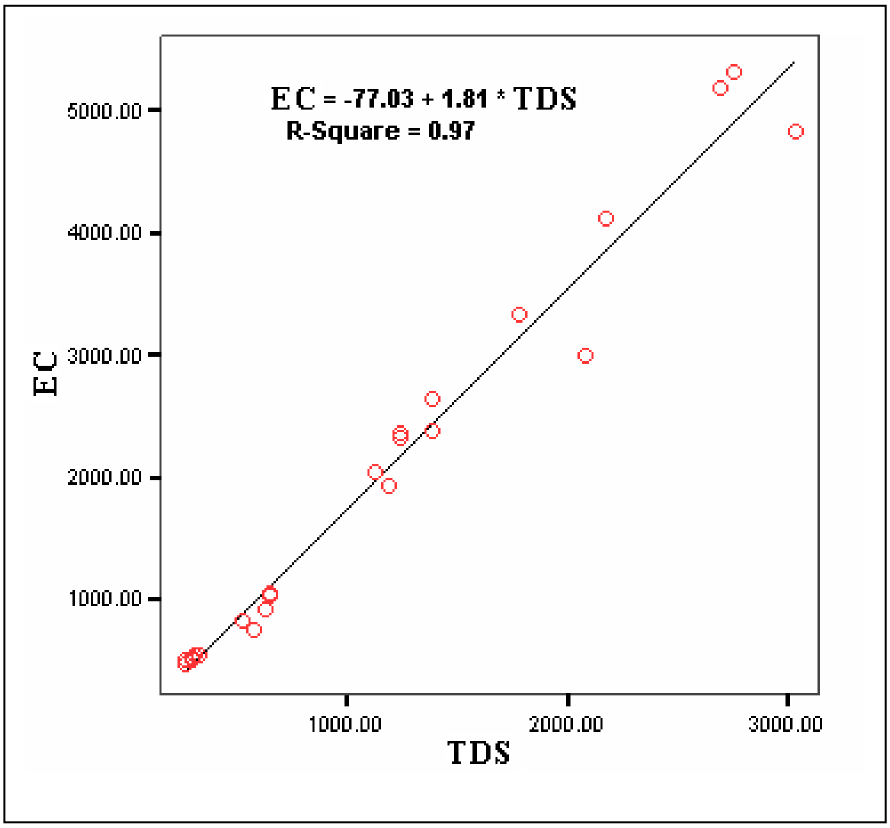


Figure 3.29: linear relationship between EC & TDS of the sampled water.

The relation lines in Figure 3.30 show that EC of the sampled water is directly proportional with Ca^{2+} and Mg^{2+} as a natural result of dolomitic carbonate dissolution that contribute in increasing the total hardness (TH). Also EC is found correlated with Na^{+}, and Cl^{-} as assign of halite mineral dissolution and/or water mixing.

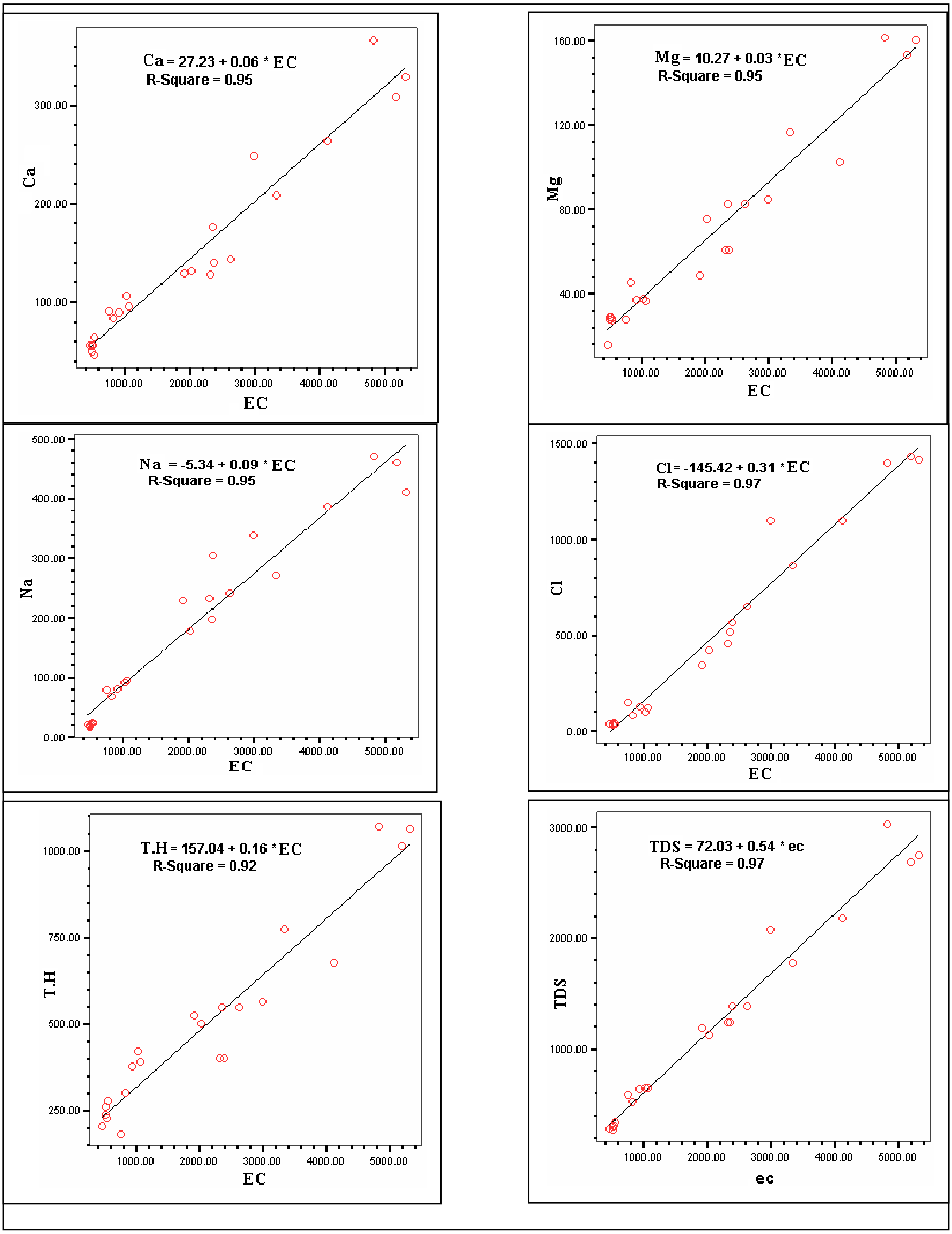


Figure 3.30: The EC relationship with Ca^{2+}, Mg^{2+}, Na^{+}, Cl^{-}, TH, and TDS in mg/L.

In general, the central results of the statistical analysis is summarized in the following points:

- Ca^{2+}, Mg^{2-}, Na^{+} and Cl^{-} are the main factors of water salinity.
- The total hardness is found increased proportionally with water salinity.
- High dissolution of carbonate minerals and halite (Fig 3.31) due to far distance of water seepage through Alluvium–Eocene formation is the main explanation of the very high correlations between Na^{+} and Cl^{-} with $Ca^{2+}$and Mg^{2+} at Al Jiftlic and Al Auja groundwater wells. This idea is supported using isotopes technique “decreasing in tritium concentration and increasing in chemicals ions forward the south-east of the water seepage”. If mixing with ancient brine water is occurred it will be also causing very high correlations between Na^{+} - Cl^{-} - Ca^{2+}- Mg^{2+}. Also the study shows Gypsum and Anhydrate dissolution are the main sources of SO_4^{2-} (Figure 3.31).

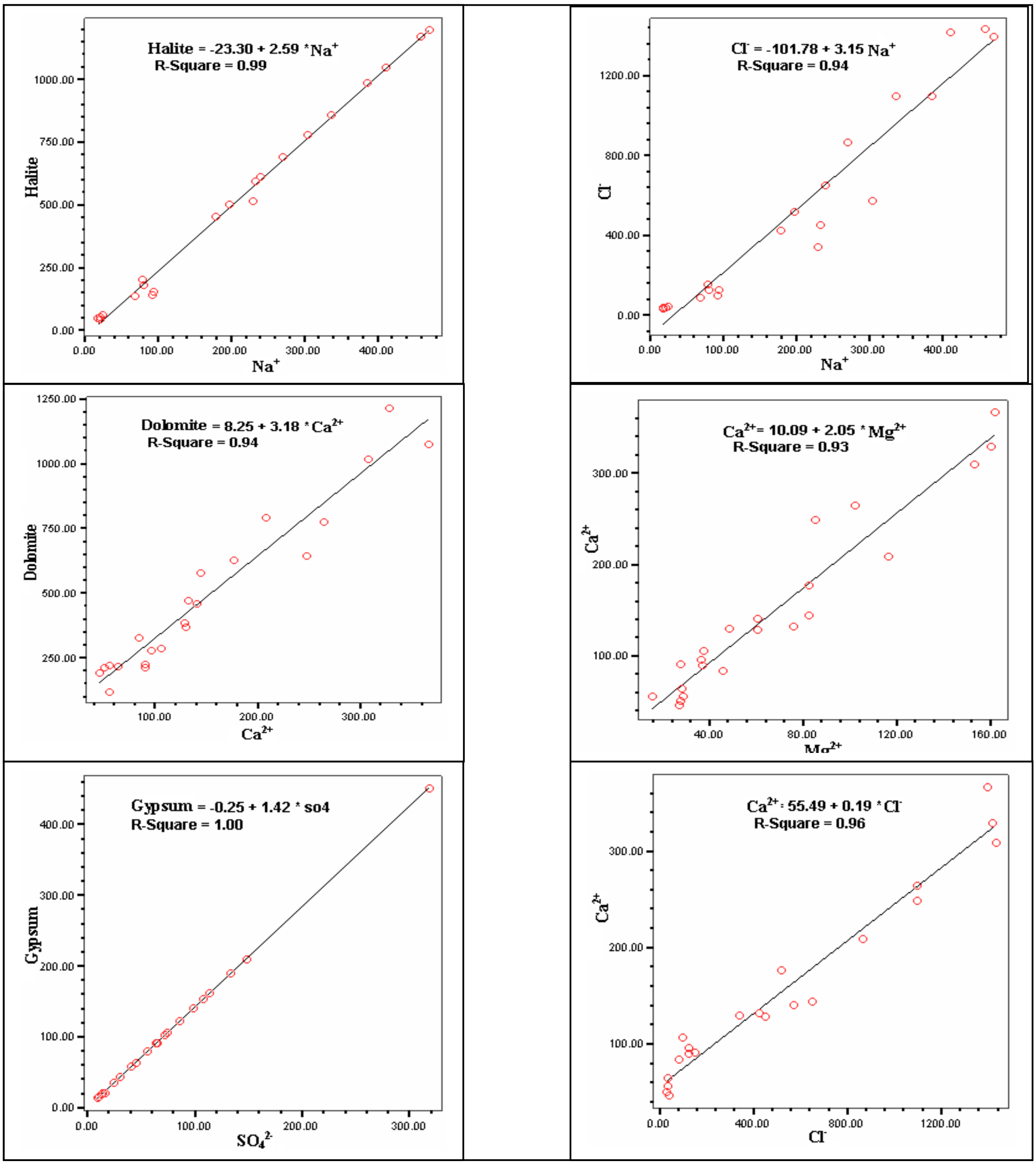


Figure 3.31: The linear relationship between Ca^{2+}, Mg^{2+}, Na^{+}, and Cl , SO_4^{2-}, and their possible minerals.

3.9.3 Cluster Analysis :

Hydrochemical cluster analysis is one of the important statistical methods that used to classify water samples into similar characteristic group based on the main cations and anions. This was done by using the statistical SPSS program ver.10. Figure 3.32 represents the compilation result on the form of the flow chart (tree diagram) of the sampled waters based on Dendrogram of Q-mode using the linkage of Ward method and the Euclidean distance. In Figure 3.32, the sampled water are mainly divided into two groups A and B which represent the low clustering level (Level 1). Based on the rescaled distance cluster combine; the similarities between the groundwater increases toward the higher clustering level where the group A and B are divided into two minor groups of high clustering levels of A1, A2, and B1, B2.

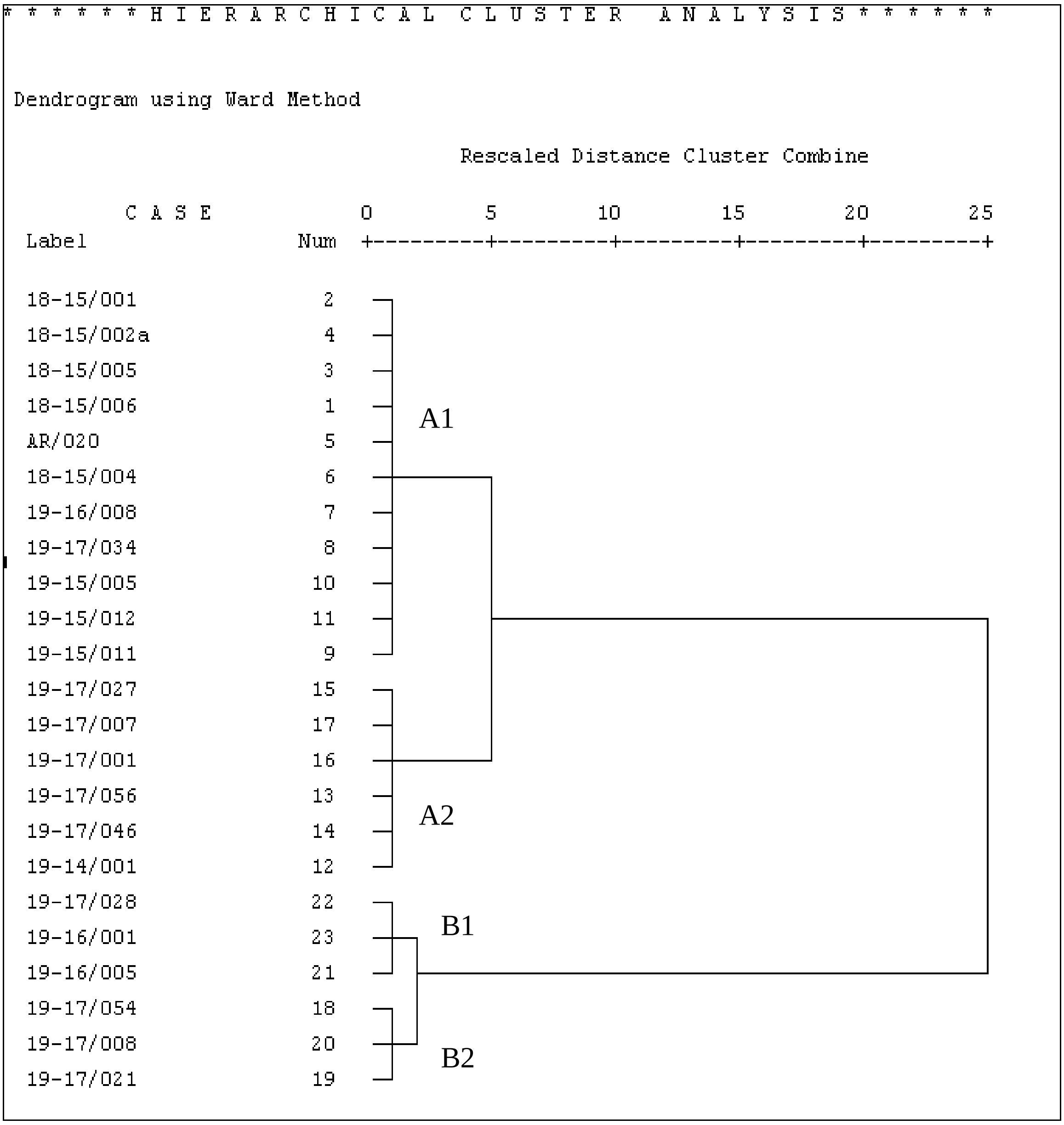


Figure 3.32: Tree diagram (Dendrogram) of Q-mode cluster analysis showing the grouping of the wells and springs into clusters.

The average ionic concentrations of each cluster in Table 3.32 illustrate that each cluster is different in its salinity range; the maximum salinity is found in the groundwater wells of cluster B2. The plot of the ionic concentrations for each cluster in Figure 3.33 shows chloride is the main dominant ion in the groundwater wells of the cluster A2, B1, and B2 which represent the groundwater wells of the Eocene-Holocene aquifers in Al Auja and Al Jiftlic areas, while bicarbonate is the main dominant ion in cluster A1 that represent the groundwater wells within the Albian-Cenomanian aquifers primary in Ein Samia area.

Table 3.32: The mean of the concentrations of the ions in the clusters.

Cluster	**EC µS**	**Ca^{2+}** (meq/L)	**Mg^{2+}** (meq/L)	**Na^{+}** (meq/L)	**K^{+}** (meq/L)	**HCO$_3^-$** (meq/L)	**Cl$^-$** (meq/L)	**SO$_4^{2-}$** (meq/L)	**NO$_3^-$** (meq/L)
A1	662.1	3.06	2.87	1.93	0.17	5.26	1.85	0.62	0.31
A2	2250.3	6.84	6.15	10.70	0.56	7.17	15.24	1.74	0.68
B1	3564.0	8.76	12.30	14.46	0.77	5.93	28.66	1.85	0.50
B2	5066.7	12.69	15.77	23.11	0.95	7.29	42.65	2.76	0.69

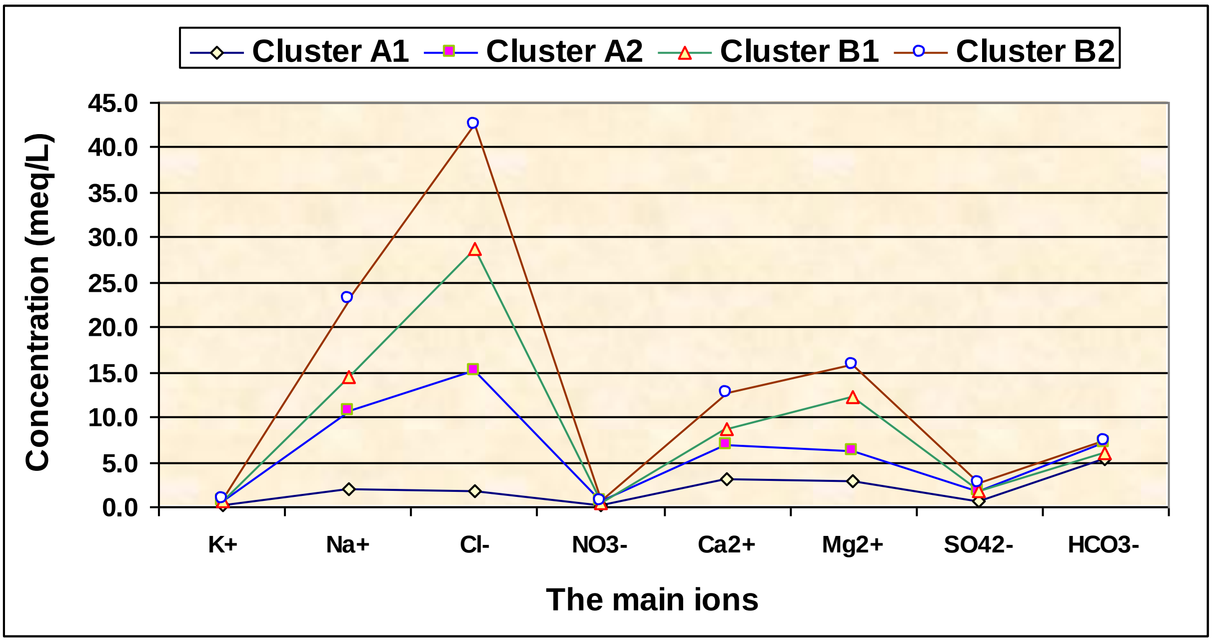


Figure 3.33 :The clusters of the study samples.

3.9.3.1 Cluster A1:

The cluster A1 represents 47.8% of the total samples. These groundwater wells are within the Albian-Cenomanian aquifers (found in Ein Samia) and Pleistocene-Holocene aquifers (found in Al-Auja and Al-Jiftlic). The groundwater wells of cluster A1 have an average EC of 662 µS/cm where the general descriptive statistics of the hydrochemical parameters are summarized in Table 3.33. The ionic constituents are dominated by calcium (38% of the cations), and bicarbonate as dominant anion (64% of the anions) in meq/L as classified as their concentration in Figure 3.34:

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

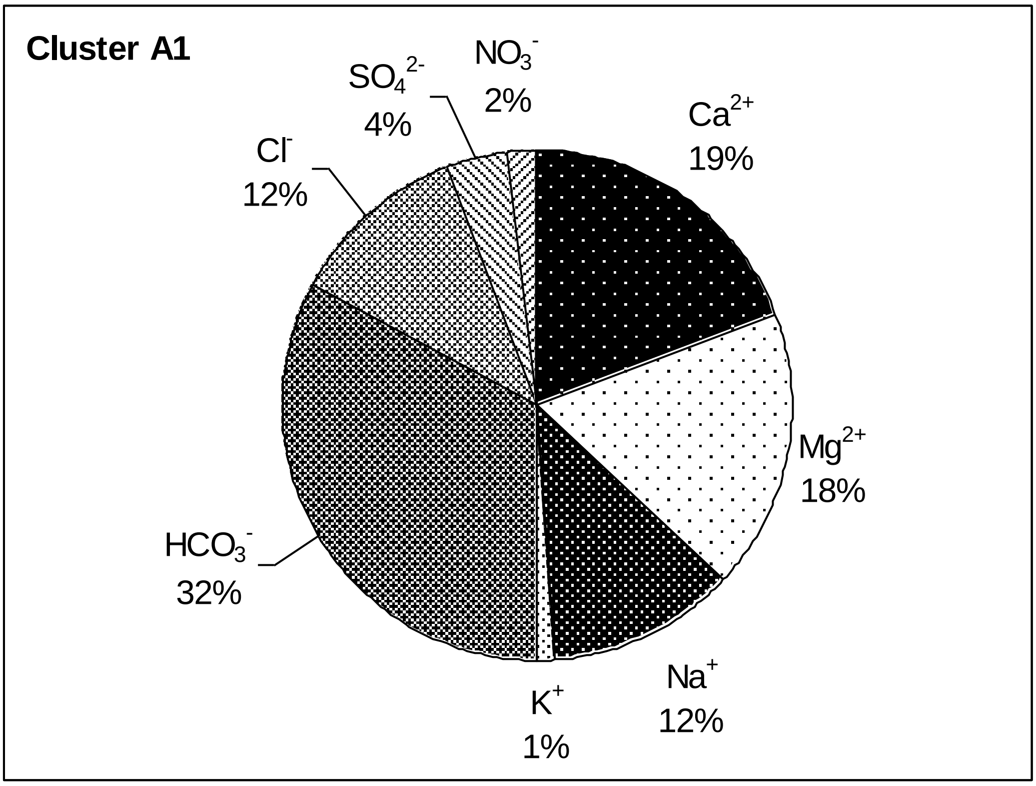


Figure 3.34: The general main ionic distribution of cluster A1 water.

Table 3.33: Descriptive statistics of Cluster A1.

Variable	Min	Max	Mean	St.dev	N
Temp (C)	20.7	26.0	22.8	1.8	11
pH	7.01	8.08	7.34	0.29	11
EC(µS/cm)	460	1054	695	227	11
TDS (mg/L $CaCO_3$)	274.4	651.4	441.5	166.5	11
TH(mg/L)	183.4	421.3	285.9	78.6	11
SAR	0.50	2.09	1.15	0.68	11
Ca^{2+}(mg/L)	46.09	106.01	72.34	21.26	11
Mg^{2+}(mg/L)	15.72	45.62	31.10	7.81	11
Na^{+}(mg/L)	18.00	94.80	49.01	33.28	11
K^{+}(mg/L)	1.20	34.74	7.47	10.67	11
HCO_3^-(mg/L)	225.78	510.87	330.78	94.04	11
Cl^-(mg/L)	30.43	150.30	72.65	44.94	11
SO_4^{2-}(mg/L)	9.50	98.75	29.94	27.02	11
NO_3^-(mg/L)	9.90	41.80	20.22	11.55	11
TDS/EC	0.54	0.78	0.63	0.06	11
Na^+/Cl^-	0.76	1.43	1.00	0.20	11
Ca^{2+}/SO_4^{2-}	0.91	5.29	3.39	1.32	11
Ca^{2+}/HCO_3^-	0.16	0.26	0.22	0.03	11
$SI_{Anhydrite}$	-2.98	-1.85	-2.51	0.36	11
$SI_{Aragonite}$	-0.35	0.24	-0.04	0.20	11
$SI_{Calcite}$	-0.20	0.39	0.10	0.20	11
$SI_{Dolomite}$	-0.57	0.62	0.15	0.39	11
SI_{Gypsum}	-2.75	-1.62	-2.29	0.36	11

The linkages between chemical parameters of the sampled water which are very high correlated coefficients of cluster A1 are tabulated in Table 3.34:

Table 3.34: The very high correlation interrelationships between ionic parameters of cluster A1.

Parameters	Correlation coefficient
TDS- EC	0.97
Ca- EC	0.94
HCO_3- EC	0.94
Na- EC	0.97
SAR- EC	0.95
Ca -TDS	0.97
HCO_3- TDS	0.90
SAR-TDS	0.99
Na-HCO_3	0.90
Na-Cl	0.93

Parameters	Correlation coefficient
SAR-Ca	0.96
SAR-Na	1.00
SAR-Cl	0.95
Na-Ca	0.97
Ca-HCO_3	0.90
$SI_{dolomite}$-$SI_{aragonite}$	0.97
$SI_{dolomite}$-$SI_{calcite}$	0.97
$SI_{anhidrate}$-Ca	0.90
$SI_{anhydrate}$- SO_4	0.92
SI_{gypsum}-SO_4	0.92

The main dominant cation Ca^{2+} is high correlated with the main dominant anion HCO_3^- . These ions resulted from carbonate dissolution such as calcite, and dolomite.

The EC of the water samples of cluster A1 as found to be in high correlated with TDS, Mg^{2+}, Na^+, and HCO_3^- which indicates salinity is proportional directly with the concentration of all those ions according to the following equations (Figure 3.35).

$TDS\ (mg/L) = 0.76 \times EC - 83.4$ R= 0.97
$Ca^{2+}\ (mg/L) = 0.09 \times EC - 11.2$ R= 0.94
$HCO_3^-\ (mg/L) = 0.39 \times EC + 61.41$ R= 0.94
$Na^+\ (mg/L) = 0.14 \times EC - 49.64$ R=0.97

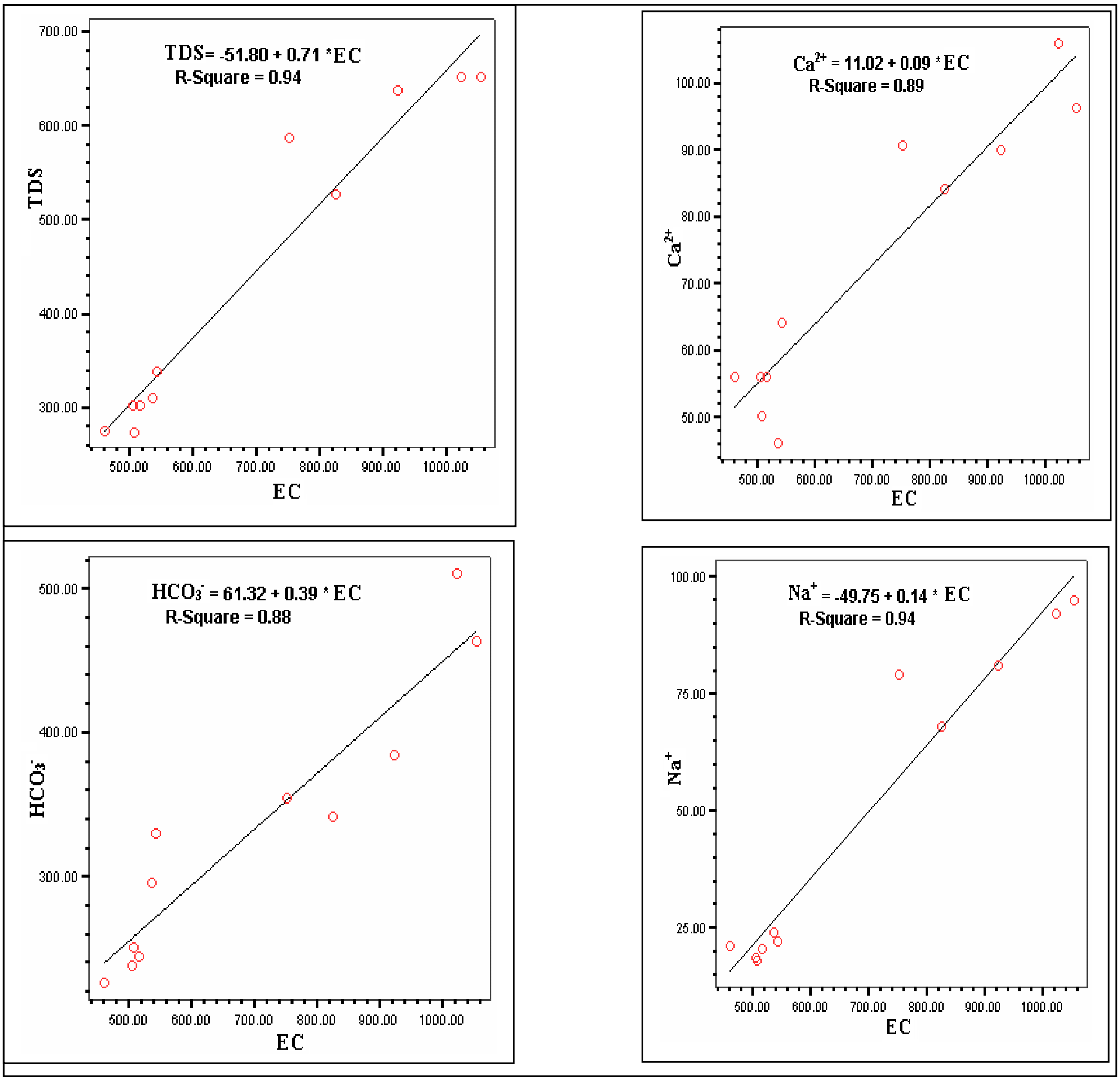


Figure 3.35: The linear relationship between EC with TDS, Ca^{2+}, HCO_3^-, and Na^+.

In general, the total hardness (TH) increases directly with salinity according the following relation.

$$\text{TH (mg/L as CaCO}_3\text{)} = 0.33\times\text{EC} + 86.57 \qquad \text{R}= 0.95$$

SAR is also affected with Na^+ and Ca^{2+} concentrations according to the following mathematical relations (Fig. 3.36):

$$\text{SAR} = 0.02\times\text{Na}^+ + 0.16 \qquad \text{R}=1.00$$
$$\text{SAR} = 0.03\times\text{Ca}^{2+} - 1.05 \qquad \text{R}= 0.96$$

Based on the relation lines in Figure 3.36; the expected major source Mg^{2+}, SO$_4^{2-}$, Na$^+$ and Cl$^-$ are from the dissolution of dolomite gypsum, and halite.

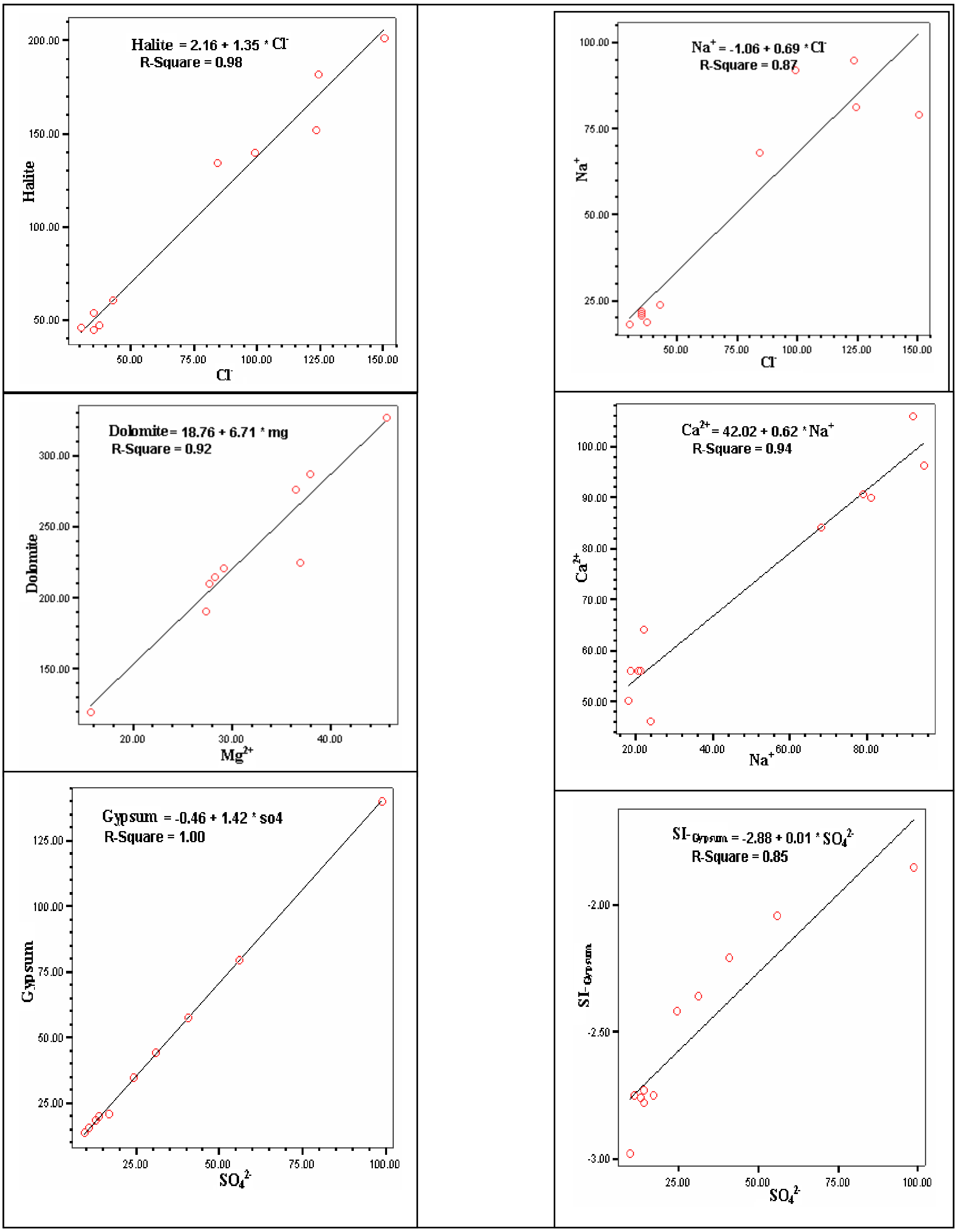


Figure 3.36: The high correlation linear relation show the expected mineral sources of Na$^+$, Cl$^-$, Ca^{2+}, Mg^{2+},SO$_4^{2}$.

3.9.3.2 Cluster A2 :

The cluster A2 represents 26% of the total study samples. All groundwater wells are of Eocene-Holocene aquifers mainly in Al Jiftlic. The average EC is 2250 µS/cm where all the general descriptive statistics of the hydrochemical parameters are summarized in Table 3.35. Figure 3.37 shows that the ions constituents are dominated by sodium (44% of the cations) and chloride (60% of the anions). The ionic constituents in the groundwater wells are classified as their concentration as the following sequences:

$Na^+ > Ca^{2+} > Mg^{2+} > K^+$

$Cl^- > HCO_3^- > SO_4^{2-} > NO_3^-$

$Cl^- > Na^+$

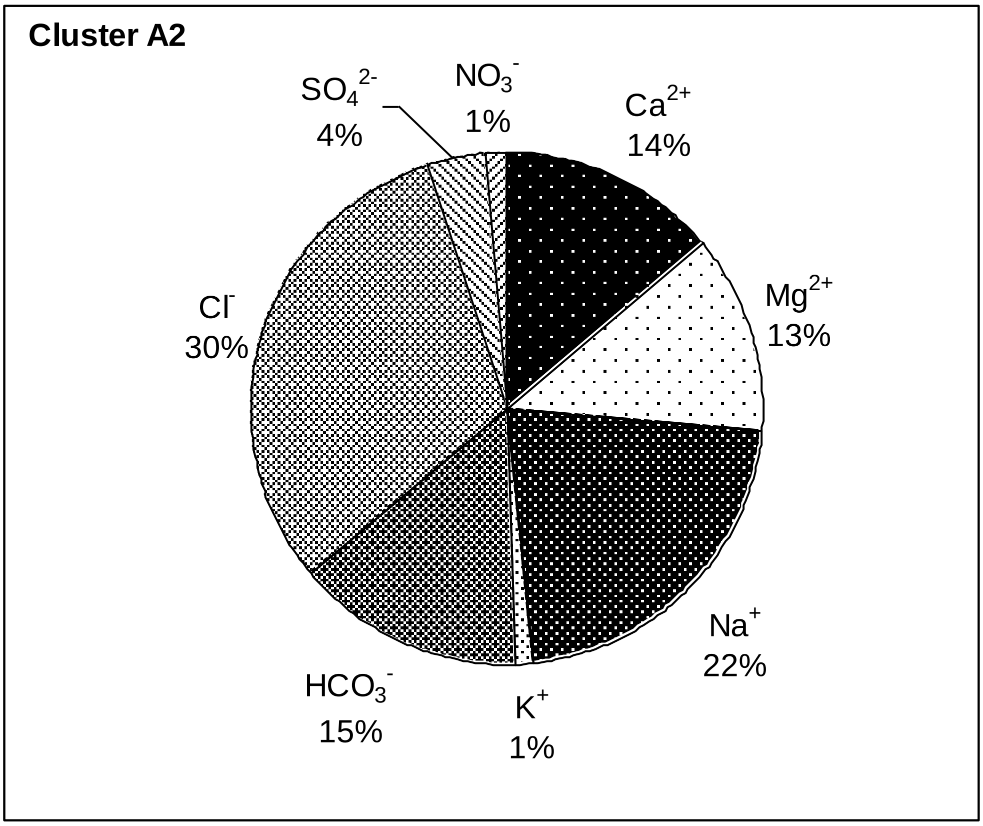


Figure 3.37: The general ionic distribution of the sampled water of Cluster A2.

Table 3.35: Descriptive statistics of Cluster A2.

Variable	Min	Max	St.dev	Mean	N
Temp (C)	23.0	25.9	1.0	24.6	6
pH	6.88	7.10	0.10	7.01	6
EC(µS/cm)	1920	2630	257	2270	6
TDS (mg/L)	1130.2	1387.4	104.5	1262.8	6
TH(mg/L $CaCO_3$)	402.5	547.5	68.1	487.7	6
SAR	3.07	5.43	0.89	4.03	6
Ca^{2+}(mg/L)	128.30	176.40	18.03	141.88	6
Mg^{2+}(mg/L)	48.62	82.70	13.93	68.57	6
Na^{+}(mg/L)	178.70	305.60	43.64	230.95	6
K^{+}(mg/L)	11.30	34.74	10.38	21.21	6
HCO_3^{-}(mg/L)	335.61	585.79	91.77	415.95	6
Cl^{-}(mg/L)	342.30	652.28	110.31	493.83	6
SO_4^{2-}(mg/L)	40.85	113.90	30.96	73.96	6
NO_3^{-}(mg/L)	15.80	65.40	18.83	34.24	6
TDS/EC	0.53	0.62	0.04	0.56	6
Na^{+}/Cl^{-}	0.57	1.04	0.18	0.75	6
Ca^{2+}/SO_4^{2-}	1.14	3.43	1.01	2.26	6
Ca^{2+}/HCO_3^{-}	0.22	0.46	0.09	0.35	6
$SI_{Anhydrite}$	-2.19	-1.75	0.18	-1.96	6
$SI_{Aragonite}$	-0.11	0.11	0.08	-0.02	6
$SI_{Calcite}$	0.03	0.25	0.09	0.12	6
$SI_{Dolomite}$	0.03	0.53	0.18	0.28	6
SI_{Gypsum}	-1.96	-1.53	0.18	-1.74	6

Table 3.36: The very high correlation interrelationships between chemical parameters of cluster A2.

Parameters	Correlation coefficient
Cl- EC	0.96
Na- SAR	0.96
Mg-Ca/HCO_3	0.92
$SI_{calcite}$-$SI_{dolomite}$	0.91
$SI_{dolomite}$-$SI_{aragonite}$	0.92
SO_4-$SI_{anhydrate}$	0.96
SO_4-SI_{gypsum}	0.96

In cluster A2, the main anion dominant Cl^- is the main factor responsible for increasing salinity (EC).

$$Cl^- \text{ (mg/L)} = 0.41 \times EC - 437.15 \qquad R = 0.96$$

This group is characterize by high relationship between HCO_3^--Mg^{2+}, and $SI_{dolomit}$-HCO_3^- which are all determine the source of Mg^{2+} is from dolomite, where all saturation indices of dolomite is positive, hence; the precipitation of dolomite is expected.

$$HCO_3^- \text{(mg/L)} = -3.43 \times Mg^{2+} + 847.1 \qquad R = 0.85$$

The hypothesis of sulfate source in the groundwater wells is expected from the dissolution of gypsum found is the rocks according to the high correlations between SO_4^{2-}-anhydrate, and SO_4^{2-}-SI $_{gypsum}$ (Table 3.36),where all SI of anhydrate and gypsum in water is undersaturation.

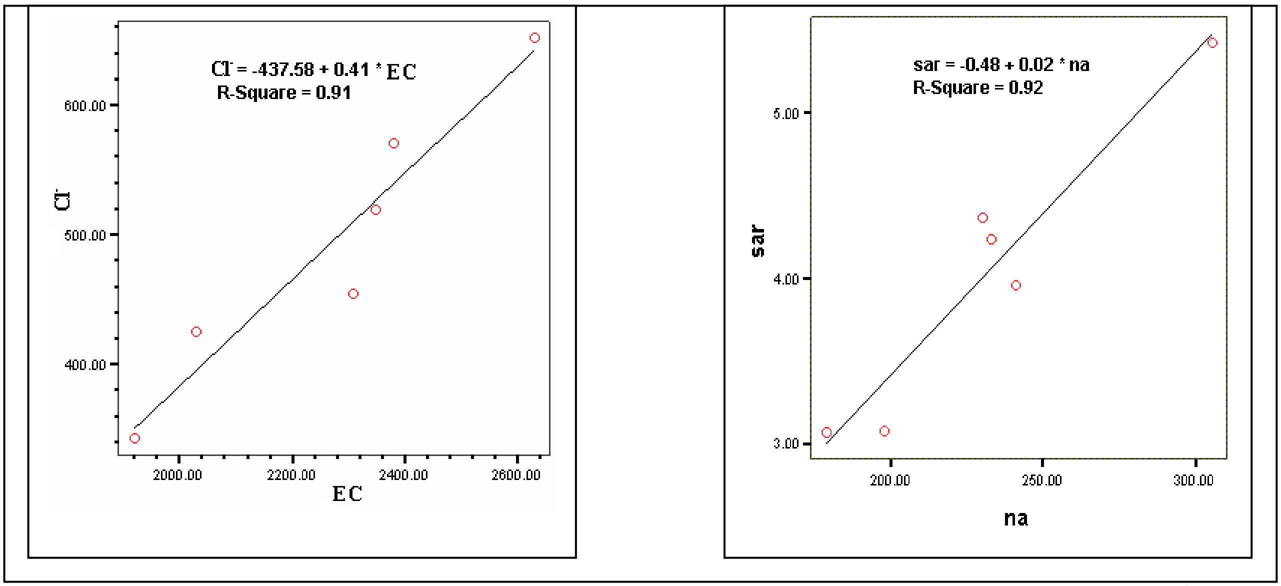


Figure 3.38: The linear relation between Cl^--EC^-, Na^+-SAR, Na^+ halite, and anhydrate-SO_4^{2-}.

3.9.3.3 Cluster B :

Cluster B is a combination of B1 and B2 clusters which represent 26% of the total samples, B1and B2 clusters are similar in their water type, but different in EC average where B1 has an average EC of 3564 µs/cm, while cluster B2 characterize with the highest EC average (5067µs/cm). Both groundwater of cluster B1 and B2 are dominated by sodium (42% of the cations) and the chloride (78% of the anions). The ionic constituents in the groundwater wells are classified as their concentration as the following sequences (Figure 3.39):

$$Na^{+} > Mg^{2+} > Ca^{2+} > K^{+}$$

$$Cl^{-} > HCO_3^{-} > SO_4^{2-} > NO_3^{-}$$

$$\text{Where } Cl^{-} > Na^{+}$$

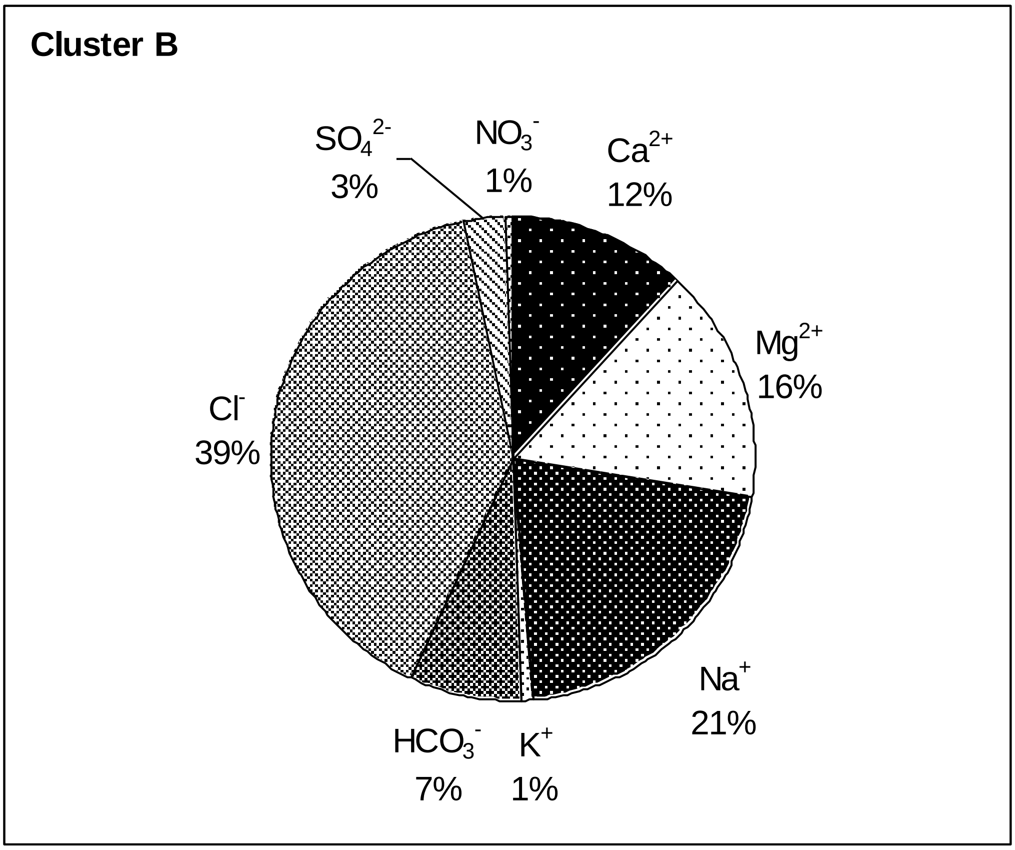


Figure 3.39: The general ionic distribution of the sampled water of Cluster B1.

Table 3.37: Descriptive statistics of Cluster B.

Variable	Min	Max	St.dev	Mean	N
Temp (C)	23.4	25.1	0.9	24.2	6
pH	6.80	7.00	0.10	6.90	6
EC(µS/cm)	2990	4110	574	3477	6
TDS (mg/L)	1778.7	2178.0	207.9	2011.9	6
TH(mg/L)	563.4	772.6	104.7	670.6	6
SAR	3.73	5.12	0.72	4.52	6
Ca^{2+}(mg/L)	208.40	264.50	28.90	240.47	6
Mg^{2+}(mg/L)	85.10	116.70	15.82	101.30	6
Na^{+}(mg/L)	271.00	387.10	58.27	332.00	6
K^{+}(mg/L)	19.40	36.30	8.45	27.73	6
HCO_3^{-}(mg/L)	335.61	439.34	51.90	388.49	6
Cl^{-}(mg/L)	864.98	1099.20	135.15	1021.04	6
SO_4^{2-}(mg/L)	64.70	134.00	35.50	94.90	6
NO_3^{-}(mg/L)	26.50	33.90	4.27	28.97	6
TDS/EC	0.50	0.70	0.11	0.58	6
Na^{+}/Cl^{-}	0.47	0.54	0.04	0.50	6
Ca^{2+}/SO_4^{2-}	1.97	3.84	0.97	2.75	6
Ca^{2+}/HCO_3^{-}	0.53	0.79	0.14	0.63	6
$SI_{Anhydrite}$	-1.86	-1.54	0.17	-1.73	6
$SI_{Aragonite}$	-0.03	0.03	0.03	0.00	6
$SI_{Calcite}$	0.12	0.25	0.07	0.18	6
$SI_{Dolomite}$	0.21	0.44	0.12	0.33	6
SI_{Gypsum}	-1.63	-1.32	0.17	-1.51	6

Table 3.38: The very high correlation interrelationships between chemical parameters of cluster B1.

Parameters	Correlation coefficient (R)
TDS-EC	0.90
Mg-EC	0.90
Ca -TDS	1.00
Cl -TDS	0.95
Na-TDS	0.94
TH-EC	0.90
TH-Mg	1.00
Na-Cl	0.93
Ca-Na	0.92
Ca-Cl	0.93
SAR-Na	0.90
SAR-Ca	0.90
SO_4- NO_3	0.91
Ca/ SO_4 - SI_{gypsum}	0.90
$SI_{calcite}$- $SI_{dolomite}$	0.92

Based on Table 3.38; the ions which are very high correlated with EC and TDS were found to fit the following equations:

TDS (mg/L) = 0.42×EC + 613.16	R= 0.90
Mg^{2+}(mg/L)= 0.03×EC -0.54	R=0.90
Ca^{2+}(mg/L) = 0.12×TDS – 3.57	R= 1.00
TH(mg/l $CaCO_3$) = 0.54×TDS – 51.97	R= 0.97
Cl^- (mg/L) = 0.63×TDS – 249.81	R= 0.95
Na^+(mg/L) = 0.15×TDS + 28.42	R=0.94

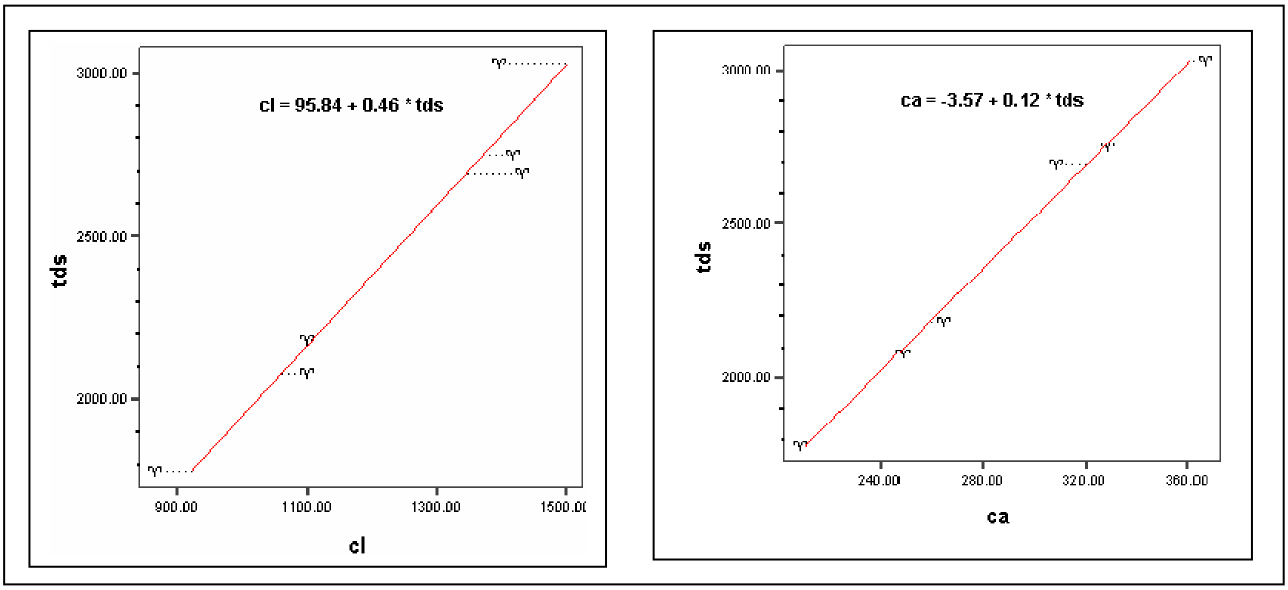


Figure 3.40: The linear relationship between TDS and both Cl^-, and Mg^{2+}.

The total hardness is proportional with TDS which is found to be very high correlated with earth alkaline such as Mg^{2+} (Figure 3.41).

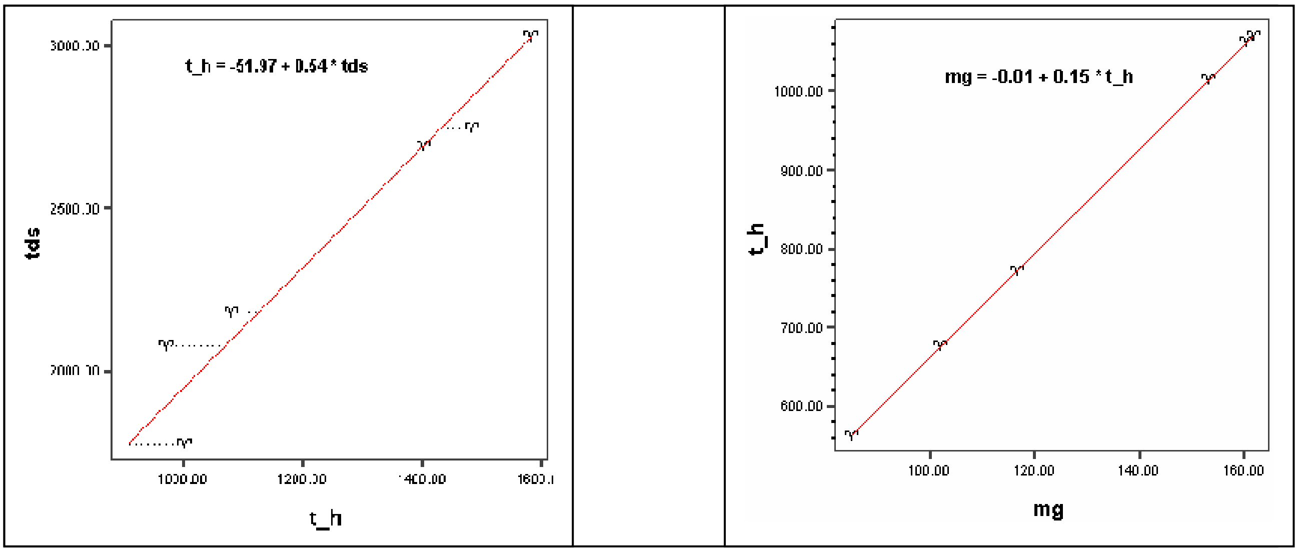


Figure 3.41: The linear relationship between TH and both TDS and Mg^{2+}.

Figure 3.42 shows that SAR is increased directly with the parameters of Ca^{2+} and Na^{+}.

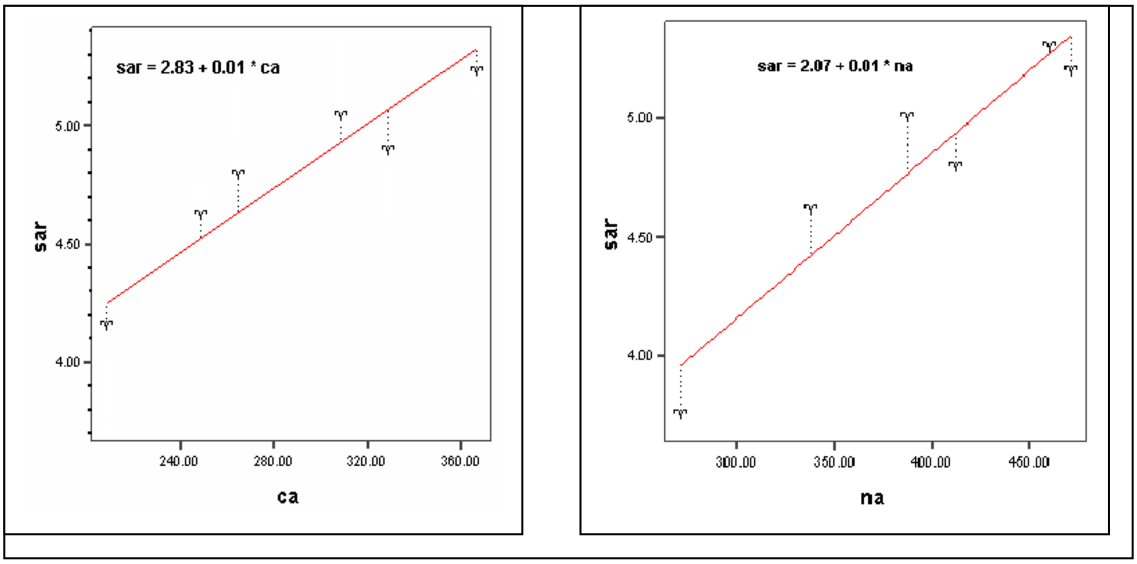


Figure 3.42: The linear relation between SAR with Ca^{2+}***, and*** Na^{+} ***concentrations.***

The majority groundwater wells show the dissolution of carbonate and evaporite minerals are correlated with both of pH of contact water, and the saturation indices of calcite, dolomite minerals in water. The odor in these groundwells is a natural result of sulfate reduction that is pH dependent (Figure 3.43).

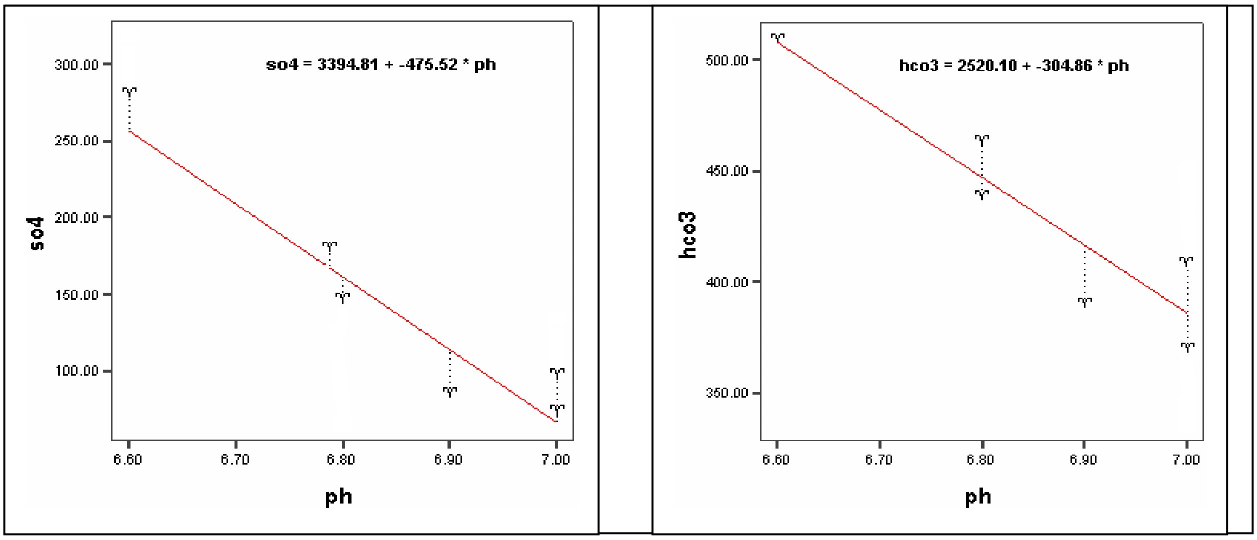


Figure 3.43: The relation ship between SO_4^{2-}***-pH, and*** HCO_3***-pH.***

The statistical processes of cluster B showed very high correlation between different parameters of Na^{+}, Cl^{-} , Ca^{2+}, and Mg^{2+} (Figure 3.44). SO_4^{2+} is very high correlated versus Ca^{2+}, gypsum, and NO_3^{-}. Based on the above correlations, the logical explanation of this water composition returns to the long time of water infiltration and seepage from Al Far'a area to Al jiftlic among different formations including limestone inter bedding with chalk, marl, or gypsum. This explanation is agreed with increasing of TDS in the south eastern part of Al Jiftlic relative to the north western part. Beside that, the very high correlation between SO_4^{2+} and NO_3^{-} is a significant pointer of groundwater wells mixing with agricultural return flow and/or domestic waste water at the long of Wadi Al Far'a.

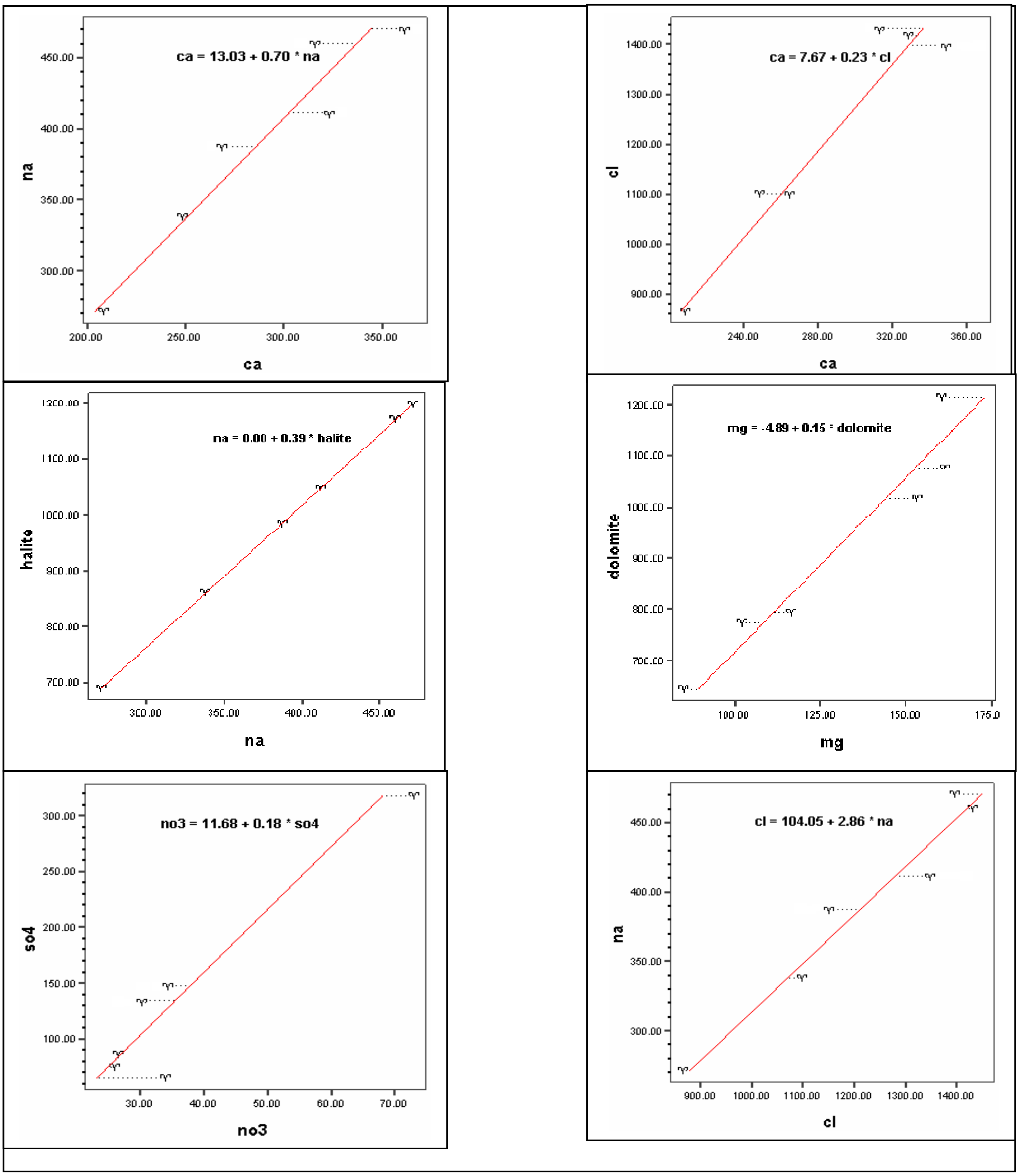


Figure 3.44: The selective relationship of earth alkalis ions versus earth alkaline ions, and SO_4^{2+} versus NO_3^-.

Chapter Four

CONCLUSION

4.1 Conclusion

The calculated parameters of water balance in Al Auja drainage basin that represent area of 40.65 Km^2 are distributed as: the mean annual rainfall represent 429 mm (17.42 MCM/yr), the surface runoff is 1.74 MCM/yr (9.8% of the annual rainfall), the infiltration is 2.6 MCM/yr (14.9%), the water recharge is 2.48 MCM/yr (14.3%), and evapotranspiration is 11.62 MCM/yr (67%).

The groundwater wells of Ein Samia extract water from the Albian-Upper Cenomanian aquifer system. The major sediments of these aquifers are limestone, dolomite, marly and chalky limestone. The sampled water of the Albian-Upper Cenomanian aquifers showed low variation in chemical and physical parameters where TDS ranges between 270-340 mg/L with average standard deviation of 23.5 as a sign of common interaction processes of water through recharging and percolation and/or due to existence of interconnection between the Cenomanian aquifers according to the presence of deep faults. The water type of this aquifer system is classified as the earth alkaline water with prevailing bicarbonate (26% of the total samples) ($Ca-Mg-HCO_3$). This water type exists also in Al Auja spring (AR/020) that characterize by low TDS and relatively high bicarbonate concentrations as a sign of recent water recharge. The very high correlation between Ca^{2+} as the main dominant cation and HCO_3^- as the main dominant anion indicate to that $Ca(HCO_3)_2$ is the main salt composition as a result of different carbonate dissolution during water contact with limestone and dolomitic limestone of the Albian-Upper Cenomanian aquifer systems. Furthermore, all ratios of Ca^{2+}/Mg^{2+} are within the ranged ratio of carbonate aquifer. The low concentrations of dissolved evaporite in the groundwater wells is a significant evidence of nonappearance of halite and gypsum in the geologic formation in Ein Samia aquifers. Thermodynamically, the shallow groundwater wells of the Upper Cenomanian aquifer are oversaturated with respect to dolomite, and calcite, and undersaturated with respect to anhydrate, gypsum, and fluorite, while the deep groundwater wells of the lower and middle Cenomanian are undersaturated with respect to those minerals. The ratios of Na/Cl indicate precipitation is the main source of groundwater wells without significant mixing with waste water or deep/saline water where $(Ca^{2+}+Mg^{2+})/(Na^{+}+K^{+})$ is similar to the natural ratio of precipitation. Beside that; the low concentrations of SO_4^{2-} and NO_3^- in groundwater wells of Ein Samia exclude any possibility of mixing with agricultural return flow or waste water. From the chemical point of view; the groundwater wells of the Albian-Upper Cenomanian aquifers of Ein Samia are suitable for drinking proposes, as the concentration of Ca^{2+}, Mg^{2+}, Na^+, HCO_3^-, Cl^- and the health hazard parameters as NO_3^-, and SO_4^{2-} are within the acceptable limits for drinking water according to the WHO (2005) guidelines. According to Wilcox classification (S1-C2); those groundwater are classified good/excellent for irrigation where can be used for irrigate plants of moderate salt-tolerance and without serious hazard on the soil structure.

The most groundwater wells of Al Auja and Al Jiftlic extract water from Eocene-Holocene systems. The major sediments of those aquifer systems are limestone interfingering with conglomerates of sandstones and silt sediments, chalk with chert, laminated marl with gypsum band, and saline marl of lacustrine deposits.

The water type of the groundwater wells that contain TDS within 500-750 mg/L in Al Auja and Al Jiftlic area is found of earth alkaline water with increased portion of alkalis and prevailing bicarbonate (22% of the total samples). The statistical process showed that EC is very high correlated mainly with HCO_3^- and Na^+. Furthermore, Ca^{2+} is very high correlated with Na^+ due to the dissolution of carbonate rocks that interfingering with halite sediment. Chemically; the majority groundwater wells of the this water type are suitable for drinking, where the concentration of Na^+, Cl^-, NO_3^-, and SO_4^{2-} are within the acceptable limits for drinking water according to WHO (2005) guidelines.

The studied Albian-Holocene aquifer systems that contain TDS within the range of 270-750 mg/L showed the following sequence of ions:

$$Ca^{2+} > Mg^{2+} > Na^+ > K^+$$

$$HCO_3^- > Cl^- > SO_4^{2-} > NO_3^-$$

$$HCO_3^- > Ca^{2+}$$

The water type of the groundwater wells of Eocene-Holocene aquifers that contain TDS between 1100 mg/L and 3500 mg/L is of earth alkaline water with increased portion of alkalis and prevailing sulphate and chloride (52% of the total samples). As EC is a good indicator of water salinity; the statistical processes showed that Na^+ and Cl^- are the main contributor of water salinity. The very high correlations between Na^+-Cl^--Ca^{2+}-Mg^{2+} and some times Ca^{2+}- SO_4^{2-} means that the sediments of carbonate, halite , and some times gypsum are the main structural of the Eocene-Holocene aquifer systems. In these aquifer systems, the groundwater wells that contain EC>2500 µS/cm have lower ratios of Ca^{2+}/Mg^{2+} and $(Ca^{2+} + Mg^{2+})/(Na^+ + K^+)$ than the natural range of limestone aquifer, and have higher ratios of Na^+/Ca^{2+} as assign of natural processes of calcium precipitation (dedolomitization) and ionic exchange with clays (water softening). Thermodynamically, the majority of the aquifer systems are oversaturated with respect to the dolomite, calcite, and undersaturated with respect to, anhydrate, gypsum, and fluorite. Despite the groundwater wells characterize by low ratios of HCO_3^-/Cl^- as a pointer of high salinity water; the study shows Cl^-/Σ(anions) and Na^+/Cl^- are much lower than the hydrological cycle of precipitation. Therefore; the recharged water that feeds Al Jiftlic groundwater wells expose to the following process/s:- mixing with agricultural and waste water during water recharge along Wadi Al Far'a, dissolution of halite and gypsum (evaporite) that interbedded the limestone in the Lisan-Alluvium formation, and mixing with deep brine water. Based on Durov diagram, the groundwater wells of south-eastern in Al Jiftlic area are exposed to higher dissolution or mixing than the north-western wells due to the long time of water recharge. This result determined the primary flow path of the recharge water is from Al Far'a forward the SE of Al Jiftlic. From the chemical point of view; the groundwater wells of this water type (TDS ~1100-3500 mg/L) in Al Jiftlic and Al Auja are absolutely unsuitable for drinking due to high levels of water salinity where i.e. Na^+ and Cl^- are much exceeding the local and national limits for drinking water according to Palestinian and WHO (2005) guidelines. Based on Wilcox (S2-C4), EC-TDS, SAR, SSP, and RSC; the majority groundwater of this water type in Al Auja and Al Jiftlic is classified into doubtful to unsuitable water for irrigate plants of salt-moderately sensitive crops. Beside that; this water type is the main reason that standing behind decreasing the soil permeability during irrigation.

The study showed that 96% of the Eocene-Holocene aquifers contain Na^+ as the main dominant cation and Cl^- as the main dominant anion where the majority sequence of the ions are:

$$Na^+ > Mg^{2+} > Ca^{2+} > K^+$$

$$Cl^- > HCO_3^- > SO_4^{2-} > NO_3^-$$

$$Cl^- > Na^+$$

The study showed that the Eocene-Holocene aquifers contain higher salinity than the Albian-Cenomanian aquifer systems. Salinity is found increases forward to the east of Al Auja, and the south- east of Al Jiftlic as far away from the recharge area. In winter these groundwater wells are shifted toward the dissolution or mixing line relative to summer. In the groundwater of Al Auja and Al Jiftlic wells. The concentration of K^+, Na^+, Cl^-, SO_4^{2-}, and NO_3^-, as well as EC are measured in winter higher than summer; this phenomenon is a natural result of flushing salts and fertilizers (in winter) that formed at the soil zone due to agricultural activities, and increasing mixing with waste water in winter during water recharge along Wadi Al Far'a. In addition to that; the very high evaporation of water in the semi arid zone of low rainfall and hot climate may play an important role in increasing the concentrations of salts at the soil zone level.

In this study; the isotopic composition ($\delta^{18}O$, and δ^2H) lie relatively close to the MMWL as a sign of recent water age of the groundwaters . The D-excess of the sampled groundwater of the study areas are arranged as:

“D-excess of Ein Samia groundwells > Al Auja > Al Jiftlic“

Accordingly; the groundwater wells of Ein Samia and Al Auja feed water from higher watershed than Al Jiftlic groundwater wells. The results show the groundwater wells of Ein Samia did not expose to mixing, while groundwater of Al Jiftlic exposes to simple mixing. Steadiness in $\delta^{18}O$ values through the first and the second sampling is a pointer of similar climatic regime through the few previous years.

The study found direct relation between water salinity (EC) and isotopic composition ($\delta^{18}O$ & δ^2H) due to long distance of chemical reaction of recharging water with carbonate rocks interbedded with salts (marine salts) represented by dissolved calcium and magnesium salts in water [$MgCl_2$, $CaCl_2$, $MgSO_4$, $CaSO_4$]. This study also showed that the deepest groundwaters of Ein Samia have the lowest tritium concentration (the oldest water), while the shallowest groundwater have the highest tritium concentrations (recent water).

The study showed inverse relation ship between groundwater salinity and ^3H concentration toward SE of Al jiftlic area. Based on both ^3H and Cl concentration, the study found that recharge water flow along Al Jiftlic area is from the NW to the SE with average range between 0.025 to 0.098 m/hr through the Alluvium-Lisan formations.

4.2 Recommendations

Because the groundwater wells of Ein Samia are the main source of irrigation in Ramallah district, and the groundwater wells of Al Auja and Al Jiftlic are the main source of irrigation in the eastern basin; this study recommended the following points in order to manage the deterioration in water quality, and to prevent further contamination and to keep sustainable environment :

- Long term spatial and temporal monitoring of groundwaters salinity, groundwaters level and drowdown, and soil salinization.

- Control the soil salinity by :

    - Substituting the serious chemical fertilizers that cause increasing soil salinity by natural fertilizers.

    - Leaching salts from the soil profile: Flush the soil between different yields or applying adequate water is required through irrigation process; these may contribute in dissolve high amount of salts to far away beneath the soil zone.

    - Keeping up high water content in the soil root zone: Water depleted in the soil profile is the main consequence of high evapotranspiration in the eastern basin, maintaining high level of water will cause low a mounts of salt concentration.

    - Improving drainage: The type and the amount of drainage is essential for salinity control, pipe drainage (tiles) is the best drainage method can be used in hot areas assists in lowering the water table below with decreasing salts in the Upper zone.

- The groundwater wells of Ein Samia are recommended to be used for domestic and agricultural.

- Classify the groundwater wells of Al Jiftlic and Al Auja into domestic and agricultural uses according to the water salinity.

- Maintaining the agriculture sustainability by bid farmers to select the best salt-tolerant crops in Al Auja and Al Jiftlic area.

- Controlling the groundwater discharge to keep balance between recharge and discharge water.

- The spring water (AR/020), and the groundwater wells are recommended to be tested for coliform and nitrate from time to time because the recharge water is with contact with the organic matters .

- Substitution the old mechanic pumping machine by developed electrical pumping machine.

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Appendices

Appendix 3.1: The meteorological data of Jericho area between 1996-2004.

Month	Temp (°C)	RH %	Rain (mm)	Press. (Pascal)	Radiation (Watt/m^2)	Evap. (mm)	Wind S (m/sec)
Jan.	13.7	70.8	42.6	1045.6	175.6	57.2	4.8
Feb.	14.7	66.3	28.9	1045.6	187.2	70.9	5.8
Mar.	17.9	58.1	27.5	1041.5	245.3	124.6	7.4
Apr.	22.3	48.4	6.3	1039.5	263.6	180.0	8.9
May	27.5	40.8	0.4	1037.0	331.4	258.8	9.0
Jun.	29.9	43.1		1033.7	356.4	279.6	9.3
Jul.	32.0	43.9		1030.9	363.1	299.5	8.9
Aug.	32.1	49.1		1032.4	352.5	268.5	7.8
Sep.	29.8	48.4		1035.9	306.2	216.9	7.4
Oct.	26.0	53.5	14.0	1039.4	261.0	152.5	6.2
Nov.	20.5	58.3	9.7	1043.1	217.4	94.8	4.9
Dec.	15.6	69.5	35.9	1045.2	171.1	63.9	5.1

Appendix 3.2: The meteorological data for Ein Samia area between 1996-2004.

Month	Temp (°C)	RH %	Rain (mm)	Radiation (Watt/m^2)	Evap. (mm)
Jan	8.9	76.9	121	122	84.7
Feb	9.6	76.5	94.7	140	76.4
Mar	12.9	66.2	65.8	202	154
Apr	15.7	58.7	21.5	239	186
May	19.5	55.8	2.7	281.2	223
Jun	23	61	0	306	271
Jul	24	62	0	242	197
Aug	23.4	74.2	0	209	172
Sep	22.2	71.9	0.63	252	215
Oct	20.1	73.1	14.7	198.1	148.2
Nov	15.2	65.8	82.4	137	82.7
Dec	9.9	69	119	98.3	27.7

Appendix 3.3: Hydrogeological Properties of Ein Samia Groundwater wells

This appendix presents the general hydraulic proprieties of the groundwater wells of Ein Samia area. The hydraulic prosperities included the drowdown, transmissivity, specific capacity, storativity, …etc (Table 3-b).

3.3.1 Ein Samia well no1 (ESW1):

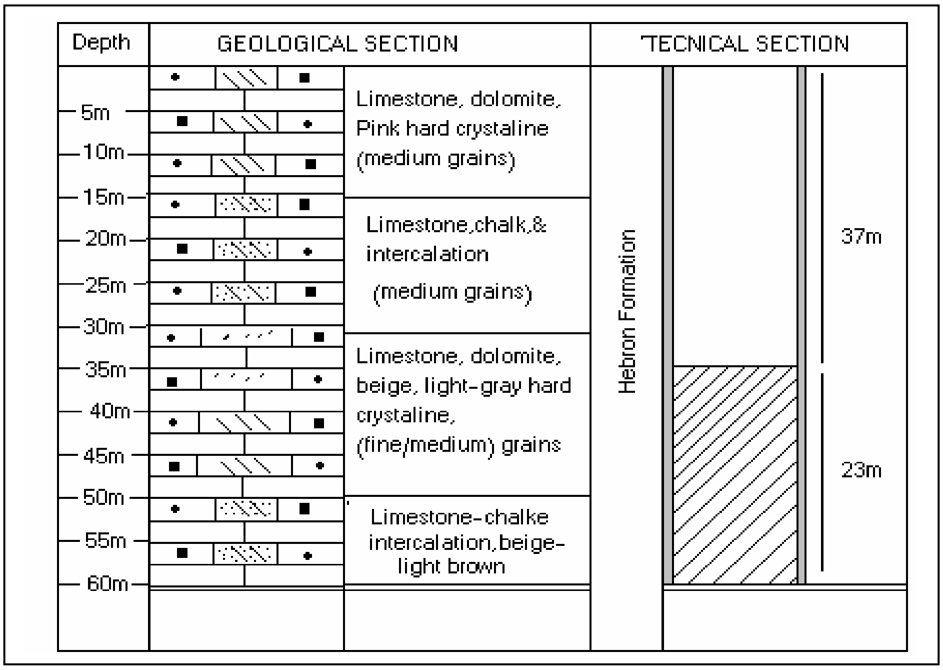
- **Well geological section:**

ESW1 receive water from the Upper Cenomanian aquifer, this groundwater well locates in the Hebron formation, the total thickness of the utilized aquifer is 23m. The Lithology of Upper aquifer consist mainly of fine and medium crushed dolomite and limestone, or chalky-limestone intervening by hard crystalline or limestone intercalation's (Figure 3-a).

- **Hydraulic properties :**

The specific capacity and average transmissivity of the groundwell is 218 m^2/day, and 266 m^2/day respectively (GTZ, 1996). Based on the storativity (7×10^{-5}), the aquifer represent a medium transmitting potentiality and normal value of confined water storativity. The productivity of the utilized aquifer is considered high "class II" (The aquifer can be utilized on lesser regional level). Based on the hydraulic conductivity (11.5 m/d , 0.013cm/s), no available of clays layer through the Hebron formation.

Figure 3-a: The general hydro-lithology cross section of ESW1:

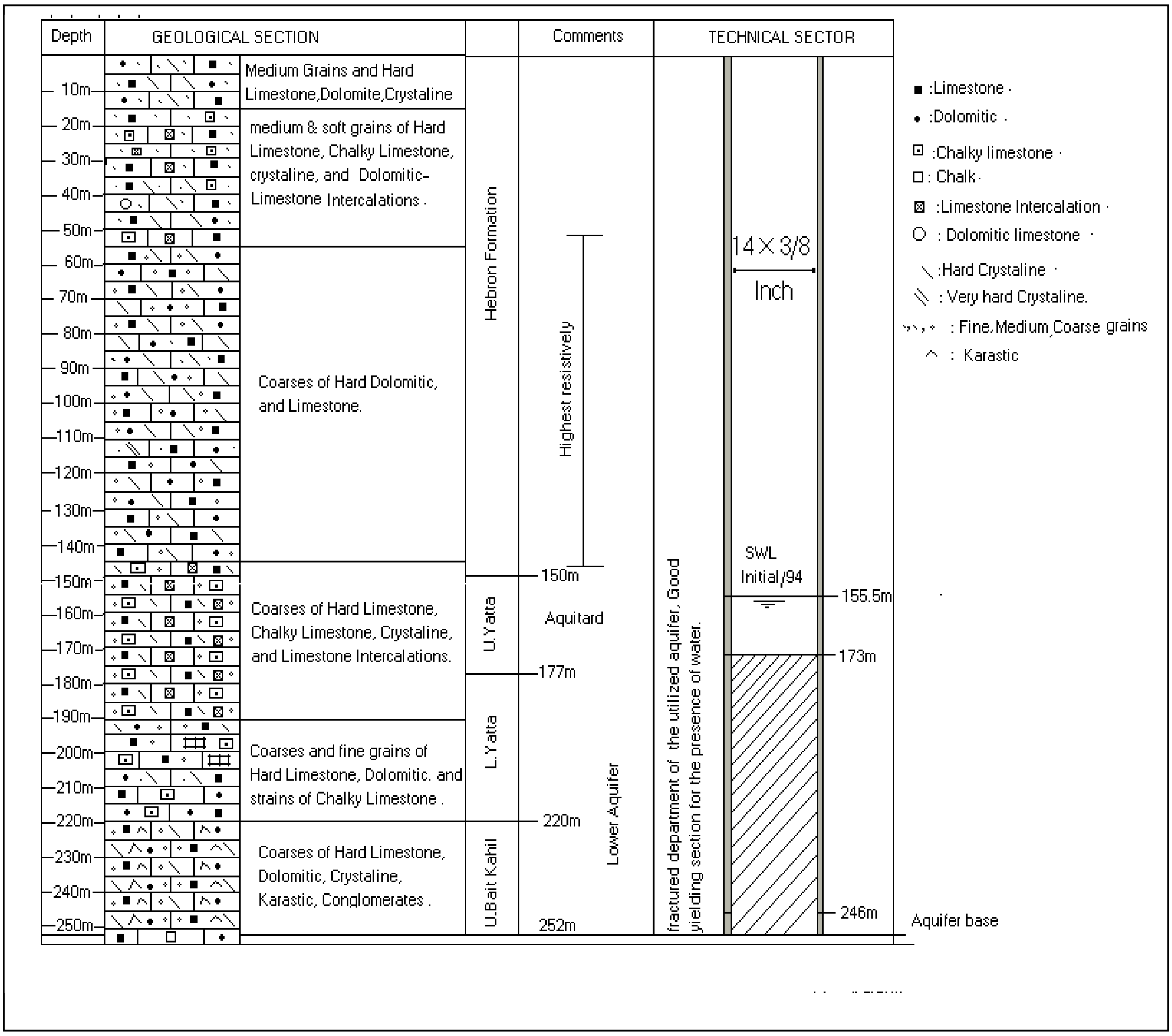


3.3.2 Ein Samia Well no2a (ESW2a)

- **Well geological section**

ESW2a receive water from the Lower Cenomanian aquifer, the well penetrated 150m in Hebron formation, 27m in Upper Yatta formation, 43m in the Lower Yatta formation, and 32m in the Upper Bait Kahil formation that form thickness of 150m. The utilized aquifer is an intermediate, which received water from the last 48m of Yatta formation and 32m of Upper part of the Upper Bait Kahil formation, this means that the total thickness of this intermediate aquifer is 80m. The lithology of intermediate aquifer consists mainly of porous dolomite and limestone. The Upper part of Yatta formation acts as an aquitard layer confining the utilized aquifer. *Figure* 3-b illustrates the geological section of ESW2a, showing the drilling depth, the utilized formation of the aquifer, and the lithology of each depth.

Figure 3-b: The hydro-geological section of Ein Samia well 2a.



- **Hydraulic properties of ESW2a:**

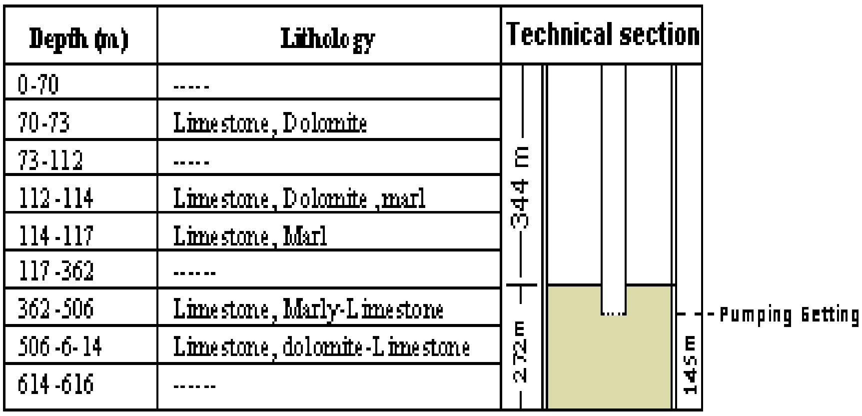
After well development by JWU the specific capacity was increased from 532 to 819 m^2/day, as a result the permeability and transmissivity is increased from 1592 to 1685 m^2/day. The storativity of the ground well range from 1.13×10^{-6} to 3.03×10^{-5} " confined aquifer " (GTZ, 1996). In general, despite the utilized aquifer is limited; the Upper Bait Kahil aquifer has a huge transmitting potentiality and normal value of confined water storativity. This area characterize by fractured rocks and very high electrical resistivity (Excellent aquiferious rocks) . All results indicate the productivity of the utilized aquifer can be considered very high of class I (the aquifer can be utilized on the regional level).

3.3.3 Ein Samia well4 (ESW4):

- **Geological cross section**

ESW4 represent the Lower Cenomanian Aquifer, the utilized aquifer received a great amount of water from the area of the Upper part of the Lower Bait Kahil formation. The total thickness of the utilized aquifer formation is 272m. The Lithology of lower aquifer consists mainly of limestone, dolomite and marly limestone *(Figure 3-c)*.

Figure 3-c: The geological column cross section of ESW4.



Depth (m)	Lithology
0-70	-----
70-73	Limestone, Dolomite
73-112	-----
112-114	Limestone, Dolomite ,marl
114-117	Limestone, Marl
117-362	------
362-506	Limestone, Marly-Limestone
506-6-14	Limestone, dolomite-Limestone
614-616	------

- **Hydraulic properties**

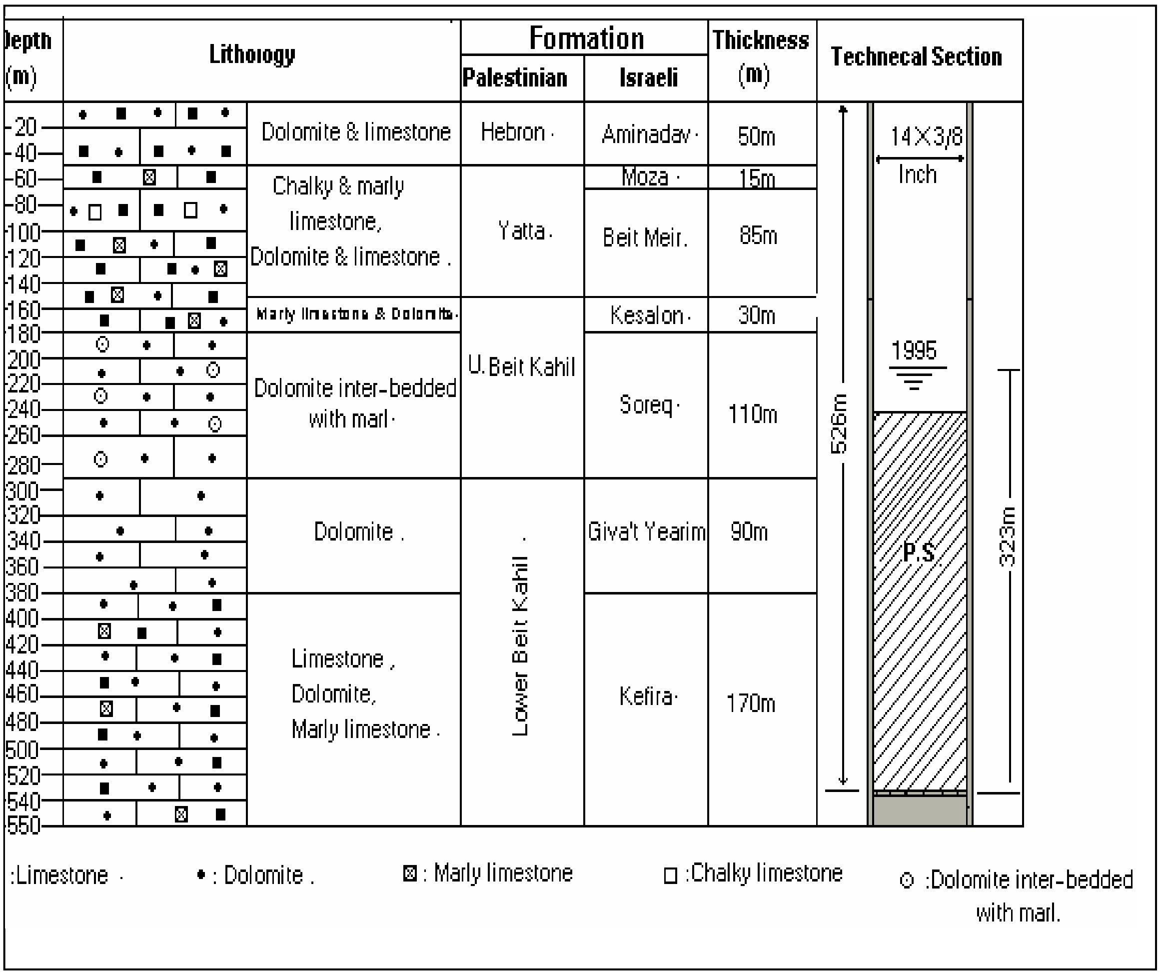
The average measured transmissivity is 17 m^2/day where the aquifer can be utilized for local water supply "small communities. The specific capacity is 14 m^3/day, and the storativity in the aquifer ranges between 10^{-5}-10^{-6} "confined aquifer". The presence of marl is evident within the structure section 220-355 m, but its concentration is not great, these marls considered the main factor in the low permeability of this aquifer. The rocks at this has a medium values of electrical resistively and less development of fracturing.

3.3.4 Ein Samia well 5 (ESW5):

- **Well geological section**

The utilized aquifer represent the Lower Bait Kahil formation, which received water from the last 63m of lower part of Upper Bait Kahil formation, as well as from the 260m thick of the Lower Bait Kahil formation. This means that the total thickness of this intermediate aquifer is 323m. The Lithology of intermediate aquifer consists mainly of porous dolomite and limestone *(Figure 3-d).*

Figure 3-d: The geological section of Ein Samia well 5.



- **Hydraulic properties**

The specific capacity and transmissivity of this groundwell is 38.4 m^3/day per m, and the 59 m^2/day respectively , and the storativity is estimated about 1×10^{-6} “confined aquifer” *(J.Guttman, 1995).* It is obvious that Lower Bait Kahil aquifer has a low permeability (transmitting potentiality) due to high presence of clay at the top of the aquifer (Yatta formation). The productivity of the utilized aquifer is classified as withdrawals for local regional importance (small communities).

3.3.5 Ein Samia Well 4 (ESW6):

ESW6 located at 182.10 E/ 154.00 N, it represents the Lower Cenomanian aquifer. The utilized aquifer received a great amount of water from the Upper Bait Kahil formation (Table 3-a). The geophysical map of the study area shows the rocks of ESW6 (east of the main fault) have a medium value of electrical resistively *(GTZ, 1996)*. The Lithology of intermediate aquifer, consist mainly of dolomite, limestone, marl, chalky limestone, fine and coarse crystalline, highly karats. Because the thickness of the Upper Bait Kahil (about 150 m) is less than that of Lower Bait Kahil formation, the effect of the fault on the hydraulic continuity is expected to be great. The transmissivity of this aquifer is low (16.8 m^2/day) with low specific capacity, where the groundwater represents a local water supply.

Table 3-a: The brief description of stratigraphy and lithology of ESW6.

Depth (m)	Lithology	Formation		Notes
		Palestinian	Israeli	
30	Limestone Dolomite crystalline	Hebron	Aminadav	Fine medium-fine coarse cuttings
59		Yatta	'En Yorqe'am	
72				
83				
135				
142				
152	Limestone, Limonite stains, crystalline	Upper Beit Kahil	Kesalon	
154	Limestone ,Dolomite, crystalline			
158				
160	Limestone, with calcite grystals.			
162	Limestone, with marly limestone			
163	Limestone			presence of water
168	Limestone, with marly limestone,			
170	Limestone			
171	Limestone, dolomitic, crystalline,			

Table 3-b: Hydrological data of Ein Samia groundwater wells (Source: GTZ, and JWU 1996; PWA, 2002; MEG, 2000; CDM, 1998)

Well-ID	Drilled year	Coordinates Km E/N	Well Elev. m (a.s.L)	Well depth m (b.g.l)	S.W.L m (b.g.l)	Pumping Setting m (b.g.l)	pumping rate (m^3/hr.)	Average drawdown (m)	S. Capacity (m^3/d/m)	Transmissivity (m^2/d)	Storativity	Aquifer
ESW1	1964	181.45/155.25	446	60	37	52	110	11	218	266	$7*10^{-5}$	Tur/U.Ceno.
ESW2a	1994	181.75/154.90	417	252	165.63	220	167.5	7.48	819	1685	$1.13*10^{-6}-3.03*10^{-5}$	M. Ceno
ESW4	1990	182.25/155.45	432	616	344	471	60	115	14	17	$10^{-5}-10^{-6}$	L. Ceno.
ESW5	1980	181.55/155.25	430	526	203	357	190	130	38.4	59	$1*10^{-6}$	L. Cen.
ESW6	1990	182.10/154.00	432	172						16.8		L. Ceno.

Appendix 3.4: The groundwater chemical parameters of the study area of Ein Samia group.

Well code	Coordinate (Km)		Well Depth	Well Elev.	Date	EC	Temp.	PH	Ca^{2+}	Mg^{2+}	Na^+	K^+	NH_4^+	HCO_3^-	Cl^-	SO_4^{2-}	NO_3^-	F^-	PO_4^-
	East	North	(m)	(m)		(µS/cm)	(°C)		(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)
18-15/001	181.45	155.25	60.3	446	28/07/2003	475	21	7.81	56.90	22.80	18.80	2.45		244.80	35.85	15.96	13.25	0.14	0.00
18-15/001	181.45	155.25	60.3	446	21/07/2004	504.6	21.3	7.57	56.11	29.16	18.60	1.20	0.01	237.98	37.81	17.00	25.10		0.01
18-15/002a	181.75	154.9	252	417	28/07/2003	516	22	7.40	60.10	21.30	19.20	2.10		256.28	34.75	15.03	17.17	0.12	
18-15/002a	181.75	154.9	252	417	21/07/2004	515	22.6	7.30	56.10	29.16	20.59	1.40	0.04	244.08	35.36	14.00	25.60		0.03
18-15/004	182.1	154	616	432	28/07/2003	540	24.2	7.07	58.00	32.00	22.00	2.30		320.00	34.00	12.00	13.00	0.13	
18-15/004	182.1	154	616	432	21/07/2004	542	26	7.15	64.13	28.30	21.98	1.50	0.01	329.51	35.36	13.00	11.70		0.50
18-15//005	181.55	155.25	526	430	28/07/2003	507	22	7.20	50.30	27.72	18.00	1.65		250.60	30.43	9.50	13.50		
18-15/006	182.25	155.45	172	432	28/07/2003	468	22.3	7.64	50.50	22.80	17.80	4.50		231.88	35.60	12.77	16.58	0.11	
18-15/006	182.25	155.45	172	432	21/07/2004	460	26	7.15	56.11	15.72	21.10	2.40		225.78	35.45	14.00	20.20		0.02

Appendix 3.5: The groundwater chemical parameters of the study area of Al Auja group.

Well code	**Coordinate (Km)**		**Well Depth**	**Elev.**	**Date**	**EC**	**Temp.**	**PH**	**Ca^{2+}**	**Mg^{2+}**	**Na^{+}**	**K^{+}**	**HCO_3^{-}**	**Cl^{-}**	**SO_4^{2-}**	**NO_3^{-}**	**F^{-}**
	East	North	**(m)**	**(m)**		**(µS/cm)**	**(̊C)**		**(mg/l)**	**(mg/l)**	**(mg/l)**	**(mg/l)**	**(mg/l)**	**(mg/l)**	**(mg/l)**	**(mg/l)**	**(mg/l)**
AR/020	186,75	151,42	SPRING	20	28/07/2003	527	20.8	7.39	42.4	32.6	28.4	6.81	292.9	32	15.4	11	0.17
AR/020	186,75	151,42	SPRING	20	11/01/2004	531	20.2	7.82	58.14	27.01	32.4	2	315.61	48.5	24.8	22.4	
AR/020	186,75	151,42	SPRING	20	14/05/2004	535	20.9	8.08	45	28	23.86	2.5	296	42.85	11	11	
19-15/011	194.59	150.94	103	-248	11/01/2004	923	22.1	7.25	60.88	54.63	81.1	15.78	384.43	124.5	98.75	12.95	
19-15/005	194,75	150,44	108	-242	14/05/2004	1023	23.4	7.21	62.52	64.28	92	16.2	510.87	99.26	56	9.9	0.05
19-15/012	194.59	150.94	103	-248	04/08/2003	1054	23.8	7.01	60.1	58.3	94.8	34.74	463.75	123.5	40.66	11.21	0.26
19-15/005	194,75	150,44	108	-242	11/01/2004	1094	22.9	6.95	69.74	58.95	108.6	23.67	489.18	147.7	71	11.7	
19-14/001	195.91	149.99	59	-268	04/08/2003	1920	24.4	6.88	80.1	78.7	230	34.74	585.79	342.3	113.9	22.5	0.28
19-14/001	195.91	149.99	59	-268	11/01/2004	2310	22.9	6.78	84.17	87.48	315.1	34.72	577.32	500.2	178.4	42.2	

Appendix 3.6: The groundwater chemical parameters of the study area of Al Jiftlic group.

Well code	Coordinate (Km)		Well Depth (m)	Elev. (m)	Date	EC	Temp.	PH	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	HCO_3^{-}	Cl^{-}	SO_4^{2-}	NO_3^{-}	F^{-}
	East	North				(µS/cm)	(◌̊C)		(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)
19-16/008	196,78	169,67	66	-260	11/01/2004	752	20.7	7.47	90.58	27.70	79.1	1.58	353.92	150.3	24.4	39.5	0
19-17/034	192,74	178,37	150	-148.88	11/01/2004	788	20.6	7.18	84.17	37.42	58.2	3.67	306.63	79	72.1	35.6	0
19-17/034	192,74	178,37	150	-148.88	14/05/2004	826	22.4	7.39	84.16	45.62	68	3.2	341.71	84.37	31	41.8	0.43
19-17/027	196.25	171.47	60	-248.9	09/01/2004	1900	23	5.2	105.81	86.51	219.3	14.2	463.8	514.5	12.5	18	0
19-17/056	194.6	174.1	147	-205	14/05/2004	2030	24.4	7	132.26	75.82	178.7	11.3	378.3	425.4	72	48.6	0
19-17/056	194.6	174.1	147	-205	11/01/2004	2070	21.6	6.9	140.28	89.91	240.8	14.2	488.2	648.9	98.4	67.6	0
19-17/027	196.25	171.47	60	-248.9	04/08/2003	2090	25.1	6.9	129.00	91.80	249.6	20.4	390.5	523	49.6	24	0.3
19-17/046	192.56	176.23	147	-167	14/05/2004	2310	25.9	7.1	128.25	60.75	232.8	12.9	360	453.8	108	65.4	0.1
19-17/027	196.25	171.47	60	-248.9	14/05/2004	2350	25.1	7.1	136.27	106.92	197.6	14.6	384.4	518.8	64	15.8	0.06
19-17/001	196.9	170.74	90	-255	09/01/2004	2380	23	6.9	140.28	60.75	305.6	20.5	451.5	570.4	40.9	26.2	0
19-17/046	192.56	176.23	147	-167	11/01/2004	2430	24	6.8	141.08	75.33	305.6	4.7	463.8	654.9	135.9	114.9	0
19-17/007	196.64	172.29	74	-243.7	09/01/2004	2560	23.5	7.3	124.25	95.74	234.6	48.9	372.2	677.8	83.6	48.7	0
19-17/007	196.64	172.29	74	-243.7	14/05/2004	2630	24.6	7.1	136.26	87.48	241	33.2	335.6	652.3	45	27	0.1
19-17/021	196.25	170.25	81	-256.2	10/05/2003	2970	24.6	6.7	188.00	140.00	259	26	310	836	25	43	5.2
19-17/054	197.6	169.15	75	-273	11/01/2004	2990	23.4	6.8	140.28	150.66	337.9	36.3	439.3	1099.2	64.7	33.9	0
19-17/021	196.5	170.6	81	-256.2	14/05/2004	3330	24.2	6.9	192.37	126.36	271	19.4	390.5	865	86	26.5	0.1
19-17/008	196.25	170.25	72	-250.7	14/05/2004	4110	25.1	7	168.33	160.38	387.1	27.5	355.6	1099	134	26.5	0.2
19-17/008	196.25	170.25	72	-250.7	09/01/2004	4420	24.8	6.8	188.38	170.10	406.9	37.9	314.9	1181.7	133.8	23.6	0
19-16/005	199.59	168.85	68	-290	11/01/2004	4820	23.9	6.6	266.93	222.10	470.9	30	510	1397	318.2	73	0
19-17/028	198.15	170.5	72	-267.9	04/08/2003	4840	26.1	6.7	211.60	214.30	636.6	55.2	390.5	1577	81.6	33.7	0.3
19-17/028	198.15	170.5	72	-267.9	11/01/2004	5100	23.5	6.7	200.40	214.33	632.7	45.8	427.1	2056.5	63.3	45.9	0
19-16/001	196.77	169.9	68	-260	09/01/2004	5150	23.6	6.7	266.13	151.63	575.6	31.6	427.1	1192.4	111.5	46.4	0
19-17/028	198.15	170.5	72	-267.9	14/05/2004	5180	24.8	7	252.49	187.11	460	37.2	451.6	1432.2	74	26	0
19-16/001	196.77	169.9	68	-260	14/05/2004	5310	27.4	6.8	328.63	160.38	411.5	22.6	463.8	1418	148	30.5	0.1

Appendix 3.7: The salinity tolerance rating for selective agricultural groups (Hoffman et al., 1981).

Salt-Sensitive Crops Group (<1000 µs/cm)			
Almond	Black berry	Okra	Raspberry
Apple	Boysenberry	Onion	Strawberry
Apricot	Carrot	Orange	
Avocado	Grapefruit	Peach	
Bean	Lemon	Plum	
Salt-Moderately Sensitive Crops Group (1000-3000 µs/cm)			
Alfalfa	Clover	Grape	Peanut
Bent grass	Corn(forage, grain, sweet)	Lettuce Lovegrass	Pepper
Broad bean	Cowpea	Meadow Foxtail	Potato
Broccoli	Cucumber	Millet Foxtail	Radish
Cabbage	Flax	Orchard grass	Rhode grass
Rice paddy	Sweet potato	Sorghum	Tomato
Sesbania	Timothy	Spinach	Trefoil big
Sugarcane	Vetch		
Salt-Moderately Tolerance Crops Group (3000-8000 µs/cm)			
Barley (forage)	Harding grass	Sudon grass	
Beet garden	Olive	Trefoil, baird food	
Brome grass	Ryegrass	Wheat	
Canary grass reed	Safflower	Wheat grass , crested and slender	
Fescue tall	Soybean	Wildrye, beardless	
Salt-Tolerant Crops Group (8000-1200 µs/cm)			
Barley grain	Sugar beet		
Bermuda grass	Wheatgrass, fairway and tall		
Cotton	Wildrye		
Date Palm			

Appendix 3.8 :The remaining ^{3}H-concentration relative to the initial decay through precipitation in Israel.

Time period	^{3}H in precipitation (TU)	Remaining ^{3}H in 2003 (TU)	Remaining ^{3}H in 2004 (TU)
1950	5	0.25	0.24
1960	30	2.68	2.53
1961-1962	125	12.15	11.49
1963	803	84.90	80.27
1964	402	44.96	42.5
1965	261	30.88	29.19
1966-1968	113-109	14.14 -15.26	13.37-14.43
1969-1972	59-54	8.74-9.47	8.26-8.95
1973-1981	41-21	7.6-6.1	7.19-5.77
1981-1991	15-8	4.36-4.08	4.12-3.85
1991-2003	4.5-8	4.08 - 5.67	3.85-4.02

Appendix 3.9: The strength of the relation between the different studied variables based on Pearson correlation coefficients.

	Temp	**Ph**	**EC**	**TDS**	**T.H**	**SAR**	**Ca^{2+}**	**Mg^{2+}**	**Na^{+}**	**K^{+}**	**HCO_3^-**	**Cl^-**	**SO_4^{2-}**	**NO_3^-**	**TDS/EC**	Na^+/Cl-	Ca^{2+} /SO_4^{2-}	Ca^{2+}/HCO3-	SI.$_{Anhydrite}$	SI.$_{Aragonite}$	SI.$_{Calcite}$	SI.$_{Dolomite}$	SI.$_{Gypsum}$
Temp	1.00																						
Ph	0.35	1.00																					
EC	0.54	-0.68	1.00																				
TDS	0.48	-0.71	0.99	1.00																			
T.H	0.52	-0.68	0.96	0.95	1.00																		
SAR	0.44	-0.72	0.88	0.89	0.78	1.00																	
Ca^{2+}	0.47	-0.70	0.97	0.99	0.96	0.84	1.00																
Mg^{2+}	0.49	-0.65	0.98	0.97	0.98	0.79	0.96	1.00															
Na^{+}	0.48	-0.72	0.97	0.98	0.91	0.95	0.96	0.92	1.00														
K^{+}	0.36	-0.68	0.71	0.74	0.70	0.81	0.70	0.63	0.77	1.00													
HCO_3^-	0.25	-0.60	0.52	0.57	0.59	0.67	0.56	0.48	0.60	0.74	1.00												
Cl^-	0.48	-0.67	0.99	0.99	0.94	0.86	0.98	0.96	0.97	0.70	0.48	1.00											
SO_4^{2-}	0.34	-0.63	0.72	0.77	0.77	0.65	0.79	0.74	0.73	0.52	0.57	0.70	1.00										
NO_3^-	0.14	-0.36	0.42	0.47	0.36	0.45	0.45	0.45	0.47	0.12	0.16	0.43	0.62	1.00									
TDS/EC	-0.53	0.19	-0.44	-0.32	-0.40	-0.29	-0.28	-0.43	-0.34	-0.17	0.13	-0.35	-0.10	0.04	1.00								
Na^+/Cl^-	-0.33	0.39	-0.73	-0.72	-0.64	-0.58	-0.70	-0.73	-0.69	-0.35	0.01	-0.77	-0.41	-0.38	0.41	1.00							
Ca^{2+} /SO_4^{2-}	-0.22	0.38	-0.33	-0.35	-0.38	-0.45	-0.34	-0.31	-0.37	-0.40	-0.57	-0.25	-0.67	-0.41	-0.01	-0.04	1.00						
Ca^{2+}/HCO_3^-	0.49	-0.61	0.94	0.94	0.88	0.78	0.95	0.92	0.91	0.60	0.32	0.96	0.68	0.42	-0.40	-0.79	-0.25	1.00					
SI.$_{Anhydrite}$	0.45	-0.70	0.82	0.85	0.82	0.85	0.84	0.79	0.85	0.72	0.73	0.78	0.86	0.50	-0.15	-0.44	-0.77	0.75	1.00				
SI.$_{Aragonite}$	0.04	-0.02	0.37	0.36	0.36	0.34	0.38	0.36	0.34	0.26	0.47	0.33	0.21	0.12	0.20	-0.07	-0.40	0.32	0.48	1.00			
SI.$_{Calcite}$	0.07	-0.04	0.40	0.39	0.38	0.38	0.42	0.38	0.37	0.28	0.46	0.37	0.24	0.13	0.16	-0.10	-0.41	0.37	0.51	0.99	1.00		
SI.$_{Dolomite}$	0.13	-0.06	0.50	0.46	0.49	0.42	0.48	0.51	0.44	0.31	0.42	0.45	0.25	0.16	-0.06	-0.20	-0.37	0.44	0.52	0.95	0.95	1.00	
SI.$_{Gypsum}$	0.44	-0.70	0.81	0.84	0.81	0.84	0.84	0.78	0.84	0.72	0.73	0.78	0.86	0.50	-0.14	-0.44	-0.77	0.75	1.00	0.48	0.52	0.52	1.00

الملخص

دراسة هيدروجيوكيميائية ونظائرية للمياه الجوفية لآبار عين سامية، والعوجا، والجفتلك

أجريت هذه الدراسة في مناطق عين سامية، العوجا، والجفتلك التي تقع في الانحدار الشرقي لطبوغرافية فلسطين بين خطي عرض 180-200 شرقاً وخطي طول 148-180 شمالاً.

هدفت هذه الدراسة بشكل رئيسي إلى تزويد قاعدة بيانات هيدرولوجية، هيدروجيولوجية، هيدروكيميائية، ونظائرية من اجل تقييم جودة المياه الجوفية، وتحديد المصادر الرئيسة للملوثات، وتقدير عمر المياه الجوفية، وحساب معدل كمية المياه السطحية الجارية، وكمية الرشح، وكمية التغذية في حوض التصريف لمنطقة العوجا.

تشير الدراسة أن الملوحة هي المشكلة الرئيسة في مياه الآبار الجوفية لمناطق العوجا، والجفتلك من الحوض الشرقي حيث وُجِدَ أن تركيز الصوديوم والكلور هي الأيونات السائدة في المياه الجوفية الضحلة. ومن الناحية الهيدروجيوكيميائية، دلت الدراسة أن نوعية معظم المياه التابعة للأحواض المائية الأيوسونية-الهلوسونية هي مياه قلوية ترابية مع زيادة القلويات وسيادة الكبريتات والكلوريدات، وهذا يعود إلى إذابة الأملاح في المياه الجارية خلال المسافات الطويلة عبر الصخور الدولوماتية الكربوني ة والتي يتخللها طبقات من الصخور الطباشيرية، الجبسية، وطبقات غير منفذة من الأملاح المارلية والتي تتبع مرحلة تكوينات اللسان-الطمية الحديثة. أثبتت الدراسة الإحصائية وجود علاقات بمعاملات ارتباط عالية بين أيونات Na، Cl، Ca، Mg وفي بعض الأحيان علاقة ارتباط عالية بين ايونٍ SO_4 و Ca كدليل على وجود الصخور الكربونية، والأملاح، وفي بعض الأحيان الجبس في المكونات الجيولوجية لمناطق العوجا والجفتلك. توصلت الدراسة أن معظم المياه الجوفية تتعرض إلى عمليات ترسيب الكالسيوم وعملية التبادل الأيوني بين Ca^{+2} و Mg^{2+} مع Na^+ و K^+ وكذلك تعرض المياه الجوفية في الجفتلك إلى عمليات خلط مع المياه العادمة المنزلية والزراعية التي تتدفق على طول واد الفارعة. ومن الناحية الثيرموديناميكية، أظهرت جميع المياه الجوفية أنها فوق الإشباع بالنسبة للمعادن الذائبة كالكلسس، الدولوميت، وتحت الإشباع بالنسبة إلى الجبس، الأنهيدريت، والفلوريت. من وجهة النظر الكيميائية, أظهرت الدراسة أن معظم مياه الآبار الجوفية مناطق العوجا والجفتلك تواجه تدهوراً في جودة مياه الشرب، حيث أن معظم المكونات الكيميائية مثل تركيز Na^+ و Cl^- قد تجاوزت كثيراً قيم منظمة الصحة العالمية لعام 2005، وهذا يعني أن تلك المياه غير مناسبة لأغراض الشرب. صُنفت كفاءة المياه الزراعية ما بين مسموح به إلى مشكوك فيه لاستخدامات ري المحاصيل الحساسة للملوحة في منطقة العوجا، ومشكوك فيه إلى غير ملائمة لاستخدامات ري المحاصيل متوسطة الحساسية للملوحة في منطقة الجفتلك، مع إظهار قليل من الخطورة على نفاذية التربة.

إن نوع مياه الخزانات الألبية–السينومانية هي من القلويات الترابية مع سيادة البايكربونات في منطقة عين سامية وبزيادة قليلة في القلويات في منطقة الجفتلك. فسرت الدراسة علاقات الارتباط العالية جداً بين الأيونات السائدة Ca^{+2} و HCO_3^- بأنها ناتجة عن الماء المتدفق والمرتشح عبر طبقات مختلفة من الصخور الكربونية الرسوبية. اعتمادا على الانحراف المعياري المنخفض للعناصر المقاسة ، تفترض الدراسة أن تكون المياه الجوفية لآبار عين ساميا تشترك في منطقة التغذية و/أو أن الخزانات السينومانية متصلة مع بعضها بسبب وجود تصدعات أرضية. أما من الناحية الثيرموديناميكية، فقد دلت الدراسة أن ماء الخزان السينوماني الأعلى في عين سامية فوق مشبعة بالنسبة إلى معدن الكلس، الدولوميت، الأنهيدريت، الجبس، والفلوريت، بينما مياه الخزانات الألبية–السينومانية المتوسطة غير مشبعة بالنسبة إلى المعادن المذكورة سابقاً. تشير الدراسة أن جميع المكونات الكيميائية والفيزيائية المقاسة في آبار عين سامية أقل من القيم الموصى بها من وزارة الصحة العالمية لعام2005 مما يعني أن المياه مقبولة للأغراض الشرب والزراعة.

وفي ضوء التحليل النظائري لعناصر $^{3}H, ^{2}H, ^{18}O$ فان المحتوى النظائري للعينات يتراوح بين –4.9 إلى –6 بالنسبة إلى $\delta^{18}O$، ومن –21.8 إلى –26.7 بالنسبة إلى $\delta^{2}H$. وبالرجوع إلى شكل العلاقة بين $\delta^{18}O$ و $\delta^{2}H$، فإن جميع العينات رسمت حول خط البحر الأبيض المتوسط مما يؤكد حداثة هذه المياه وأنها من مياه الأمطار. بينما تدل الدراسة الإحصائية أن أفضل علاقة بين $\delta^{18}O$ و $\delta^{2}H$ في مناطق الدراسة هي المعادلة الخطية $\boldsymbol{\delta^{2}H = 5.48*\delta^{18}O + 6}$.

فسرت الدراسة العلاقة الطردية بين ملوحة المياه والمكونات النظائرية ($\delta^{18}O$ & $\delta^{2}H$) في آبار العوجا والجفتلك بسبب العلاقة الطردية بين بعد منطقة التصريف وكمية الأملاح البحرية والرسوبيات الكربونية المذابة . اعتماداً على الدمج بين نتائج مكونات ^{3}H و تركيز أيونات Cl في الماء ، فان المياه الجوفية في منطقة الجفتلك تحصل على التغذية من حوض التصريف لمنطقة الفارعة والباذان. وقد تم تحديد اتجاه تدفق المياه نحو الجنوب الشرقي وبمعدل سيلان يتراوح بين 0.025 إلى 0.098 م/ساعة . تدل قيم ^{3}H الواقعة بين 0.4 إلى 5.4 TU، بأن المياه الأقدم في تلك الآبار الجوفية تعود إلى ما بعد 1950 حيث تعتبر مياه الآبار الجوفية في منطقة الجفتلك أكثر قدماً من العوجا. على الرغم من أن جميع الآبار الجوفية في عين ساميا تتشارك في منطقة التغذية، لقد أظهرت الدراسة بان المياه الجوفية الأكثر عمقاً في تلك المنطقة تحتوي على تركيز ^{3}H أعلى من تلك المياه الأقل عمقاً.