Deanship of Graduate Studies

Al-Quds University

Hydrochemical and Isotopic Composition of Groundwater in Jericho Area

Mohammad Rushdi Mohammad Al-Jundi

M.Sc. Thesis

Jerusalem – Palestine

2005

Hydrochemical and Isotopic Composition of Groundwater in Jericho Area

Prepared By:

Mohammad Rushdi Mohammad Al-Jundi

B.Sc: Tikrit University -Republic of Iraq

Supervisor: Dr Amer Marie

A thesis Submitted in Partial Fulfillment of

Requirements for Degree of Master of

Environmental Studies

Department of Earth and Environmental Sciences

Al-Quds University

2005

Al-Quds University
Deanship of Graduate Studies
Program of Environmental Studies
Department of Earth and Environmental Studies / Faculty of Science and Technology

Thesis Approval

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Prepared By: Mohammad Rushdi Mohammad Al-Jundi

Registration No.: 20111456

Supervisor: Dr Amer Marie

Master thesis and accepted. Date 11/9/2005

The names and signatures of the examining committee member are as follows:

1- Head of committee	Dr. Amer Marie	Signature.......................
2- Internal Examiner	Dr. Qasem Abdul-Jaber	Signature.......................
3- External Examiner	Dr. Marwan Ghanem	Signature.......................

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Dedication

To my parents, the candles who's light the road for me.

To my brothers, and sisters for their help and encouragement.

To my wife "Inas" for her continuous, unlimited help and support.

To my lovely son "Luai", the future of my life.

Mohammad

Declaration:-

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

Signed ....

Mohammad Rushdi Mohammad Al-Jundi

11/ September 2005

Acknowledgments:-

I would like to thank my Supervisor Dr. Amer Marie the academic affairs assistant in Al-Quds University for his support and fruitful suggestion during the course of my study. Special thank go also to the other committee members Dr. Qasem Abdul-Jaber, Dr. Marwan Ghanem for their important suggestions, lot thanks goes also to the other Department members of Earth and Environmental Sciences in Al-Quds university (Dr. Adnan Lahham, and Dr. Mutaz Al-Qutb).

I am grateful to the staff of the Environmental Laboratory members in Al- Quds University; for their help in the chemical analysis of the study samples, lot thanks go also to Mr. Mohammad Sbeih for his great help especially in GIS software, and Arcview maps.

Thanks also extended to the members of the Palestinian mean meteorological office in bier nabalah for their great help in the historical rainfall data.

Abstract:

During the last two years 30 groundwater samples were collected from Jericho in addition of 37 surface water samples were collected from flood water of Wadi Al-Quilt and five samples from its channel, Chloride content of floodwater collected during the rainy months of 2003 has an average of 37.05 mg/L and the Na/Cl ratio is 0.83 which is close to the ratio in the rainwater. The $SO4^{-2}$ and the $NO3^{-}$ concentrations are less than 1.0 mg/L. A small increase in Ca^{+2} contents with an increase in HCO_3^{-} was noticed during the flood took place during March 2003 which indicate a relative long duration time of water in the soil horizon. The Ca^{+2}, Mg^{+2} content are parallel to each other indicating that they are originated from the same source which is carbonate rocks, while the Ca^{+2} is higher than Mg^{+2} that is related to the dominant of Limestone in the rock than dolomite. The Na/Cl ratio in all surface water samples is less than the ratio of Na/Cl in wastewater in the region which is 1, and closed to the ratio of rainwater 0.86, meaning that the influent of human activity in the catchments area is limited. The groundwater mixing interpretation shows that there is a high percentage of surface water infiltration into the groundwater reservoir and the ratios from surface water input to the groundwater ranging between 70 % up to 100 % in the western part of Jericho area and decreases eastward and far away from Wadi Al-Quilt and reach 20 % - 10 %, this conclusion conceder by the chemical results of the ground water samples, which show a low content of chloride 260 mg/L in the western part, and increased to 1700 mg/L in the eastern part, in the same direction the electrical conductivity ranging from 1400 μs/cm up to 6800 μs/cm toward the east, Na^{+},Ca^{+2} concentration increasing from 140 mg/L up to 940 mg/L, 65 mg/L up to 200 mg/L respectively in the east. In the other hand the tritium content rebut this theoretical mixing due to the high content of tritium in the groundwater samples which is parallel to the increasing of salinity toward the east, this mean the traveling time of the flooding water is very short but enough to dissolute the minerals of the Lisan formation as a result the groundwater quality is degraded, and utilized the use of the available water for both domestic and agricultural activities.

List of Definitions

‰	Per mil
ARIJ	Applied research Institution – Jerusalem
B^-	Negative Beta Particles
Ca^{2+}	Calcium (ion)
Cl^-	Chloride (ion)
CO_2	Carbon dioxide
EC	Electrical Conductivity
EDTA	Ethylenediaminetetraacetic Acid
GTZ	Deutsche Gesellschaft fur Technische
HCl	Hydrochloric acid
HCO_3^-	Bicarbonate (ion)
IAEA	International Atomic Energy Agency
IPCRI	Israel Palestine Center for research Information
K^+	Potassium (ion)
MCM/y	Million Cubic meter Per Year
Meq/L	Milliequivalent Per Liter
Mg^{2+}	Magnesium (ion)
Mg/L	Milligram Per liter
μm	Micrometer
MMWL	Mediterranean Meteoric Water Line
MWL	Meteoric Water Line
Na^+	Sodium (ion)
NO_3^-	Nitrate (ion)
PET	Polyethylene Bottles
pH	Acidity Value
PWA	Palestinian Water Authority
SMOW	Standard Main Ocean Water
SO_4^{2-}	Sulfate (ion)
T	Temperature
TDI	Total Dissolved Ions
VSMOW	Vienna Standard Main Ocean Water
WBWD	West Bank Water Department
WQ	Wadi El-quilt
WQC	Wadi El-quilt Channel
1TU	One Tritium Unit
^2H	Deuterium
^3H	Tritium
^3He	Helium
^{18}O	Oxygen – 18

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Hydrochemical and Isotopic Composition of Groundwater in Jericho Area

Prepared By:Mohammad Rushdi Mohammad Al-Jundi

Supervisor: Dr Amer Marie

CHAPTER 1

1. INTRODUCTION

Groundwater quality is essential for the health, economy, stability, and development in the Middle East. The availability of water and the suitable climate in the Jordan Valley provide the ideal place for establishing the first settlement in the history of human species before 7000 year. Inhabitants in the lower Jordan Valley during the history, depend on local groundwater, for developing their agriculture activities. Furthermore, due to the anticipated increase in tourism, economic growth and viability are linked to the preservation and the increase in sustainable water sources. Yet, the only source of freshwater in this area is derived from groundwater, which is tapped from the aquifer systems of the shallow Plio-Pleistocene and the deep Cenomanian (Eastern Mountain) aquifers. The groundwater quality of the shallow aquifer system has been deteriorating in this area for some time. In the Jericho region, for example, dissolved chloride concentrations have increased to more than 2000 mg/L during the last 30 years **(**Marie and Vengosh, 2001).

The study area is part of Jericho area which bounded by the Jordan River in the east, Wadi Fassayil in the north, the Kafr Malik- Taybe hills in the west and Wadi-el-Quilt in the south (Fig. 1.1).

The main town, Jericho, is located at the southern edge of the study area. It is the site of civilization’s oldest known urban settlement, founded in the seventh millennium B.C. The modern town is situated at a junction of roads leading to ElJiftliq, Ramallah, Jerusalem and Hussein Bridge on the Jordan

River. The chemical composition, salinity, and the isotopic analysis of the groundwater well used as an important indicator to evaluate the quality of the groundwater, and the utilization of the groundwater for both domestic and agriculture application, these indicators are used to evaluate the sources and mechanisms of salinity in groundwater of Jericho area, in order to develop a plan for future water management, including protection and sustain the limited water resources.

The major problem in the study area is the increasing of salinization (i.e., chloride content) of local groundwater. The high levels of salinity degraded the quality of the available water, and limit the utilization of groundwater for both domestic and agriculture applications. The aim of this study is to evaluate the sources and mechanisms of the salinity of the groundwater in Jericho area.

1.1 Climate of the study area:

Jericho area locates in the Rain shadow of the West Bank and receives about 150 mm/y rainfall, during the winter months which extend from October until April. The distribution of this amount varied from year to anther but 90% of this rainfall take place between November and March, (Golani, 1972). The average temperature is 24 ºC during winter season and 30 ºC during the Summer season. (ARIJ, 2004).

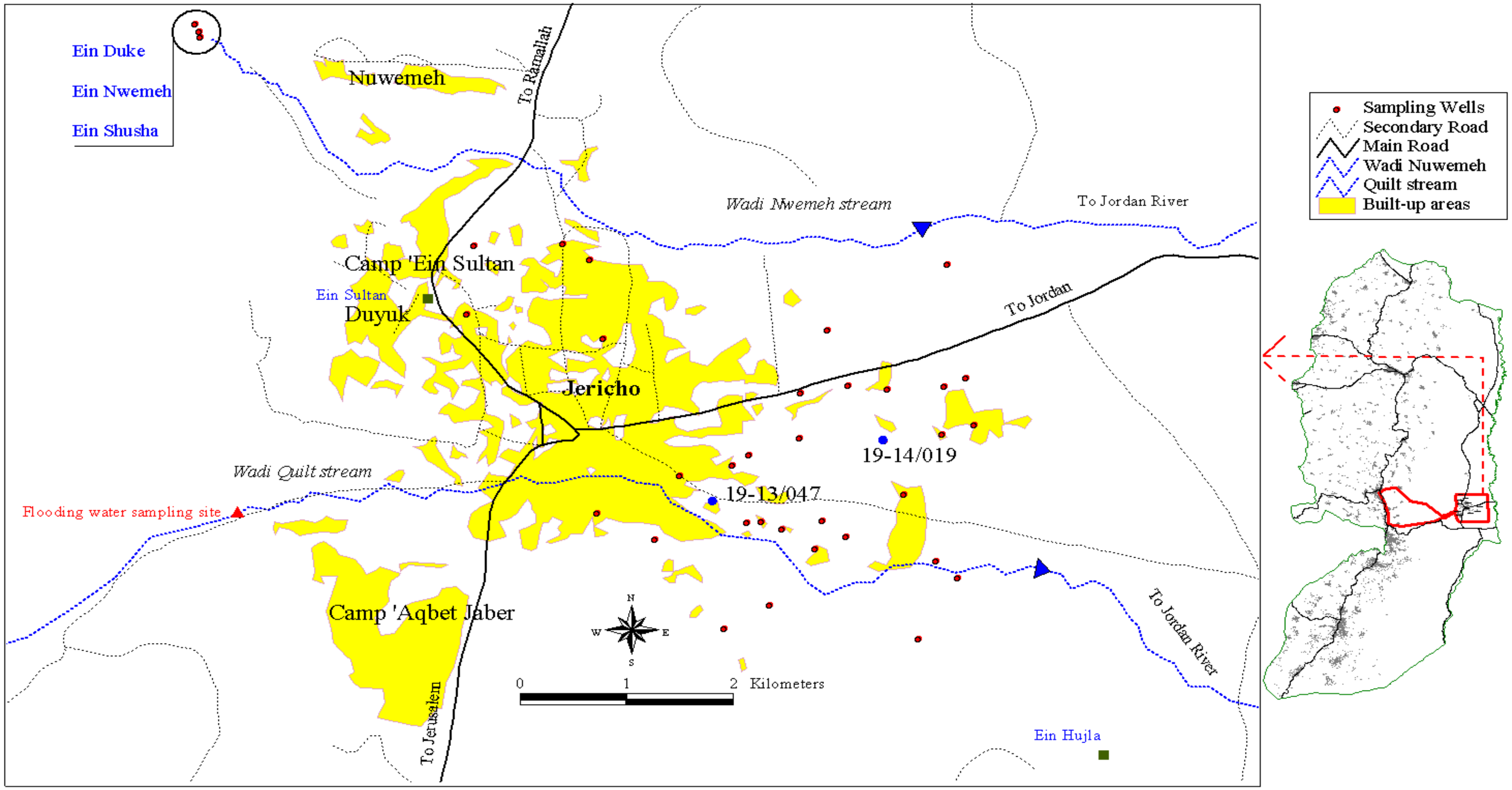

Fig 1.1: Location of the Study Area.

1.2 Land Use:

Jericho District locates in the eastern part of the West Bank with an area of 353.3 km^2. It is bordered geographically from the West by Ramalah – Al-Bereh District, and with Jenin District from the north, and Jerusalem District in the South, where the Jordan River from the East. While this district locates in the rain shadow with less than 150 mm/y, most of the land is range land. Only few spots where groundwater is available, intensive agricultural activity take place. The total irrigated area is 2419 dunums (~24.2 km^2). Crops like Bananas, citrus, tomatos, palm trees are the major plants.(Jericho Agricultural Station.1994).

The major building up area is Jericho city with 5.8 km^2, Al-Uja with 0.6 km^2, Aqbat- Jaber with 1.53 km^2, Al-Nuwemeh with 0.5 km^2. In all these urban centers no sewer system is available and wastewater is collected in permeable septic tanks are built under the ground with an average depth of 3m .

1.3 Water Use:

Four main springs in Jericho area are Ein Sultan, Ein Uja, Ein Nuwemeh, and Ein Dyouk with a total discharge of 24.7 MCM/y. The present data of the different uses of springs in Jericho area shows that most of the water is used for irrigation.

58 Wells are located in Jericho area (Fig. 1.2). These well abstract 2.5 MCM/y, from the Plio-Pleistocene, Pliocene aquifer systems. All of these wells are used for agricultural activities, (PWA, 2002).

1.4 Previous Studies:

Marie and Vengosh, 2001:

The hydrological and geochemical data show that Salinization of groundwater occurs in three aquifer units in the vicinity of the Jericho area:

(1) The lower subaquifer of Lower Cenomanian age;

(2) The upper sub aquifer of Middle-Upper Cenomanian age; and

(3) The shallow aquifer of Plio-Pleistocene age.

The chemical composition of the saline groundwater (Cl^- up to 5000 mg/L) in the Cenomanian aquifer points to a single saline source with Na/Cl ratio 0.5 and Br/Cl^- 7 x 10^{-3}. This composition is similar to that of thermal hypersaline springs that emerge along the western shore of the Dead Sea **(**Marie and Vengosh, 2001). They argue that the increase in Cl^- in both Middle-Upper Cenomanian and Lower Cenomanian subaquifers is derived from mixing of fresh groundwater with upconing of deep-seated brines with similar chemical composition. The deep-seated brine flow through the Rift fault systems and their mixing proportions are dependent upon the freshwater discharge of the eastern mountain aquifer.

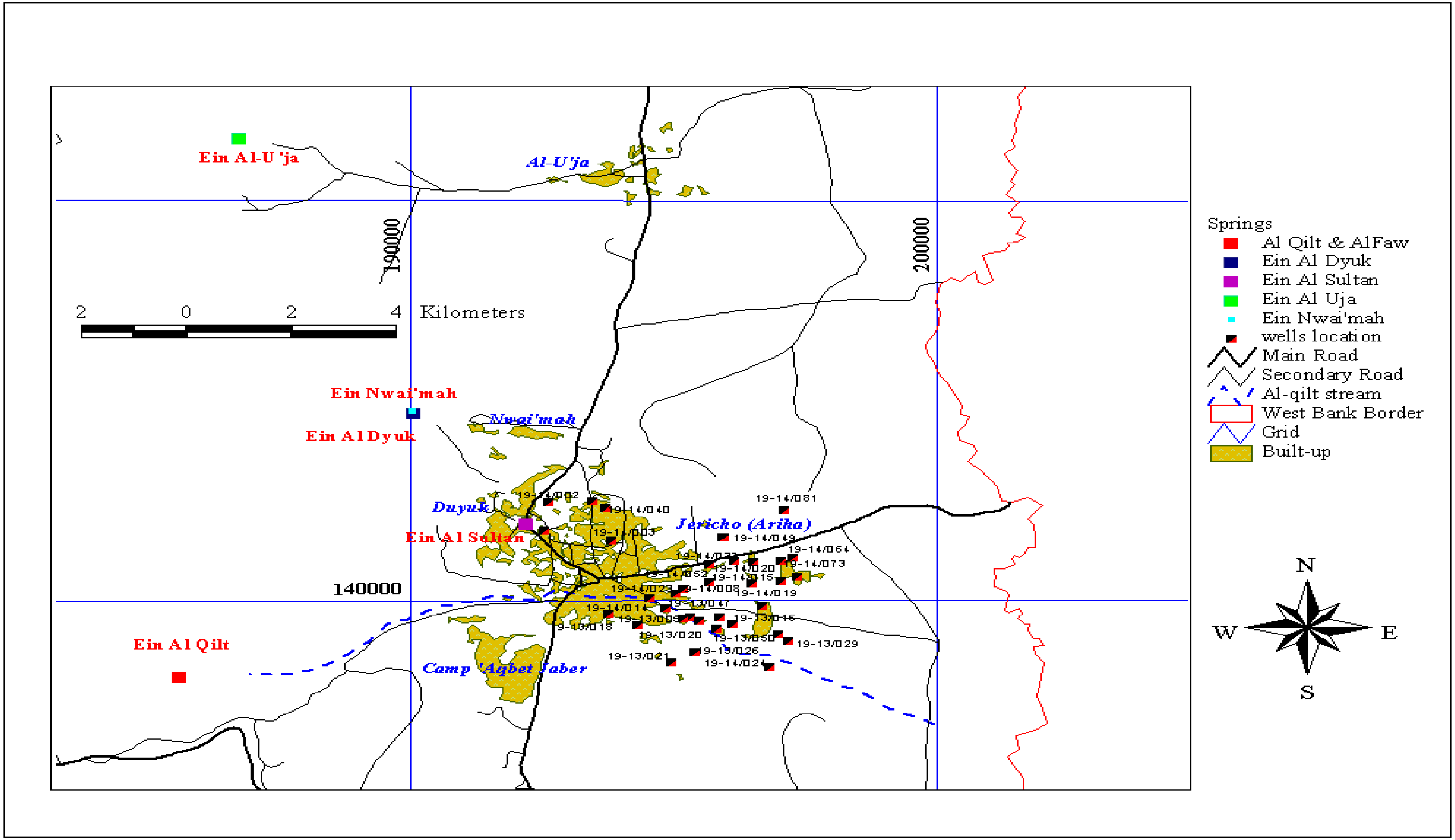

Fig 1.2: Location of the main wells and springs in the study area.

The chemical composition of groundwater from the shallow Plio-Pleistocene aquifer suggests that the high Cl^- (up to 2000 mg/L), particularly in the eastern part of the aquifer, is derived from several sources. These include:

(1) Upconing of deep brines.

(2) Leaching of salts within the aquifer. and

(3) Anthropogenic contamination of agriculture return flow and waste water infiltration.

The shallow depth of the unconfined Plio-Pleistocene Aquifer makes it sensitive to surface contamination. Under the extreme arid conditions of the lower Jordan Valley, recycling of salts through pumping and irrigation can further increase the salinity of the local groundwater **(**Marie and Vengosh 2001).

The chemical results provide the basic tools for delineating the possible sources of the salinity and hence for understanding the salinization processes in other areas of the Jordan Valley. This evaluation is crucial for management and future exploitation of any aquifer in which salinization occurs. Their data suggest that future utilization of the two hydrological systems, the deep Cenomanian and the shallow Plio-Pleistocene aquifers, will further increase the salinization rates (Marie and Vengosh, 2001). In both systems, the degradation of water quality will require special remediation measures. Moreover, salinization rates are expected to increase further if water will be extensively utilized from the deep aquifer for large-scale desalinization.

Future planning of any desalinization plant should, therefore, take into consideration this expected rise of salinity (Marie and Vengosh, 2001).

Geyer et.al, 2005:

There are three main zones of different salinity in Jericho area by using different diagnostic Hydrochemical fingerprinting as tracers for elucidating the sources of salinity. It was concluded that the most probable sources of salinity are:

1) The geological formations of the region, which form inter-fingering layers of both the Samara and Lisan formations of Pleistocene age, where the eastern Arab Project aquifers show the highest amount of sulphate. The location and geological formation of these wells within the Lisan suggested that the source of high sulphate content is the dissociation of gypsum (Geyer et.al, 2005).
2) The NaCl water within the same area may also be upwelling from a deep brine aquifer or from a fresh- water aquifer which contains salt-bearing rocks with particles becoming finer from west to east. This noticeable high TDS to the east should be affected by the rate of pumping from the upper shallow aquifer, especially in the wells of the Arab Project. Which are in continuous pumping during the year.
3) The third possible source of salinity is from anthropogenic influences. This can be easily shown by the increment of nitrate, bromide and

sulphate, depending on whether the location of the well is coincident with urban or agricultural areas. This reflects the addition of agricultural chemical effluents or sewer pollution from adjacent septic tanks which are mainly constructed in top gravel in the Samara layer (Geyer et.al, 2005).

1.5 Scientific Objectives of this Research

The main objectives of this research are:

1- Determination of the chemical parameters (Na^+, K^+, Mg^{2+}, Ca^{2+}, Cl^-, So_4^{2-}, HCO_3^-, NO_3^-, NH_4^+).

2- Interpretation of the geochemical and isotopic data.

3- Evaluation of the different sources of the dissolved substances. (Natural as well as anthropogenic).

4- Determinations of groundwater recharge mixing, and flow pattern from isotopic and chemical data.

5- Evaluation of the water salinaization in the study area.

Chapter 2

Geology and Hydrogeology of Jericho area

2. Geology of the study area:

The Dead Sea Group consists of three formations, the Samra Formation, the overlying Lisan Formation, and Alluvial Deposits. The Samra Formation is built up by clastic fan sediments while the Lisan Formation is represented by chemical sediment deposited in a lake environment. Both formations interfinger laterally. The Samra Formation dominates with possible occurrence of the Lisan Formation at the east margin (Fig 2.1). However mapping of these Formations is very difficult because they can be only seen in the wadies which cut deeply into these sediments. Otherwise they are overlaid by younger alluvium and soils. Because of this there was no differentiation made between this Quaternary deposits, Samra, Lisan, and Alluvial Deposits. (BEGIN .1975a). These formations discussed as it shown bellow:

2.1 Alluvial Deposits:

These deposits cover the area adjacent to the Jordan valley starting by 1 km in the north and 5 kms in the south as two parallel lines. It is of the Pleistocene to recent in the age, bounded structurally by the Jordan rift regional fault in the east and another fault of 12 km length in the west (The Geological map of Israel.1974).

The alluvial deposits consisting of talus stream gravels, soils and sabha soils occur as loose sediments, several meters thick, mainly in the Jordan valley. The distinction between talus and stream gravels was made according to their geomorphologic position, the alluvial deposits occur on interfluvial areas. The soils were differentiated from the silt of the Samra formation according to the same criterion. The soils, which are of the terarosa type, are restricted to recent stream beds (of the Jordan River and wadi Mafjar) or to mountain valleys, mainly along the samra Fault Strip. The silt member, however, covers extensive area outside of recent streams, the sabha soils are salty soils, exposed over the lisan formation in the Jordan valley southeast of fassayil (The geological map of Israel.1974).

2.2 Lisan Formation:

The Lisan Formation consists of laminated chalk, gypsum, marl and clay layers reaching a maximum thickness of 35 m at the Jordan River (Fig. 2.1). The sediments have been deposited in a lake environment with salinity ranging from hypersaline to fresh BEGIN. (1974). The formation fills the lower portions of the Jordan Valley with outcrops occurring up to a maximum elevation of -180 m b.s.l., however a level of -240 m b.s.l. is the most common in the Jericho area BEGIN. (1974).

2.3 Samra Formation:

The Samra Formation consists of conglomerates, sands and silts. It crops out along Wadi el-Quilt where it enters the Jordan Valley, and more or less weathered on the surface of the Jordan Valley. According to BEGIN. (1975a) the silts of this formation are the parent material for the rich soils of Jericho. The texture of these clastic sediments is highly variable, where particle sizes vary from fine silt to boulders 30 cm in diameter. The particles vary from well rounded to angular and the sediments also poor to well sorting is observed.

Sedimentary structures of the Samra Formation measured by BEGIN. (1975b) in the Jericho area indicate a deposition in a wide channel flowing North-North East. This differs the modern one in its flow direction, which was caused by a blocking ridge which was faulted down before the deposition of the lake Lisan sediments (~60,000y). All of the Geological formations in the study area and the other Formations of Palestine are shown in the (Table 2.1).

Table 2.1: The generalized geological columnar section indicating the aquiferial characteristics of the various formations of the study area. (Marie, and Vengosh, 2001),

<table>
<tr><th>Period</th><th colspan="2">age</th><th>Group</th><th>Formation</th><th>Hydrology</th></tr>
<tr><td>Quaternary</td><td colspan="2">Pliocene-Pleistocene</td><td>Dead sea</td><td>Lisan Samra</td><td>Aquifer / Aquiqlude (200-300 m)</td></tr>
<tr><td rowspan="6">Upper Cretaceous</td><td colspan="2">Senonian-Paleocene</td><td>Mount Scopus</td><td>Abu Dies</td><td>Aquiqlude (100-300 m)</td></tr>
<tr><td colspan="2">Turonian</td><td rowspan="9">Judea</td><td>Jerusalem</td><td rowspan="3">Aquifer (230-300 m)</td></tr>
<tr><td rowspan="4">Cenomanian</td><td rowspan="2">Upper</td><td>Bet Lehem</td></tr>
<tr><td>Hebron</td></tr>
<tr><td rowspan="2">Lower</td><td>Yatta</td><td>Aquiqlude</td></tr>
<tr><td>Upper Bet Kahil</td><td rowspan="2">Aquifer (200-270 m)</td></tr>
<tr><td rowspan="4">Lower Cretaceous</td><td colspan="2" rowspan="4">Albain</td><td>Lower Bet Kahil</td></tr>
<tr><td>Qatana</td><td rowspan="3">Aquitard / Aquiqlude</td></tr>
<tr><td>Ein Qinya</td></tr>
<tr><td>Tamun</td></tr>
</table>

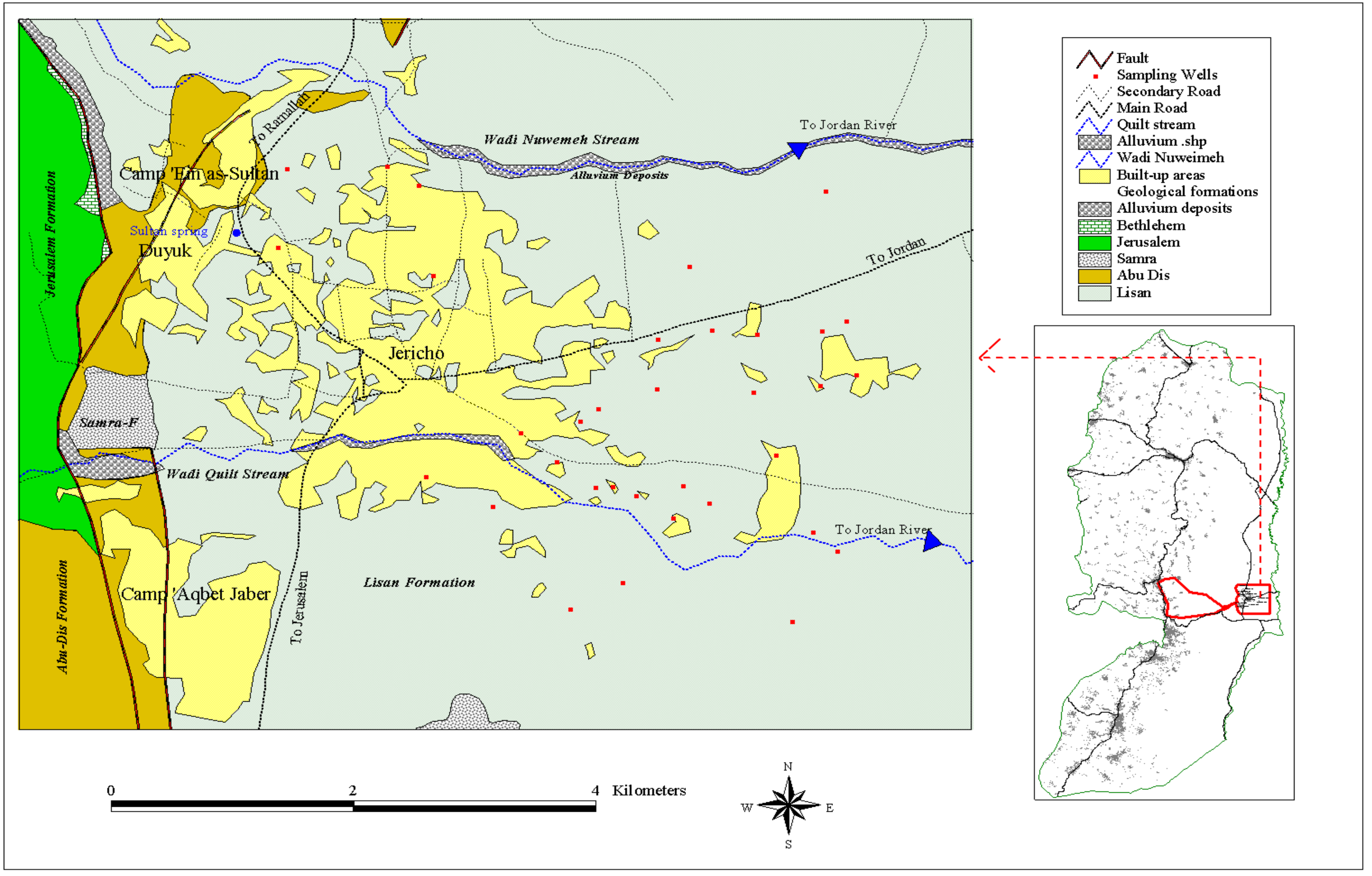

Fig. 2.1: Geology of the Study area. (Environmental Research laboratory of AI-Quds University, 2005)

2.4 Water Resources of the Study Area:

The main source of surface water in the study area was the springs that locate along the Rift Valley and surface water of the Jordan River ~ 1335 MCM/y. Due to the diversion of the Upper Jordan River during the last century, this source of water became a tertiary source and abstractions of groundwater from the shallow aquifer system become the first source. The aerial length of Jordan River is 165 km, with an area length of 320 km. In addition to the religious meaning of the River as a place where Juses went into the river. Controlling the water of this river is still, a source of tension between Jordan, Syrian, Lebanon and Israel.

Hydrologically the Jordan River divided into three parts:

1. The Upper Jordan River includes the tributaries, Hasbani, El Dan, and Banias.
2. The Middle Jordan River which include the area between Lake Hula and Tiberia.
3. The Lower Jordan River, which starts from Lake Tiberia until the discharge point into the Dead Sea, the length of this part is 105 km. (Gwyn.1984), and (Al-Dabagh, 1965).

The slope of the River valid from 2 meters per km in the upper part to 17.5 meter per km in the Middle part, and reach 1.79 meter per km in the lower

Table 2.2: The water flow rates for the Jordan River Tributaries and Dead sea Basin. (Al-Dabagh.1965, Ali.1964.Thomas and Matson.1984,Gwyn, R.1984)

Number	Description	Tributaries	Average Discharge	Total
1-	**The Upper Jordan River**	Banians	143 MCM/y	549 MCM/y
		Dan	259 MCM/y	
		Hasbani	147 MCM/y	
2-	**The Middle Jordan River**	the area between Lake Hula and Tiberius		549 MCM/y from the upper part
3-	**The Lower Jordan River**	Yarmouk	478MCM/y	786 MCM/y
		Zarqa	75 MCM/y	
		Jalout	30 MCM/y	
		Surrounding Wadies	203 MCM/y	
----------	Total (MCM)	--------------------	--------------------	1335 MCM/y

Part (Saleh.1984), the water flow rates from the Jordan River tributaries is explained the table 2.2 Al-Dabagh, (1965). Ali, (1964). Thomas, N. and Ruth, M. (1984). Gwyn, R. (1984). The River flow through Baslt in the Upper and Middle part and through Lisan Formation in the lower part. The availability of water, and the warm climate made this area suitable during the history for human activity and historical cities like Jericho, Besan, Tiberia in the Western part of the Rift and Shunah, Tapqat Fahel in the eastern part of the Rift were established and were well known for there agricultural and trade activities.

Before the diversion of the River in the middle of the last century by Israel, the annual discharge was 1335 million cubic meter (MCM). This amount includes water Tiberias 549 MCM/y, 583 MCM/y from Yarmouk River and rest 203 MCM/y from wadies and springs in both side of the Wadi. After deranging the River, the discharge reduced to about 120 MCM/y. The majority of water originates from the groundwater, salt springs around Tiberia, and waste water from fish ponds. The diversion of the river caused disaster for the ecological life where in the past fish were grown and cause also a decline in the Dead Sea level which is about 20 m in the last decades.

The surface catchment area of the Jordan River is about 18,850 km^2. The Jordan River drains groundwater from basaltic aquifer in the northern part in the eastern portion, from calcareous aquifer in the central part, and from the local shallow aquifer in the Jordan Graben.

Sediments of Pleistocene to recent age fill the valley, composed of marl, sand, conglomerate, calcite and dolomite (Hazan, 2003). In the southern part the River flow through the Lisan Formation of late Pleistocene, which consists of marls, gypsum and aragonite overlying with Samra Formation which consists of marls, sand, conglomerate and chalk (Begin, 1974, Landmann et al., 2002, Waldmann 2002). Many wadies crossing the sediments of the valley into the Jordan River like Wadi Maleh, Wadi Faria, Wadi El- Ahmar, Wadi Uja and Wadi Quilt.

Alluvial sediment, sand and conglomerate are filling the drainage system of these wadies. Due to the high hydraulic conductivity of this detritus sediment, they are important for the local aquifer system and they build in some areas like in Jericho part of the shallow aquifer.

Jericho area, which represents the southern part of the lower Jordan Valley, have four main natural spring's issue in this area which is, Ein Al-Sultan with an average discharge of 4 MCM per year, Ein Al-Uja with an average discharge of 10 MCM per a year, Ein el-Quilt with an average discharge of 5 MCM per a year, Ein Al-Dyouk which includes Dyouk, Newemeh, and Shosha 8 MCM. (WBWD, 1994).

58 Wells were drilled in the area with a total abstraction 2.5 MCM/A (Appendix 6.1). Jericho area well known as an oases through out the history, where agricultural activities is the major job for the inhabitants in Jericho.

2.4.1 Aquifer Systems:

The Recent and Quaternary alluvial deposits form the most productive aquifer in the Jordan Valley. These deposits are discontinuous (in the form of gravel, sand and conglomerate lenses). The boundaries of these lenses are not well defined, either vertically or horizontally. Eastward, toward the Jordan River, the sediments become more marly, and the alluvial fans and other recent sediments inter-finger with saline, clay-rich deposits. The unconsolidated deposits are distributed mainly in the floor of the Jordan Rift Valley, as well as at the mouths of valley-floor wadies, forming a local aquifer system and providing relatively high-quality groundwater. The distribution and thickness of the deposits vary laterally. The thickness of the deposits decreases from west to east, where the outcrops of Lisan Formation become dominant (CH2M HILL. 2001). The low-permeability of the Lisan Formation explains the existence of Deir-Hejleh spring near the contact zone between Lisan and alluvial deposits, this supports the idea of two aquifer systems (one alluvial deposits with high transmissivity, and the second the Lisan Formation with low transmissivity). None of the wells drilled in the area are believed to tap the Lisan Formation (CH2M HILL. 2001).

The main component of aquifer recharge is infiltrating water from runoff during the winter season through Wadi beds of Wadi El-Quilt, Wadi Nuwemeh and Wadi Marrar. Another large component of infiltrated water is from return flow, mainly from base flow of Duyuk, Nuwemeh, Shosah, El-Quilt, Fawwar and Sultan springs. Direct rainfall recharge to the aquifer is considered negligible because of low precipitation and high evapotranspiration, In addition to these components, the lateral flow from the Mountain Aquifer is believed to recharge both the alluvial deposits and Lisan Formation at certain locations (CH2M HILL. 2001).

The groundwater flow direction in the alluvial deposits is toward the Jordan River and, ultimately, to the Dead Sea. The highest quality groundwater occurs near the recharge areas (or Wadi mouths), while the water becomes more saline near the fringes of the fans, toward the Jordan River. Circulation of groundwater along the Jordan Valley brings it in contact with saline formations, which can contaminate previously freshwater (CH2M HILL. 2001).

2.4.1.1 Pleistocene aquifer:

The Pleistocene aquifer consists of unconsolidated beds of sand, gravels, cobbles, and boulders of different sizes separated by impermeable layers of saline marls of lacustrine deposits. This came mainly from adjacent formations exposed within the catchments area, which are composed of limestone, Dolomite, chert, sand and clay filling the interstices forming alluvial fans, ventricular-shape varies in size and thickness extension (GTZ. 1995). The groundwater is available in the alluvial fans. The good quality of groundwater occurs around the apex where freshwater recharge is readily available, while the groundwater is more saline near the fingers. The very steep dipping occurring along the Jordan valley cause deep circulation of the groundwater with salty formations at depth contaminating, the freshwater in the Pleistocene aquifer causing the brackish springs (GTZ Report. 1995). This aquifer Bounded in the West Bank, and locates in the Jordan Valley in (Bardala and Ein Beida area). which extended from Jericho in the south to Marj Na'jja and lower Wadi Faria' in the north, with [Cl^-] ranging from 100-200 mg/L. with annual pumping about

9.0 MCM/y from wells in this aquifer which show peisometic level variations between – 300m to – 337m, (GTZ Report. 1995).

2.4.1.2 Upper Cenomanian aquifer (Upper aquifer)

This subaquifer shows peisometic level lower than the peisometic of the lower Cenomanian aquifer. This aquifer consist mainly of interbedded dolomites and chalky Limestone and classified to be a fairly good aquifer in the West Bank Although it has a limited thickness and produces limited quantities of water. This aquifer is utilized in Ein Samia and Beit Fajjar. The water of this aquifer contains chloride ranging between 30-149 mg/L. with annual pumping about 8.0 MCM/y from wells in this aquifer (GTZ. 1995).

2.4.1.3 Lower Cenomanian aquifer:

The lower Cenomanian aquifer consists mainly of dolomitic Limestone, thick to thin bedded with marly Limestone. This aquifer is deep seated and classified to be an excellent aquifer due to its thickness (1260 m) and extension. It has been exploited in the West Bank after 1967 and all the deep wells North West of Rammallah (Shibteen), Ein Samia, Bethlehem and Nablus pump out of this excellent aquifer for domestic use only. The concentration of the chloride in this water ranges from 27-30 mg/L, during the 1980s this aquifer showed an increase in Cl^-, followed by a decrease after 1991-1992 (GTZ Report. 1995), in contrast to the water level variations that show a significant increase after this unusual wet years. High saline groundwater in this aquifer was also revealed in the wells in the Jericho 2 with [Cl^-] of 13.000 mg/L and Mitzpe Jericho 3 with [Cl^-] of 6200 mg/L (Marie, and Vengosh, 2001), with annual pumping about 13-14 MCM/a, from wells in this aquifer.

2.5 Groundwater Basins:

The general groundwater flow direction in this area is to the east and southeast towards the Jordan River and the Dead Sea. The Jericho district overlies two sub-basins of the Eastern Aquifer System (ARIJ. 1995). These two sub-basins are:

1. Auja-Fasayel Sub-basin which drains the Neogene/Pleistocene and Upper Cenomanian aquifers, and flows towards the southeast direction.
2. Ramallah-Jerusalem Sub-basin which drains the Neogene and Pleistocene, Lower Cenomanian and Upper Cenomanian aquifers and flows towards the east and southeast direction.

2.6 Springs Of the Study Area:

There are four main spring systems in the Jericho district emerging from the eastern groundwater basin underlying the Jericho area. The total annual discharge of these springs reached 27 MCM.

2.6.1 Wadi el-Quilt Spring System:

The total average annual discharge of this system is about 5 MCM (IPCRI, 1993). The discharge of the spring system varies with rainfall form year to anther, (WBWD. 1994). Wadi El-Quilt is fed from three main springs Ein Fara, Ein Fawwar, and Ein El-Quilt (Rofe & Raffety, 1963; Scarpa .1994).

2.6.1.1 Ein Fara:

Ein fara Is a seasonal spring which emerges upstream at an elevation of 325 m above sea level through the floor of the Wadi.

2.6.1.2 Ein Fawwar:

Is a seasonal spring which emerges 4 km downstream at an elevation of 80 m above sea level with an average discharge of about 30,000-100,000 m^3/day. Both Fara and Fawwar springs drain from the Quaternary Alluvium Aquifers.

2.6.1.3 Ein El-Quilt:

Merges 2.5 km downstream of Ein Fawwar at an elevation of 10m above sea level. Its flow rate is almost constant with a little variation from winter to summer. It has a catchments area of about 176 km^2 and an average annual rainfall of 550 mm, of which about 20% recharges the groundwater in the Upper Cenomanian-Turonian Aquifer (ARIJ. 1995), (Goldschmidt, 1967)

2.6.2 Ein Al-Sultan Spring System:

It is located to the northeast of Wadi A1-Quilt in Jericho city and related to the Upper Cenomanian Aquifer. Its annual flow discharge of about 4 MCM (ARIJ. 1995). This spring is used to fulfill the municipal and agricultural needs of the Jericho population (WBWD. 1994).

2.6.3 Ein Dyouk Spring System:

This system is composed of three springs; Dyouk, Newemeh, and Shosha emerging on a fault parallel to the Rift fault. They drain the Pleistocene Lisan Formation and are fed from the Upper Cenomanian aquifer (Davidson & Hirzallah, 1996). (WBWD. 1994).

2.6.4 Al-Auja Spring System:

Ein A1-Auja has a catchments area of 170 km^2 and receives an average rainfall of about 500 mm annually. The average annual discharge of this system is about 10 MCM (IPCRI. 1993) which drains the Upper Cenomanian-Turonian aquifer (Rosenthal & Kronfeld, 1982). Its water is used for irrigation purposes and its discharge is affected by rainfall variation (WBWD.1994).

CHAPTER 3

Methodology

3.1 Measurements of the Major Ions:

Hydrogeological data including aquifer system, groundwater table, well depth and well abstraction were collected from the PWA, (2004). Historical data about chloride and nitrate concentration of few wells were taken from chemical archive of the PWA. During the hydrological years (2002/2003 and 2003/2004) 37 flooding water samples were collected from Wadi El-Quilt. In addition to 30 groundwater samples were collected through the same period. Floodwater samples were collected from one site, one bottle (polyethylene bottle) with a volume of two liters each, the water sample was filtered through filter paper

45μm, stored in ice box and transported directly to the laboratory. Groundwater samples were collected from wells after 10 minutes pumping time, also two liters (PET bottles) are used and the samples were stored in ice boxes before transport to the laboratory of AI-Quds University. For the isotope analyses ($\delta^{18}O$ and $\delta^{2}H$) one liter (PET bottles) was used, after sealing the bottles, the samples were shipped to laboratory of the Environmental Research Centre UFZ in Germany. Onsite measurements like pH, T, EC and dissolved oxygen were carried out in the field.

Sodium and potassium were analyzed by Flame Photometer Instrument, calcium and magnesium with EDTA titration, chloride, sulfate, and nitrate by Spectrophotometer, bicarbonate by titration with HCl. $\delta\ ^{18}O$ and $\delta\ ^{2}H$ were measured by isotope ratio mass spectrometry after equilibrating the water sample with hydrogen and CO_2 gas, respectively. The isotope analyses were carried out at the Environmental Research Center UFZ/Leipzig-Halle and the chemical analyses were carried out at the Environmental Lab of AI-Quds University/Jerusalem.

3.2 Tritium ^{3}H:

Tritium is the heavy isotope of hydrogen its symbol is 3H or T. Its decay forming 3He atoms which companied by B- particles:-

$$T \xrightarrow[12.3Y]{} \beta^{-} + {}^{3}He \ .$$ (Unterweger et al., 1980)

Half-life of tritium is 12.3 year, the concentration of tritium in water is expressed by the ratio of "T" atoms to "H" atoms:-

[Ratio of $\frac{T}{H} = 10^{-18}$ is defined as 1 tritium unit (1TU)] The natural tritium production originated from interacts of the cosmic ray neutrons in the upper atmosphere with nitrogen, producing ^{15}N which is radioactive and disintegrates into common carbon (^{12}C) and tritium (^{3}H).

$$^{14}N + n \rightarrow {}^{15}N \rightarrow {}^{12}C + {}^{3}H \ .$$

The tritium atoms are oxidized to water and become mixed with precipitation and so enter the groundwater. The natural production of tritium introduces about (5TU) to precipitation and surface water. In the saturated zone water is isolated from the atmosphere, and the tritium concentration drops due to the radioactive decay. Hydrogen bomb testing added large amounts of tritium to the atmosphere, which increased the concentration of tritium in the groundwater by precipitation especially in heavy or rainy seasons (IAEA, 1983).

3.2.1 Measurements of tritium:

Tritium analytical procedure can be divided into four steps:-

1. pre-distillation and purification : in order to separates dissolved minerals and suspended load from the water phase, distillation is preformed under N_2 to avoid contamination by atmospheric water vapour if there is additional solutions the water sample stored under charcoal filled containers before pre-distillation .

2. Electrolytic enrichment: the water molecules are spilt up into O_2 and H_2 thereby, reducing the amount of the water, increasing the tritium content of the residual water.
3. Final distillation: by adding $PbCl_2$ to the residual water.
4. Radiometric measurement and the counting of the tritium activity: tritium is pure beta decaying radioactive process, with a half-life 4492 day (±8 day), the maximum energy of the tritium decay is only 17 Kev. The liquid scintillation spectrometer is used for the low level tritium analysis. This method relies on the transfer of the kinetic energy of the beta particles to the scintillates molecules, which in turn transform the activation energy into light, this light is detected with two photomultiplier tubes.

3.3 Stable Hydrogen and Oxygen Isotopes:-

Water is composed of hydrogen and oxygen, so it occurs with different isotopic combinations in its molecules. Most common and interest to hydrochemists are $^{1}H_2O^{16}$ (common), $^{1}HD^{16}O$ (rare), and $^{1}H_2{}^{18}O$ (rare), the water molecules may be divided into light molecules ($^{1}H_2{}^{16}O$) and heavy water molecule ($^{1}HD^{16}O$ and $^{1}H_2{}^{18}O$). The isotopic composition of water is expressed in comparison to the isotopic composition of ocean water. For this purpose an internationally agreed sample of ocean water has been selected called standard mean of ocean water

(SMOW) (Carig. 1961). The isotopic composition of water determined by mass spectrometry is expressed in per mil ‰ deviations from (SMOW) standard,

These deviations are written (δD) for deuterium and ($\delta^{18}O$) for ^{18}O:

$$\delta D\% = \frac{(D/H)sample - (D/H)SMOW}{(D/H)SMOW} * 1000$$

$$\delta^{18}O\% = \frac{(^{18}O/^{16}O)sample - (^{18}O/^{16}O)SMOW}{(^{18}O/^{16}O)SMOW} * 1000$$

Where δD and $\delta^{18}O$ are in ‰ .

Water with less deuterium than SMOW has a negative δD, and water with more deuterium than SMOW has a positive δD, and the same is true for $\delta^{18}O$. The isotopic compassion of water is measured by mass spectrometry by using 50 ml of the water sample.

3.3.1 Measurements of $\delta^{18}O$:

The most common method for determining the oxygen isotope composition of water is by equilibration with CO_2; generally it is easily applied in commercial automated preparation lines to handle a larger number of samples at one time. Each run of the automated preparation of the system comprises determination of 20 duplicate and 8 standard samples, at the end the equilibrated CO_2 gas is measured by a connected mass spectrometer.

The equilibrium device consists of two valve blocks (units) with 24 sample connections. Each valve block is mounted on a pneumatic lift and consist of 3 banks of 8 sample valves. Bellow valves are used to separate the banks. The two valve blocks again are connected through isolation valves to the manifold in the lower part of the cabinet. Through this manifold the units are evacuated, filled with equilibrium gas, and connected to the mass spectrometer via a cold trap that prevents water vapour from entering the inlet.

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

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

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

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

The isotopic exchange reaction can be written as:

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

The glass containers keeping the samples are connected to the preparation line via capillaries between the sample and the bank valves, each 50 mm x 0.001" (i.d.) to minimize isotope fractionation during the evacuation process, removing the gasses except for water vapour. After reaching the desired pressure equilibrium gas (CO_2) can flow into the containers whose temperature is kept below ambient temperature within an isolated tempered water bath which is controlled by a precision thermostat and a flow through cooler to avoid condensation inside the walls of the sample bottles. For reaching the short equilibration time of four hours the water samples are efficiently agitated by means of stirring magnets in the sample bottles and an electromagnetic stirring system immersed into the water bath. When equilibrium is reached the CO_2 is transferred from the sample bottles consecutively via the cold trap to the mass spectrometer system. Here it is measured against a CO_2-reference gas of known isotopic composition (dual inlet technique,). The $\delta^{18}O$ value is referred to the Vienna Standard Main Ocean Water (VSMOW) standard and exhibits an error of 1‰.

3.4 Measurements of deuterium (δD):

Hydrogen isotope analysis is carried out in principle the same way as for $\delta^{18}O$ but using hydrogen of known isotopic composition as equilibrium gas. The equilibration procedure takes around 30 minutes. To promote equilibration a platinum catalyst (Hokko Beads, 1 mm diameter) filled into a basket is used. Since H_2S poisons the practically indefinite reusable Pt catalyst it has to be removed prior. Each equilibrated hydrogen gas sample is then transferred into the mass spectrometer, which again is operated in dual inlet configuration. There it is isotopically analysed against a H_2- reference gas of known isotopic composition. The sample is referred to the VSMOW standard. The error is specified to be 0.8 ‰.

Chapter 4

Results and Discussion

4.1 The Flood water:

35 flood water samples were collected from the Wadi el-quilt (Table 4.1, and Appendix 6.2), some of these samples were excluded (5 from Wadi el-Quilt channel) and (2 from Wadi el-Quilt) because they exceeded the range of the ionic balance. The remaining 30 samples were separated according to the year of sampling as the following: 14 samples collected during the year 2001, 4 samples during the year 2002, and 12 samples during the year 2003.

The chemical analyses were carried out at the environmental research laboratory.

For the year 2001, the chemical analysis was shown in the Table 4.2, while the catios and the anions were shown in the Fig. 4.1 and 4.2 respectively with an average Na^{+}/Cl^{-} ratios is 0.83 and the average Ca^{+2}/Cl^{-} is 1.7. Table 4.3 and Fig. 4.3 and 4.4 respectively shown the chemical analysis of the flood water during the year 2002, with Na^{+}/Cl^{-} average ratio is 0.72 and Ca^{+2}/Cl^{-} is about 1.64. In the other hand the Na^{+}/Cl^{-} and Ca^{+2}/Cl^{-} ratios for the year 2003 is about 0.84,and 1.94 respectively (Table 4.4) as it shown in the Fig. 4.5 and Fig. 4.6. While the Fig. 4.7 and Fig. 4.8 show the Na^{+}/Cl^{-} and the Ca^{+2}/Cl^{-} ratios of all of the flooding water samples Flood water of Wadi el-Quilt infiltrate through the Wadi deposits, which is the major recharge source of freshwater for the Plio-Pleistocene aquifer system. Channel leakage, agricultural return flow, and infiltration from septic tanks are minor sources (Golani 1972, Marie and Vengosh 2001).

It is to emphasis that the hydrogeological system of the Plio-Pleistocene aquifer is hydraulically separated from the Upper Carbonate aquifer of Upper Cretaceous age in the west through the impermeable chalk unit of Senonian age. The replenishment of the shallow aquifer system depends mainly on the flooding sequence of the Wadis, mainly el-Quilt Springs issuing in the western part are feeding from the Upper aquifer system in the mountains area (Begin, 1975 a) and (Golani, 1972).

The western part of Wadi el-Quilt catchment's area has a semi humid climate, receives up to 600 mm/a rainfall, whereas the eastern part of the catchment area receives 150 mm/a (Appendix 6.3). The amount of rainfall fluctuated from year to another but in general rainfall decreases rapidly from the mountains in the West to the Jordan Valley in the East (Arad and Michaeli, 1967). While the rainfall decreases eastward, the average annual air temperature increases from 17°C in the West to 24 °C in the East (Wolf.1998).

Table 4.1: List of flooding water samples and there chemical.

No.	Lab I.D	Date of sampling	Location	EC µS/c	pH	Temp. C°	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
1	Q1	23.02.2001	Wadi el- Quilt		8.3		71.7	20.5	34.1	4.8	231.9	63.9	25.8	30.5
2	Q2	23.02.2001	Wadi el- Quilt		8.4		74.7	19.7	36.4	5.1	250.2	68.5	26.8	30.3
3	Q3	24.02.2001	Wadi el- Quilt		6.9		67.2	19.6	30.2	4.0	219.7	55.6	22.7	24.8
4	Q4	24.02.2001	Wadi el- Quilt		8.0		57.5	19.4	31.7	4.5	195.3	59.3	23.2	25.2
5	Q5	18.02.2001	Wadi el- Quilt		7.9		45.5	25.0	30.0	3.1	170.9	58.0	28.7	32.3
6	Q6	20.02.2001	Wadi el- Quilt		7.9		41.3	24.9	29.8	3.0	183.1	57.9	28.1	32.6
7	Q7	26.02.2001	W.Q.Channel		8.3		74.6	19.2	27.9	3.7	250.2	50.8	21.5	21.7
8	Q8	25.02.2001	Wadi el- quilt		7.6		48.5	21.5	30.9	4.8	164.8	58.2	38.1	23.6
9	Q9	25.02.2001	Wadi el- quilt		7.6		31.0	18.8	29.5	4.0	122.0	57.7	22.7	19.2
10	Q10	10.03.2001	W.Q.Channel		8.0		59.2	18.7	20.5	3.0	138.2	36.5	18.3	13.5
11	Q11	15.03.2001	W.Q.Channel		7.7		43.3	22.7	28.8	3.2	113.4	51.1	28.4	9.6
12	Q12	27.04.2001	W.Q.Channel	480.0			3.0	45.9	18.0	2.8	187.1	37.7	14.8	13.2
13	Q13	02.05.2001	Wadi el- quilt	450.0			44.7	7.5	17.0	5.6	130.2	31.9	34.1	15.3
14	Q14	03.05.2001	Wadi el- Quilt	550.0			59.8	12.0	22.4	6.2	168.8	39.2	33.2	19.1
15	Q15	02.01.2002	W.Q.Channel	403.0	8.5		60.0	36.5	34.0	10.0	207.4	36.8	14.0	5.3
16	Q45	24.03.2003	Wadi el- Quilt	464.0	7.7	23.3	42.8	15.2	19.3	1.5	207.5	35.3	23.3	25.3
17	Q46	29.03.2003	Wadi el- Quilt	448.0	7.7	21.5	41.5	14.6	18.8	1.4	207.5	34.3	23.0	24.3
18	Q47	04.05.2003	Wadi el- Quilt	448.0	7.8	21.7	37.1	16.2	20.0	1.5	207.5	38.1	22.0	24.3
19	Q48	04.02.2003	Wadi el- Quilt	460.0	7.8	27.3	39.7	15.8	20.4	1.4	207.5	38.6	24.1	25.7
20	Q49	04.07.2003	Wadi el- Quilt	447.0	7.8	24.6	37.0	16.3	20.6	1.3	207.5	36.0	21.0	23.5
21	Q50	31.03.2003	Wadi el- Quilt	462.0	7.8	24.2	41.0	15.5	20.2	1.4	195.3	36.8	23.6	25.7
22	Q51	22.03.2003	Wadi el- Quilt	471.0	7.8	24.1	44.3	15.1	20.0	1.5	195.3	35.4	22.0	24.2
23	Q52	04.02.2003	Wadi el- Quilt	462.0	7.7	24.5	39.9	15.7	19.9	1.2	231.9	37.0	23.3	25.4
24	Q53	17.03.2003	Wadi el- Quilt	463.0	7.8	25.1	38.4	16.0	20.4	1.3	231.9	38.6	22.0	26.2
25	Q54	20.03.2003	Wadi el- Quilt	489.0	7.8	25.3	45.7	15.5	21.4	1.6	219.7	39.8	22.3	26.6
26	Q55	31.03.2003	Wadi el- Quilt	455.0	7.8	25.3	40.0	14.6	20.2	1.4	219.7	35.6	23.8	26.0
27	Q56	17.03.2003	Wadi el- Quilt	461.0	7.8	26.2	38.6	16.0	20.4	1.3	195.3	39.1	21.8	26.7
28	*1	01.12.2002	Wadi el- Quilt	406.0	8.2	12.7	34.0	13.3	21.3	2.1	146.5	40.0	34.0	23.9
29	*2	20.01.2002	Wadi el- Quilt	448.0	7.1	12.0	54.0	12.9	23.9	2.1	268.5	45.0	31.0	23.9
30	*3	12.11.2001	Wadi el- Quilt	362.0	7.4	12.3	38.5	7.8	26.7	3.4	207.5	50.0	26.0	15.4
31	*4	13.01.2002	Wadi el- Quilt	409.0	7.0	12.2	45.0	13.3	21.1	2.0	134.2	50.0	32.0	26.0
32	*5	01.12.2001	Wadi el- Quilt	446.0	8.2	12.5	51.9	12.7	25.8	2.0	256.3	40.0	29.0	28.9
33	*6	12.12.2001	Wadi el- Quilt	417.0	7.4	12.3	39.0	10.0	35.1	4.2	231.9	65.0	24.0	18.2
34	*7	12.07.2001	Wadi el- Quilt	358.0	7.4	12.5	34.8	7.2	25.8	3.3	207.5	55.0	28.0	18.4
35	*8	14.01.2002	Wadi el- Quilt	400.0	8.1	12.2	41.4	12.8	20.2	1.9	219.7	55.0	34.0	27.6

Table 4.2: The Cations, Anions concentration in meq/l of Wadi El-Quilt Flood water during the season (2001).

No	Lab ID	Date of Sampling	Location	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	Na^+/Cl^-	Ca^{+2}/Cl^-
1	Q5	18/02/2001	Wadi El-Quilt	2.27	2.06	1.30	0.08	2.80	1.64	0.60	0.52	0.79	1.38
2	Q6	20/02/2001	Wadi El-Quilt	2.06	2.05	1.30	0.08	3.00	1.63	0.59	0.53	0.80	1.26
3	Q1	23/02/2001	Wadi El-Quilt	3.58	1.69	1.48	0.12	3.80	1.80	0.54	0.49	0.82	1.99
4	Q2	23/02/2001	Wadi El-Quilt	3.73	1.62	1.58	0.13	4.10	1.93	0.56	0.49	0.82	1.93
5	Q3	24/02/2001	Wadi El-Quilt	3.35	1.61	1.31	0.10	3.60	1.57	0.47	0.40	0.83	2.13
6	Q4	24/02/2001	Wadi El-Quilt	2.87	1.60	1.38	0.11	3.20	1.67	0.48	0.41	0.83	1.72
7	Q8	25/02/2001	Wadi El-Quilt	2.42	1.77	1.34	0.12	2.70	1.64	0.79	0.38	0.82	1.48
8	Q9	25/02/2001	Wadi El-Quilt	1.55	1.55	1.28	0.10	2.00	1.63	0.47	0.31	0.79	0.95
9	Q13	02/05/2001	Wadi El-Quilt	2.23	0.62	0.74	0.14	2.13	0.90	0.71	0.25	0.82	2.48
10	Q14	03/05/2001	Wadi El-Quilt	2.98	0.99	0.97	0.16	2.77	1.11	0.69	0.31	0.87	2.68
11	*7	12/07/2001	Wadi El-Quilt	1.74	0.59	1.12	0.08	3.40	1.55	0.58	0.30	0.72	1.12
12	*3	12/11/2001	Wadi El-Quilt	1.92	0.64	1.16	0.09	3.40	1.41	0.54	0.25	0.82	1.36
13	*5	01/12/2001	Wadi El-Quilt	2.59	1.04	1.12	0.05	4.20	1.13	0.60	0.47	0.99	2.29
14	*6	12/12/2001	Wadi El-Quilt	1.95	0.82	1.53	0.11	3.80	1.83	0.50	0.29	0.84	1.07

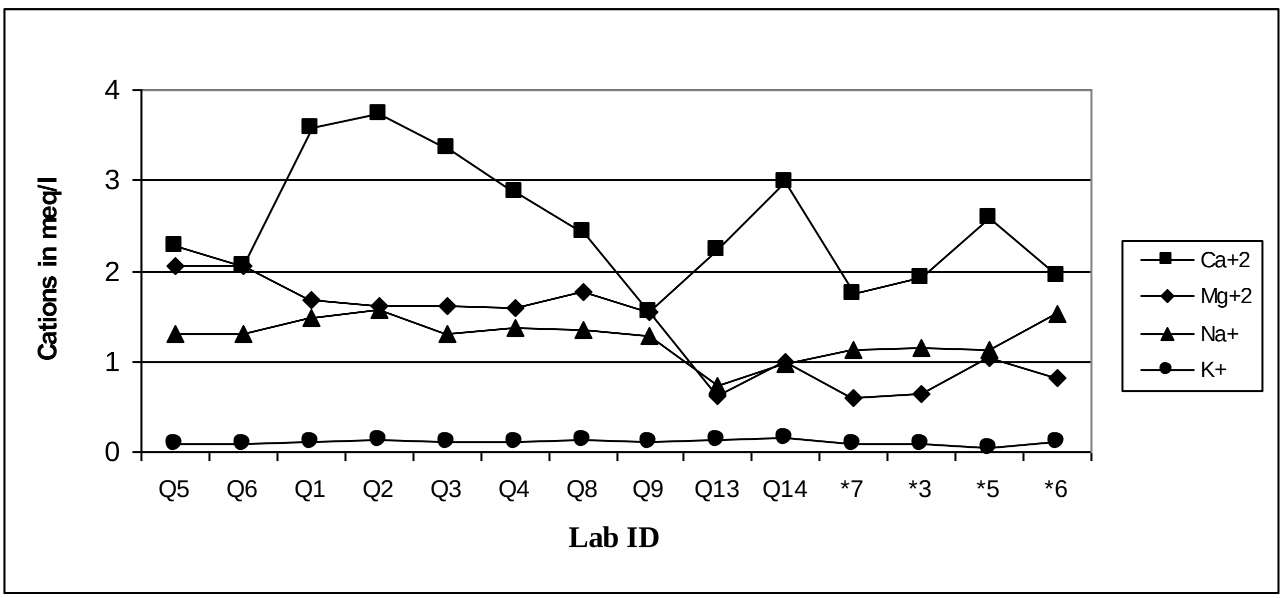

Fig. 4.1: The Cations concentration in meq/l of Wadi El-Quilt Flood water during the season (2001).

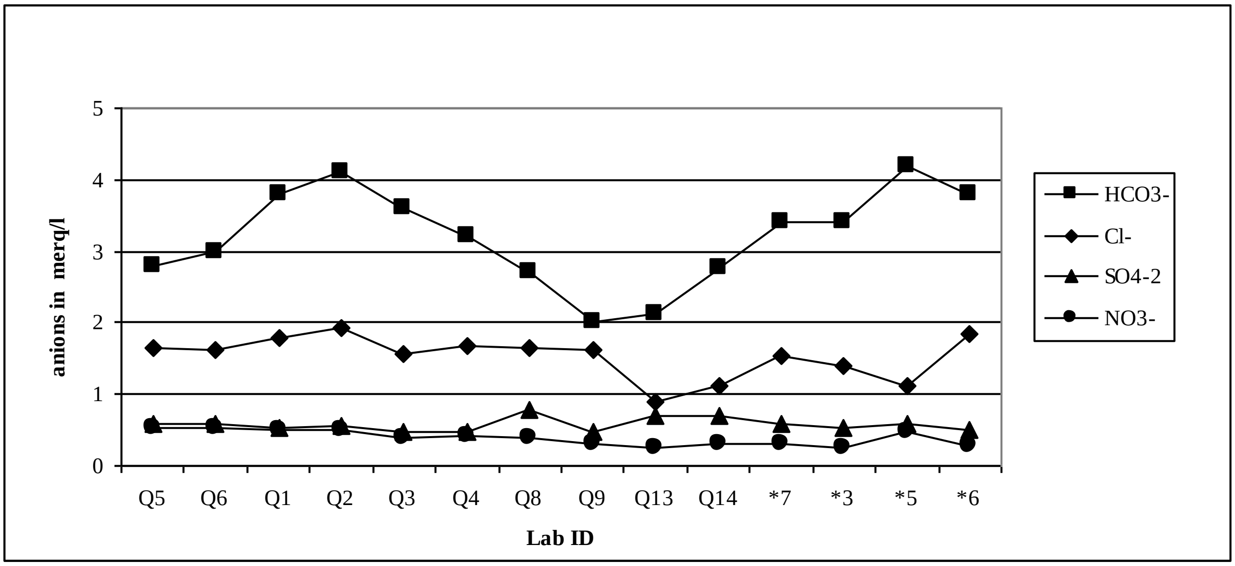

Fig. 4.2: The Anions concentration in meq/l of Wadi el-Quilt Flood water During the season (2001).

The Na, Cl, SO_4 values show a constant concentration during the flooding time, the Na/Cl ration (0.82) is very close to the ration in the rain water (0.86). The increase in Ca, HCO_3 after one weak of rainfall from 18.02.2001 to 23.02.2001 present the reaction between stored water in the unsaturated zone and Ca-holding minerals. The result in increasing Ca-concentration in flood water because this water seeped from the soil horizon but during the last day at 25.02.2003 the Ca^{2+} concentrations decrease to the level of rainwater because most of water stamen from direct runoff the duration time in the unsaturated zone is very short.

Table 4.3: The Cations, Anions concentration in meq/l of Wadi El-Quilt Flood Water during the season (2002).

No	Lab ID	Date of Sampling	Location	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	Na^+/Cl^-	Ca^{+2}/Cl^-
1	*1	01/12/2002	Wadi El-Quilt	1.70	1.09	0.93	0.05	2.40	1.13	0.71	0.39	0.82	1.50
2	*4	13/01/2002	Wadi El-Quilt	2.25	1.09	0.92	0.05	2.20	1.41	0.71	0.45	0.65	1.60
3	*8	14/01/2002	Wadi El-Quilt	2.06	1.05	0.88	0.05	3.60	1.55	0.71	0.45	0.57	1.33
4	*2	20/01/2002	Wadi El-Quilt	2.69	1.06	1.04	0.05	4.40	1.27	0.65	0.39	0.82	2.12

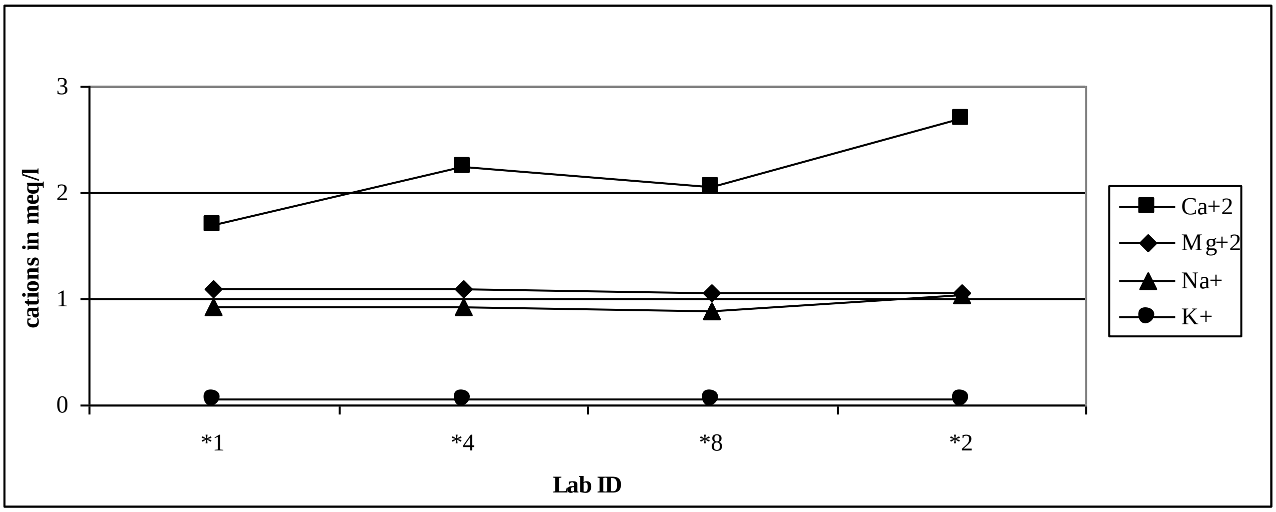

Fig. 4.3: The Cations concentration in meq/l of Wadi El-Quilt Flood water during the season (2002).

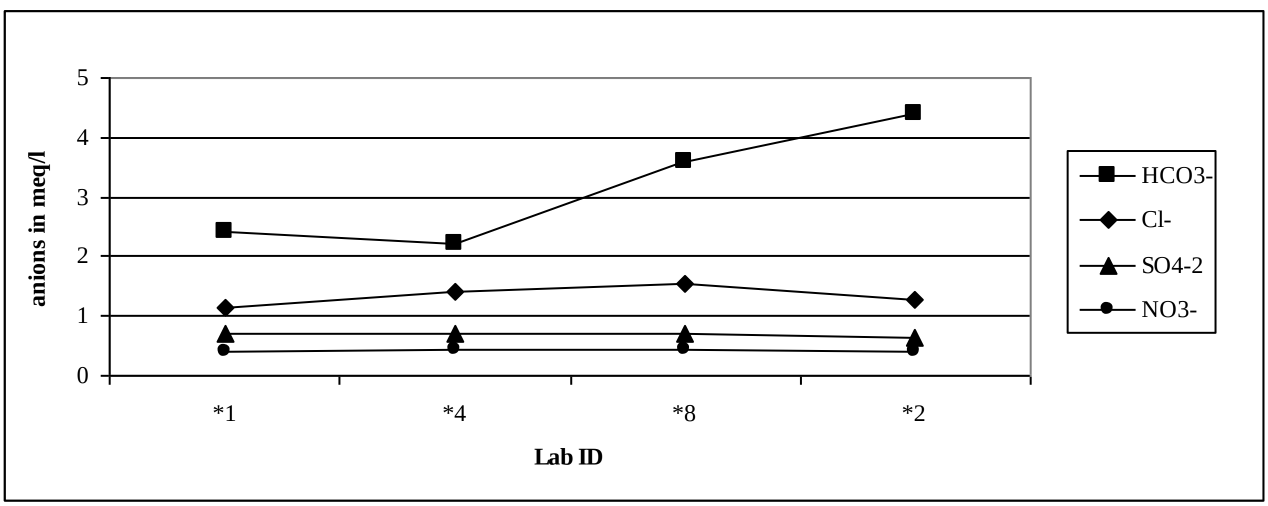

Fig. 4.4: The Anions concentration in meq/l of Wadi El-Quilt Flood water during the season (2002).

Table 4.4: The Cations, Anions concentration in meq/l of Wadi El-Quilt Flood water during the season (2003).

No	Lab ID	Date of Sampling	Location	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	Na^{+}/Cl^{-}	Ca^{+2}/Cl^{-}
1	Q48	04/02/2003	Wadi El-Quilt	1.98	1.30	0.89	0.04	3.40	1.09	0.50	0.41	0.82	1.82
2	Q52	04/02/2003	Wadi El-Quilt	1.99	1.29	0.87	0.03	3.80	1.04	0.49	0.41	0.84	1.91
3	Q53	17/03/2003	Wadi El-Quilt	1.92	1.32	0.89	0.03	3.80	1.09	0.46	0.42	0.82	1.76
4	Q56	17/03/2003	Wadi El-Quilt	1.93	1.32	0.89	0.03	3.20	1.10	0.45	0.43	0.81	1.75
5	Q54	20/03/2003	Wadi El-Quilt	2.28	1.28	0.93	0.04	3.60	1.12	0.46	0.43	0.83	2.04
6	Q51	22/03/2003	Wadi El-Quilt	2.21	1.24	0.87	0.04	3.20	1.00	0.46	0.39	0.87	2.21
7	Q45	24/03/2003	Wadi El-Quilt	2.14	1.25	0.85	0.04	3.40	1.00	0.49	0.41	0.85	2.14
8	Q46	29/03/2003	Wadi El-Quilt	2.07	1.20	0.82	0.04	3.40	0.97	0.48	0.39	0.85	2.13
9	Q50	31/03/2003	Wadi El-Quilt	2.05	1.28	0.88	0.04	3.20	1.04	0.49	0.41	0.85	1.97
10	Q55	31/03/2003	Wadi El-Quilt	2.00	1.20	0.88	0.04	3.60	1.00	0.50	0.42	0.88	2.00
11	Q47	04/05/2003	Wadi El-Quilt	1.85	1.33	0.87	0.04	3.40	1.07	0.46	0.39	0.81	1.73
12	Q49	04/07/2003	Wadi El-Quilt	1.85	1.34	0.90	0.03	3.40	1.02	0.44	0.38	0.88	1.81

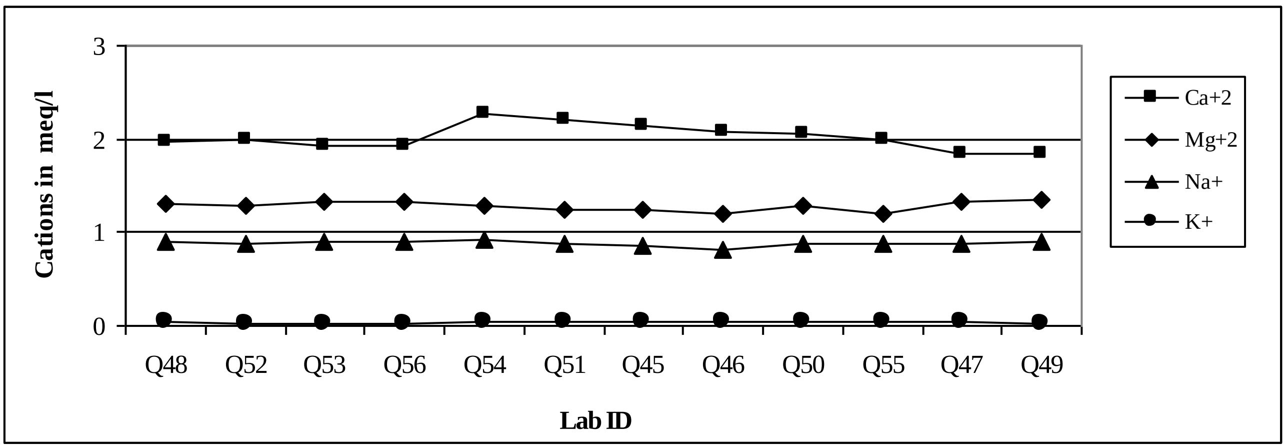

Fig. 4.5: The Cations concentration in meq/l of Wadi El-Quilt Flood water during the season (2003).

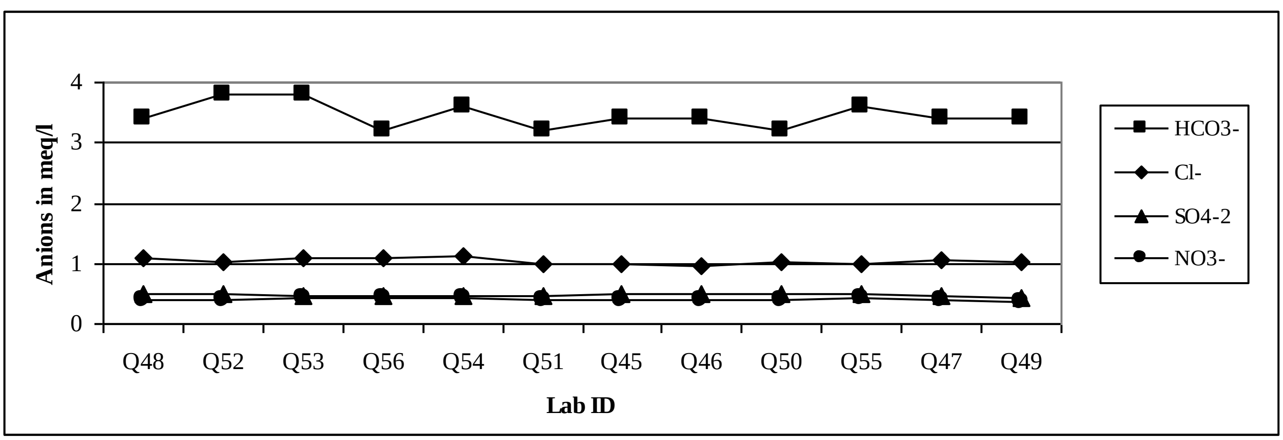

Fig. 4.6: The Anions concentration in meq/l of Wadi El-Quilt Flood water during The season (2003).

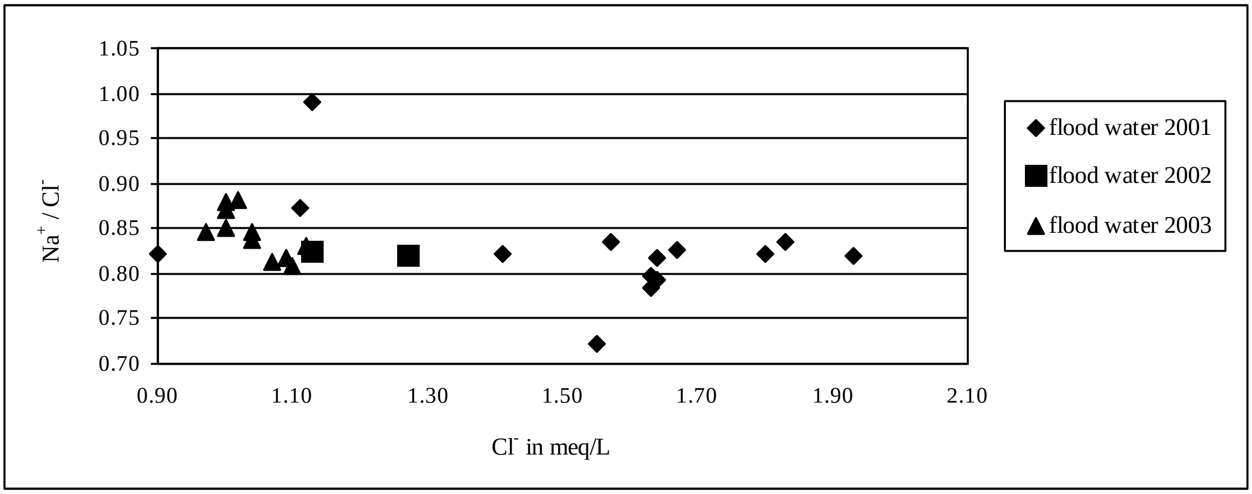

Fig.4.7: The Na^{+}/Cl^{-} ratio with Cl^{-} in the flooding water during the years 2001, 2002 and 2003.

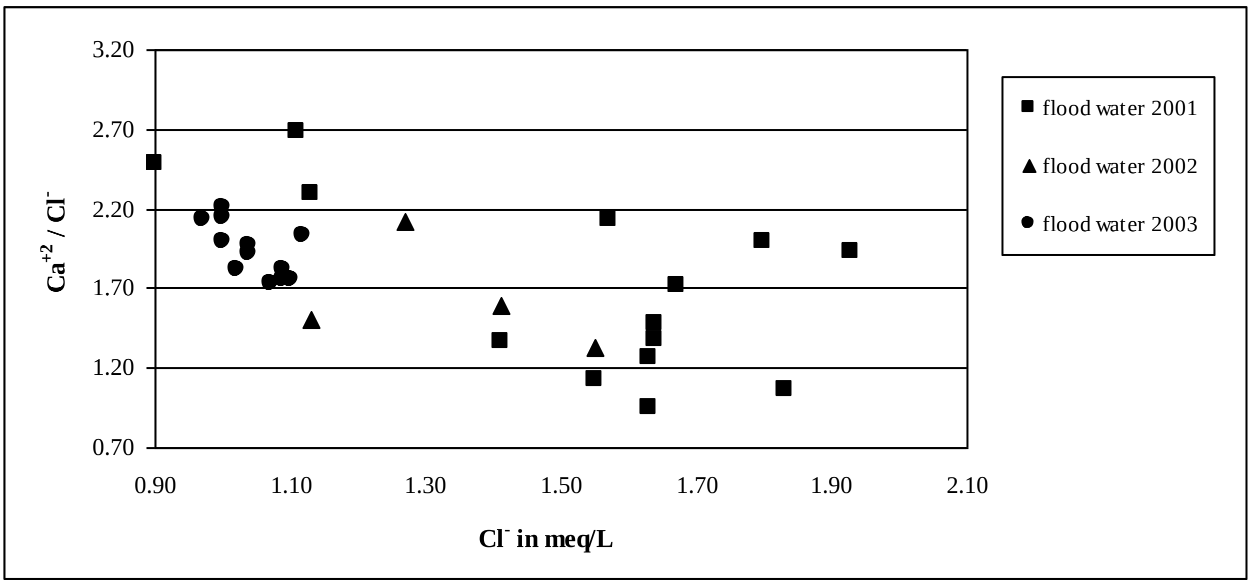

Fig. 4.8: The Ca^{+2}/Cl^{-} ratio with Cl^{-} in the flooding water during the years 2001, 2002, and 2003.

The chloride content of floodwater during the year 2003 has an average of 37.05 mg/L and the Na/Cl ratio is 0.839 which is close to the ratio in the rainwater 0.86. The SO_4^{-2} and the NO_3^{-} are below the 1.0 mg/L. A small increase in Ca parallel with an increase in HCO^{-}_3 was noticed during the flooding of march 2003 which indicate a relative long duration time of water in the soil horizon, or this water have staid a time in horizon before it was released as flood water. The Ca^{+2}, Mg^{+2} curves are parallel to each other which indicate the same source which is calcium carbonate, while the Ca^{+2} is higher than Mg^{+2} that is related to the dominant of limestone in the rock than dolomite. The Na/Cl ratio in all surface water samples is less than the ratio in wastewater 1.2. This means that the influent of human activity in the catchments area is very limited and the small fluctuation is within the range of rain water.

Fig. (4.9) present the Ca/Cl ratio of rain, surface, and groundwater from Wadi el-Quilt channel shows that the origin of the groundwater in Wadi Quilt channel locate at a different line that the surface water location because this water originate from few springs issue from the upper aquifer system of Toranian age. Group II present groundwater sample from the plio-pleistocene shallow aquifer system of Jericho area, this group have a lower ratio that the first group due to the affect of evaporites in the Lisan Formation. While the Fig (4.10) present the Mg/Cl ratio of Rain, Flood water, and groundwater from the Season (2001-2003) and the Fig (4.11) present the Mg/Cl ratio of Rain, Wadi el-Quilt Flood and Wadi el-Quilt Channel water from the season (2001-2003).

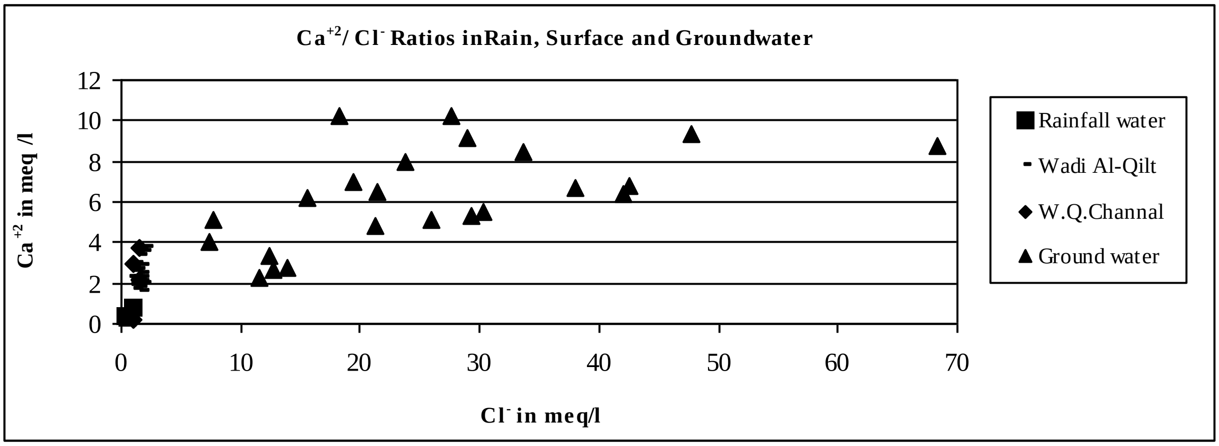

Fig. 4.9: The Ca^{+2}/ Cl^- Ratios in meq/l of Rain, Flood water and groundwater from the Season (2001-2003).

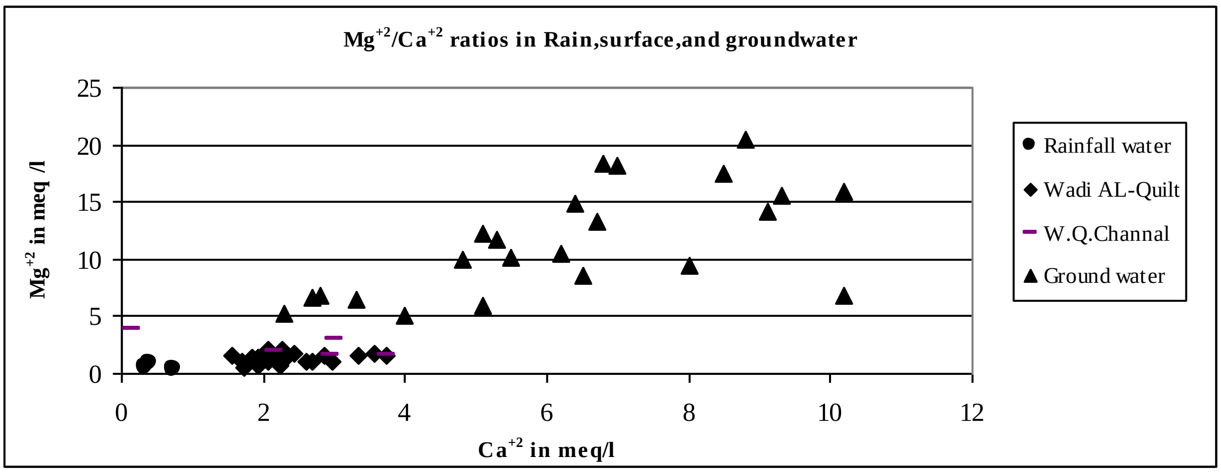

Fig. 4.10: The Mg^{+2}/ Cl^- Ratios in meq/l of Rain, and Flood water from the Season (2001-2003).

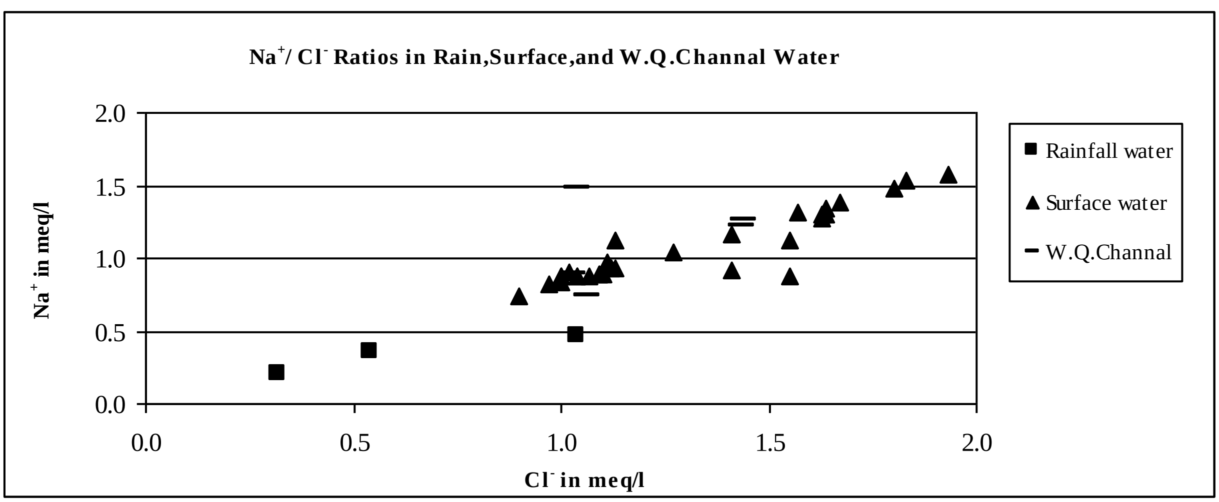

Fig. 4.11: The Na^+ / Cl^- Ratios in meq/l of Rain, Wadi el-Quilt Flood and Wadi el-Quilt Channel water from the season (2001-2003).

The catchment area of Wadi el-Quilt (WQ) is about 176 km^2, extends from the Jordan River in the East to the crest of the Mountains in the West (Al-Bereh-Jerusalem line), (Fig. 4.12). (Arad and Michaeli, 1967) calculated the average flood water runoff for Wadi el-Quilt of about 10% of the total precipitation. (Goldschmidt, et al. 1967) gave the regression of the flood water runoff in Wadi el-Quilt as:

$$Runoff = 0.237*(Precipitation-252mm/a)$$

With coefficient of regression 99.8%. Rainfall data were collected from Ramallah weather station which is very close to the western part of the catchment area (Table 3.9). With these data, the calculated flood surface water ranges between 49.2 to 105.4 mm/a. While the central and the eastern part of the catchment area locates in the rainfall shadow. Abu Dies weather station was additionally used to represent this part, and consequently the annual flood surface runoff ranges between 46.0 to 57.6 mm. (Al Quds University, 2005). The calculations of surface catchment area of Wadi el-Quilt by using Arcview GIS software shows that this area extends over 183 km^2 (Fig. 4.12). Calculated floods produced in this catchment area have a volume ranging between 9.4 MCM (minimum value calculated according to Abu Dies weather station data) and 19.3 MCM (maximum value calculated depending on Ramallah weather station data) (Appendix 6.4) .

The natural base flows of the Study area consist of discharge of the three springs which are Fara, El Fawar and el-Quilt (Fig. 4.1), these springs issue at elevation between 290m and 10m above sea level, they are feeding from the upper aquifer of upper cretaceous age. This base flow is redirected to the Wadi el-Quilt concrete Channel (WQC). The total discharge of these springs range between 300 l/s to 1200 l/s (Wolf 1998). Water from these three springs is diverted to Agbat Jaber Refugees Camp and Jericho City for drinking and irrigation purposes respectively. The bad condition of the channel let non accountable volume of water to leak. During flooding time water flows over the channel and discharge into the Wadi

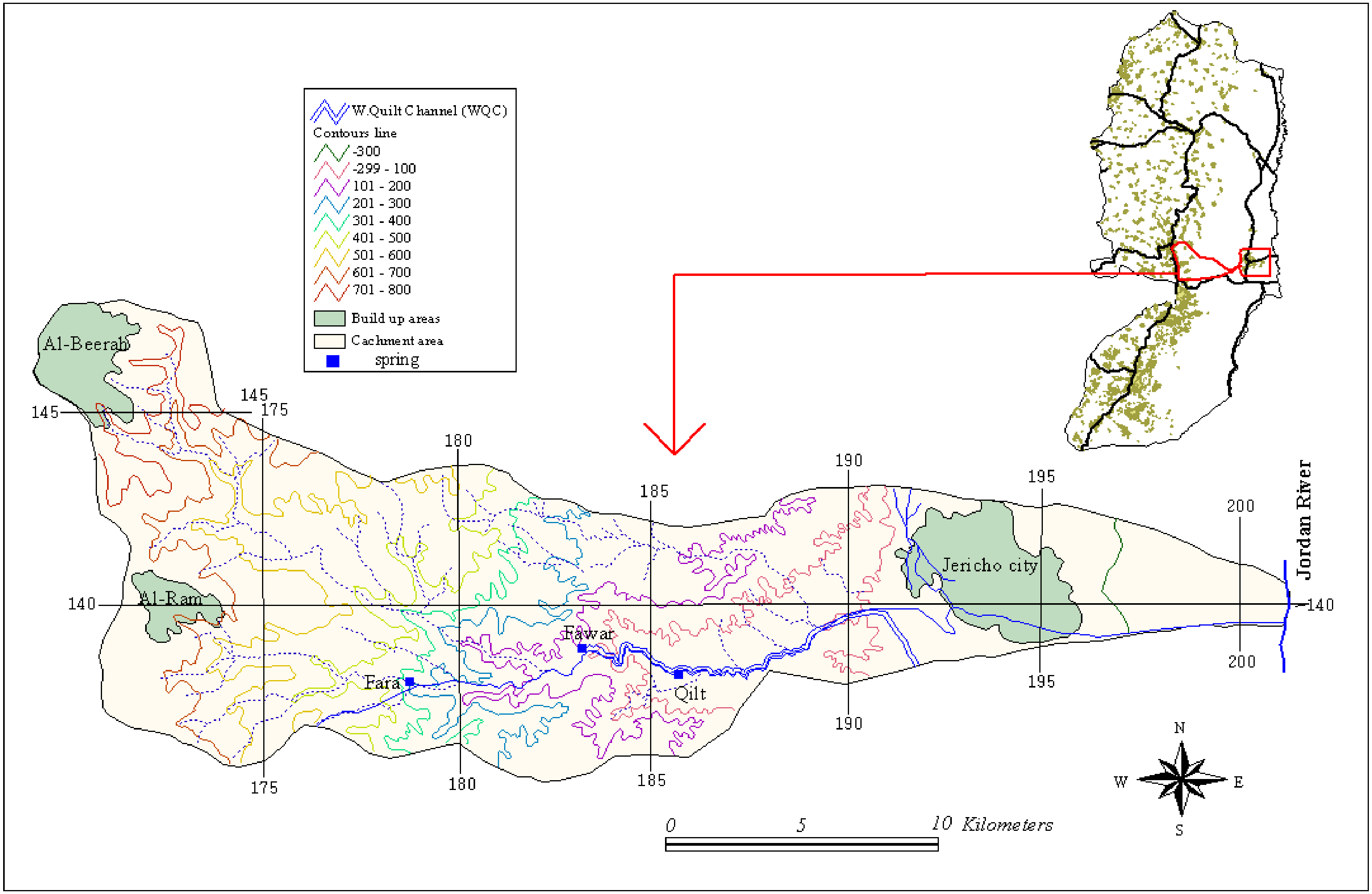

Fig. 4.12: Location of the Wadi El-Quilt catchment area.

4.2 Chemical and Isotopic Properties of the Water:

The following Tables present the chemical and isotopic data, (Table 4.1) flood water from Wadi el-Quilt and Wadi el-Quilt channel, (Table 4.5) and (Appendix 6.5) shows groundwater from wells of Plio-Pleistocene aquifer system, (Table 4.6) and (Table 4.7) for rainwater collected in Abu Dies weather Station, (Table 4.8) spring water (Wadi el-Quilt group).

4.2.1 Salinity:

Salinity of water defined in this Research by the chloride concentration in mg/L. The international limit of chloride content in drinking water should not exceed 250 mg/L WHO (1996). Average chloride contents of rainfall is 15.9 mg/L and increase to 34 mg/L in springs water of Wadi el-Quilt group, this value rise to 42.6 mg/L at the end of the WQC. This increase related to natural reasons such as the affect of evaporation or to accidental resound when certain minerals/rock fall into the channel or due to the affect of animals (goats and sheep) because the catchment area used as grassing area. The average chloride content of the flood water during the years 2001 until 2003 is 44.2 mg/L (Table 4.1), as soon as this water infiltrated, its salinity increase and reach between (200-800) mg/L in the western part of the aquifer, and rise to (1000-2400) mg/L in the eastern part of the study area (Fig. 4.13). Previous studies (Nasser ed Din, 1999) and (Geyer et. al, 2005) interpret the rising of salinity for two possible reasons, first up-conning

Table 4.5: List of Groundwater samples, their chemical and Isotopic composition

Well ID	Date	Coordinates	Depth	EC	pH	Temp	Cl^-	NO_3^-	SO_4^{-2}	$HCO3^-$	Na^+	K^+	Ca^{+2}	Mg^{+2}	$\delta^{18}O$	δ^2H	Tritium
				us/cm		^0C	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	[‰]	[‰]	(TU)
19-14/067	06/07/2003	197,010--140,560	73	4930	7.08	26.7	1505.0	34.5	240	414.0	614.1	94.00	136.2	223.0	-5.29	-22.9	
19-14/073	06/07/2003	197,030--141,050	80	3530	7.03	26.8	920.0	25.6	100	439.3	414.4	77.66	101.8	148.7	-5.38	-23	
19-14/066	06/07/2003	197,310--140,660	33	4790	5.97	26.4	1195.0	20.2	300	463.8	579.1	71.53	169.9	212.7	-5.4	-23.4	
19-14/024A	06/07/2003	196,785--138,449	65	3150	7.08	26.1	686.5	32.2	250	390.5	349.5	41.55	139.4	221.2			
19-13/018	06/07/2003	193,770--139,750	83	1415	7.30	24.8	258.3	23.5	116	341.7	147.0	24.53	79.3	61.2	-5.3	-23.2	3.3
19-14/003	06/07/2003	193,830--141,550	120	2970	6.97	29.5	843.0	9.1	52	414.9	284.0	34.06	159.5	114.6	-5.37	-23.8	
19-14/020	12/01/2004	196,490--141,020	60	3930	7.19	23.4	1489.1	61.5	156	488.2	406.2	91.54	127.5	180.8			
19-14/019	12/01/2004	196,460--140,500	67	3990	6.78	22.0	978.9	71.1	368	488.2	391.8	56.81	230.6	192.9	-5.4	-22.7	2
19-13/069	12/01/2004	196,950--139,250	132	4060	7.10	25.0	1039.8	27.2	108	506.5	618.3	85.22	105.8	142.4	-5.4	-23.5	1.1
19-14/015	12/01/2004	195,670--140,530	93	2350	6.68	22.0	554.6	57.4	70	579.7	237.3	18.49	123.4	127.8	-5.6	-24.4	1.8
19-14/066	12/01/2004	197.310--140.660	33	5820	6.82	25.0	1691.6	44.9	384	591.9	801.6	89.96	186.8	188.6	-5.5	-22.8	1.3
19-13/006	12/01/2004	195,500--139,580	80	2490	6.68	22.4	645.7	75.9	187	439.3	266.0	7.90	204.4	82.6	-5.6	-23.8	
19-13/047	12/01/2004	194,850--139,880	74	1338	6.91	22.0	245.3	33.5	69	457.7	172.5	11.04	62.5	59.3			3.7
19-13/015	12/01/2004	196,100--139,510	63	2110	7.05	23.9	493.0	32.7	54	451.5	266.0	33.14	56.9	83.1	-5.5	-23.2	
19-13/052	12/01/2004	195,880--139,670	120	3540	6.87	19.8	1025.5	61.3	311	396.6	406.2	33.14	182.8	172.0	-5.4	-23	
19-14/023	12/01/2004	195,040--140,240	60	1378	6.88	21.6	271.6	87.4	51	518.7	140.2	14.20	102.6	71.4			3.7
19-13/048	12/01/2004	195,310--139,660	57	1448	6.90	22.0	438.2	54.9	111	451.5	179.7	14.20	65.7	79.2			
19-13/050A	12/01/2004	195,810--139,380	100	1922	7.01	22.9	452.4	40.8	85	445.4	219.3	33.14	53.7	81.6			2.9
19-14/052	12/01/2004	195,680--140,980	82	2900	6.85	23.0	1073.0	45.0	89	518.7	366.7	33.14	109.8	122.5			
19-13/020	12/01/2004	194,320--139,480	83	1574	6.99	22.3	407.5	58.9	161	463.8	222.9	15.78	45.7	63.2			
19-14/067	12/01/2004	197.010--140.560	73	6840	6.80	25.0	2423.7	55.2	190	451.5	938.2	116.79	177.2	249.3	-5.3	-22.9	
19-14/026A	04/12/2004	192,573--141,834	90	1134	6.93	22.8	117.0	16.9	19	512.6	71.0	6.00	42.1	72.9			
19-13/021	04/12/2004	194,960--138,560	72	2990	7.34	22.4	680.6	31.6	105	402.7	317.0	54.00	92.2	119.0			
19-14/038	04/12/2004	193,450--142,530	110	2240	6.98	25.5	496.3	9.4	53	457.7	166.0	19.00	120.2	97.2			
19-14/037	04/12/2004	196,120--141,060	83	3610	6.98	24.5	882.7	21.5	155	418.0	349.0	43.00	144.3	140.9			
19-14/003	04/12/2004	193,830--141,550	120	3210	7.01	26.0	857.9	6.8	64	366.0	289.0	21.00	144.3	116.6	-5.4	-23.8	

Table 4.6: chemical and isotopic analysis for Abu Dies rainfall samples.

Date of Sampling	Rain fall	Temp	EC	pH	Cl^-	NO_3^-	SO_4^{2-}	HCO_3^-	Na^+	K^+	Ca^{2+}	Mg^{2+}	$\delta^{18}O$	δ2H
	mm	^0C	uS/cm		mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	[‰]	[‰]
27/10/2001	1.4	20.4	378.0	6.1	23.0	115.0	22.0	12.2	10.4	3.8	40.0	3.7	-2.63	-0.7
28/10/2001	0.6	20.9	143.1	6.9	12.0	18.8	8.0	12.2	5.4	0.6	12.0	1.2	-3.50	-10.3
(16-18)/11/2001	21.6	11.4	1054.0	7.2	12.0	4.3	1.0	36.6	8.6	1.3	5.3	1.0	-6.42	-29.7
(21-22)/11/2001	7.6	12.7	252.0	7.1	60.8	5.5	20.0	36.6	31.0	1.5	11.0	3.6	-4.10	-14.0
(30/11)-(1/12)/2001	9.4	13.4	98.8	6.9	13.2	5.8	13.0	12.2	5.3	1.1	10.1	1.3	-2.79	-4.5
(4-6)/12/2001	65	12.0	30.1	7.2	1.2	0.9	1.0	12.2	1.0	0.1	5.3	1.4	-2.56	-11.2
(15-21)/12/2001	28.6	9.2	59.5	7.2	2.4	2.4	1.0	24.4	1.9	0.1	11.0	2.6	-5.07	-27.8
03/01/2002	1.2	10.8	100.0	7.0	1.6	4.0		24.4			12.6	2.9		
07/01/2002	1.6	6.5	23.5	6.9	6.4	0.3	1.0	12.2	1.8	0.1	3.0	6.4		
(7-8)/01/2002	39	7.1	65.2	7.2	16.0	1.1	2.0	24.4	6.7	0.4	6.9	6.9		
(8-9)/01/2002	33.2	7.3	12.5	6.7	8.0	0.4	1.0	12.2	2.0	0.2	2.2	2.2		
(9-12)/01/2002	67.6	5.3	20.7	6.7	4.4	0.1	1.0	12.2	1.2	0.2	2.9	5.0		
20-21/01/2002	12.6	9.4	41.4	7.1	1.6	2.1	1.0	12.2	3.2	0.2				
(21-22)/01/2002	16.6	9.4	20.0	6.8	0.4	0.2	1.0	12.2	1.6	0.3	8.0	10.7		
22/01/2002	9.8	6.1	15.7	6.3	2.0	0.3	1.0	12.2	1.2	0.1	1.8	58.5		
22/01/2002	11.4	8.8	15.6	6.8	3.6	0.0	1.0	0.0	1.0	0.1	2.9	49.3		
27/01/2002	3.2	11.8	89.3	7.0	12.4	7.1	16.0	12.2	3.5	0.6	10.4	44.7		
(28-29)/01/2002	13.8	11.4	47.1	7.3	8.4	1.7	0.0	12.2	2.6	0.2	6.6	28.8		
29/01/2002	6.6	12.0	47.3	6.6	9.6	1.2		12.2	2.3	0.3	1.2	0.2		
11/02/2002	9.4	14.2	42.9	7.2	0.8	1.2	1.0	12.2	1.6	0.5	7.2	0.3		
(11-12)/02/2002	10.6	13.3	76.5	7.7	24.4	0.0	8.0	24.4	4.9	0.0	4.0	10.9		
(12-13)/02/2002	14	12.0	40.2	7.4	1.6	1.0	1.0	24.4	3.0	0.0	5.6	1.3		
(13-15)/02/2002	2.4	12.6	95.2	7.4	6.0	5.9	11.0	36.6	3.8	0.0	10.6	0.0		
(27-30)/03/2002	39.2	11.7	51.6	7.2	11.6	1.5	0.0	12.2	0.8	0.0	3.4	0.6		
(1-7)/04/2002	43.4	15.9	93.0	7.0	8.8	2.9	12.0	24.4	3.5	0.0	6.7	0.0		
(14-15)/05/2002	1.2	16.1	297.0	6.6	44.0	37.9	41.0	36.6	12.5	2.8	21.6	2.4		
31/10/2002	13.2	19.0	20.1	7.2	9.6	12.9	13.0	36.6	2.0	0.6	9.2	0.0		
25/11/2002	0.2	15.0	29.8	6.8	22.8	10.3	8.8	12.2	19.2	2.7	6.8	4.9		
29/11/2002	1.2	13.5	30.1	7.1	32.0	10.8	10.0	12.2	6.2	1.6	7.6	4.9		
10/12/2002	7.4	14.1	89.3	7.1	15.2	8.7	8.0	12.2	2.6	0.0	5.9	0.0		
(10-11)/12/2002	20.6	10.1	61.2	6.0	16.0	4.7	1.0	12.2	4.8	0.0	1.9	0.0		
11/12/2002	0.4	14.5	128.0	6.7	28.0	7.7	6.0	12.2						
(17-18)/12/2002	12.2	13.0	11.6	7.0	7.2	7.0	1.0	12.2	3.1	0.0	4.0	2.9		
(19-21)/12/2002	117.6	9.4	110.0	6.5	12.4	6.4	4.0	36.6	11.7	0.5	3.2	0.0		
21/12/2002	2.2	9.3	95.3	7.0	20.4	9.7	5.0	N.D	8.0	0.0	3.2	0.0		
(24-27)/12/2002	26.8	12.7	36.6	6.7	3.6	7.0	1.0	12.2	3.4	0.4				
(30-31)/12/2002	3.2	12.5	74.9	7.0	8.0	9.7	10.0	12.2	1.3	0.0	9.1	0.0		
(3-4)/1/2003	13.2	12.7	29.8	6.9	6.0	6.1	0.0	12.2	0.4	0.0	0.0	0.0		
(14-15)/1/2003	4.8	13.9	136.9	6.9	22.0	5.1	9.0	24.4	8.6	0.0	9.7	0.0		

Table 4.7: chemical and isotopic analysis for Abu Dies rainfall samples.

Date of Sampling	Rain fall	Temp	EC	pH	Cl^-	NO_3^-	SO_4^{2-}	HCO_3^-	Na^+	K^+	Ca^{2+}	Mg^{2+}	$\delta^{18}O$	$\delta^{2}H$
	mm	^0C	uS/cm		mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	[‰]	[‰]
(19-20)/1/2003	15	11.4	27.0	6.4	2.7	1.2	1.7	24.4	0.6	0.0	0.0	0.0		
(20-21)/01/2003	9.8	12.7	23.4	6.5	1.7	0.9	1.1	12.2	0.6	0.0	0.0	0.0		
(4-5)/02/2003	11	11.0	127.3	7.3			15.0	24.4	6.8	0.0	7.8	0.0		
(8-16)/02/2003	60.4	10.8	51.6	7.1	6.0	1.2	3.0	12.2	2.9	0.0	1.7	0.0		
(18-19)/02/2003	6.6	13.3	111.4	7.1	15.4	5.8	6.4		6.3	0.8	5.4	0.0		
(20-22)/02/2003	55.4	10.6	68.3	7.3	6.9	1.0	3.1	36.6	3.3	0.0	6.0	0.0		
(22-23)/02/2003	5.4	11.2	49.5	6.8	4.8	1.1	4.0		2.1	0.0	1.5	0.0		
(25-28)/02/2003	135.4	10.0	49.5	6.8	6.3	0.7	2.9		7.5	0.5				
(4-5)/03/2003	0.6	13.1	57.8	6.9	6.9	2.4	5.2		2.3	0.0	2.2	0.0		
(18-19)/03/2003	55.8	14.5	131.5	7.4	15.8	2.0	9.4		7.6	0.7	8.5	0.0		
(21-22)/03/2003	5.2	11.5	180.5	7.1	28.9	3.6	11.7		13.7	0.7	9.4	1.4		
(24-25)/03/2003	11.4	10.1	110.0	7.9	5.8	4.7	16.3	48.8	2.8	0.5	11.5	0.0		
(25-26)/03/2003	43.8	9.9	84.4	7.2	10.4	1.9	4.0		4.9	0.0	7.4	0.0		
27/04/2003	9.8	15.5	54.6	6.8	42.0	9.1	17.5		17.2	1.3	19.7	2.5		
(10-11)/11/2003	14.6	19.0	199.1	6.5	32.0	8.6	17.0	24.4	16.6	1.5	19.2	7.3		
(23-24)/11/2003	1.4	17.5	423.0	7.4	127.7	21.1	57.4	73.2	69.1	0.3	52.1	4.9		
(1-2)/12/2003	7.6	16.8	88.6	6.7	10.0	7.9	12.6	30.5	3.0	1.0	9.6	2.9		
05/12/2003	25.2	13.3	36.0	7.1	2.6	1.3	2.5	6.1	2.5	0.3	12.0	0.5		
06/12/2003	2	18.5	123.5	18.5	10.3	2.0	11.9		6.4	0.3				
14/12/2003	7.2	17.2	62.4	7.2	8.4	4.6	9.2	6.1	3.3	0.3	4.0	1.9		
(18-19)/12/2003	0.2	10.4	62.0	7.5	9.2	0.8	4.1	12.2	8.4	0.3	12.0	1.0		
27/12/2003	0.5	15.0	212.0	7.2	91.0	7.2	31.0	12.2	15.3	1.7	23.2	19.4		
28/12/2003	0.2	19.6	119.2	7.0	51.3	5.4	19.8	18.3	5.9	1.0	16.8	5.3		
08/01/2004	320.4	11.0	120.0	7.3	68.0	4.5	28.5	6.1	12.6	0.9	15.2	ND		
09/01/2004	0.8	16.7	45.9	7.2	3.8	1.0	3.1	12.2	1.6	0.2	15.2	ND		
(12-13)/1/2004	17	16.6	64.1	7.5	5.9	1.2	2.6	30.5	1.6	0.2	11.2	ND		
(13-14)/1/2004	12.8	16.8	60.0	7.2	6.2	0.9	2.6	30.5	2.4	0.1	8.8	ND		
(14-15)/1/2004	2.2	15.0	89.9	6.8	10.6	2.1	4.6	24.4	2.9	0.1	18.4	ND		
(22-23)/1/2004	6.8	16.7	109.5	6.5	2.7	3.0	3.0	45.8	2.1	0.2	19.2	8.7		
27/1/2004	14.8	17.6	160.5	7.6	17.5	3.0	7.9	51.9	14.0	0.6	13.6	ND		
(27-28)/1/2004	0.8	16.3	108.3	7.4	5.0	0.3	8.0	48.8	6.0	0.5	12.8	ND		
(28-1)-(6/2)/2004	25	18.5	68.4	7.4	23.0	0.3	4.0	33.6	2.0	0.3	6.4	8.3		
(13-14)/2/2004	31.2	16.4	318.0	7.5	49.0	3.0		73.2	15.0	1.0	32.9	5.3		
(14-15)/2/2004	8.8	12.4	188.8	7.4	47.0	0.3	15.0	54.2	14.0	1.0	29.7			
(19-21)/2/2004	0.8	15.9	92.5	6.9	31.0	0.5	8.0	48.8	5.0	0.4	9.6	2.4		
(6-7)/3/2004	6.8	15.6	125.0	7.2	86.0	1.0	8.0	54.9	18.0	0.4	16.0	1.5		
13/3/2004	2.6	16.8	282.0	7.2	48.0	4.0		67.1	18.0	2.0				
02/05/2004	2.6	20.6	910.0	6.9	140.0			158.7			126.3	8.5		

Table 4.8: Chemical composition of the study area springs.

No.	Location	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
1	Ein Sultan	80.2	19.4	22.5	1.0	286.8	39.0	23.0
2	Ein Fara	42.6	17.4	0.3	0.1	3.7	0.9	8.2
3	Ein Fawar	48.0	15.7	0.9	0.1	4.1	1.0	5.8
4	Ein el-Quilt	50.1	17.0	0.9	0.1	3.7	1.0	8.0
5	Ein Hujla	222.4	162.0	9.6	1.2	4.3	22.5	245.0
6	Ein Dyouk	68.9	26.7	24.1	2.61	311.2	37.2	20.2

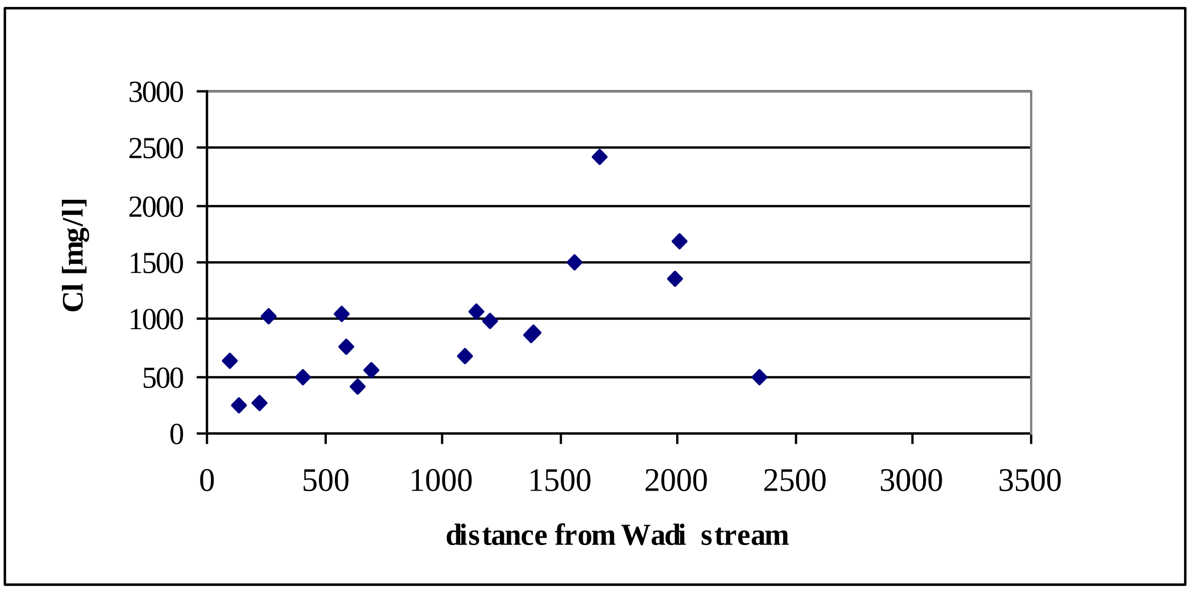

Fig. 4.13: Relation between salinity and distance from the Wadi stream.

Of brine due to the over pumping, second due to the mixing between freshwater and saline water.

Depending on the understanding of the geological, lithological framework of the study area, flood water infiltrates through fan deposit in the western part, and flow laterally through the alluvial deposits into the sand-silt layers of Samra Formation, then into the Lisan Formation in the east. Through this pathway the hydraulic conductivity decreases eastwards, Because of the inter-fingering between Samra Formation and Lisan Formation, and the changing of the lithological formation cause a relative long contact time between groundwater and the rock, so minerals are dissolute and groundwater salinity increase.

4.2.2 Na/Cl - ratio:

Sodium-chloride ratio of rainwater is to have the same ratio of the rain water 0.86. This ratio varies with distance increasing from the shore line into the inland or when additional source of chloride or sodium is added to the rain. The weighted average of Na^{+}/Cl^{-} ratio in the rainwater at Abu Dies weather station is 0.6, this station lies in the rain shadow of the mountain ridges.

Springs water of Wadi el-Quilt group (WQ), and water from the Quilt group Channel (WQC) have very closed ratio to the rainfall namely 0.86 and 0.82 respectively. Flood water have the close ratio of the rainwater 0.80, these springs are feeding from the carbonate aquifer of upper cretaceous age. (Fig. 4.14). Presents the relationship between Na/Cl and 1/Cl, it shows that with increasing the underground pathway, the salinity increased and the Na/Cl-ratio decrease and reach its minimum in the water of Ein Hujla where the ratio becomes 0.43 (Table 4.8). This is due to the absorption of the Na^+ by the clay minerals of the Lisan Formation. Two wells (19-13/047, 19-14/019) are an exception to this rule in which the ratio is 1.07 and 0.90 respectively, in both wells the calcium concentration is less than the sodium (Table 4.5), this is due to the natural softening through absorbance of calcium and releasing of sodium through clay minerals.

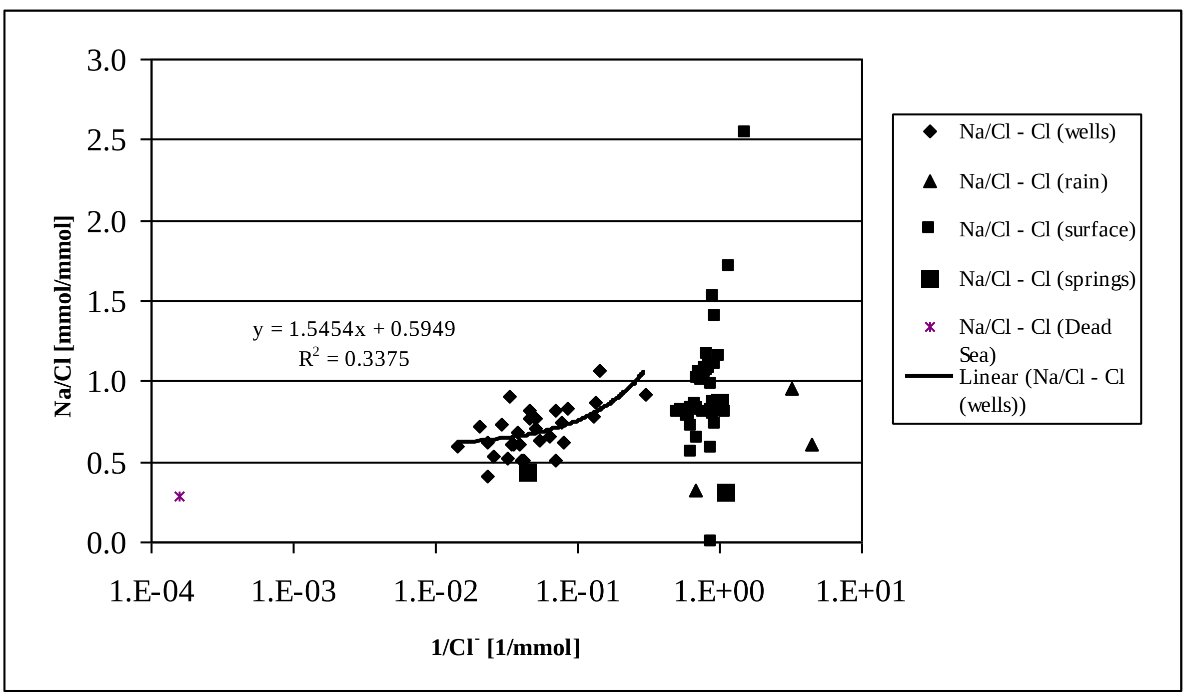

Fig. 4.14: Relation between Na/Cl and 1/Cl.

4.2.3 SO_4/Cl^- ratio:

Sulfate-chloride ratio in the water of Wadi el-Quilt spring group has an average of 0.08 and this ratio rise to 0.16 .The sulfate increase is related to the contact between flood water and rocks along the Wadi drainage system. The main source of sulfate contents in the groundwater of the Plio-Pleistocene is the dissolution of gypsum from Lisan Formation. The average initial concentration of the floodwater is 25.4 mg/L. This water infiltrates into the aquifer system and dissolves the gypsum of Lisan Formation. The distribution of the sulfate values shows no clear trend, so the values were divided into two categories which are;

1- Values with 100 mg/L and less.

2- Values with more than 100 mg/L.

By constructing a line between the first categories which show that this line flow parallel to the present Wadi el-Quilt flow line. This mean, that these wells locate along old Wadi el-Quilt alluvial deposits and water from this Wadi washout the most of the salts of Lisan Formation, and due to this, there is water with low sulfate contents. The average SO_4/Cl ratio of these wells is 0.2

In the western part, the direction of the section A-B is to northeast and after point B the river change the direction to the southeast (present status), by extending the A-B section and the sulfates line, they are to meet by well 19-14/026A (Samed), (Fig. 4.15). This well has the lowest chloride contents (19 mg/L).

The conclusion is that, the old flow path of Wadi el-Quilt could be locates in average 1.5 km and 3.5 km to the north of the present one in the eastern and western part of the study area. The SO_4/Cl-ratio ranges by the rest of the wells between 0.06 and 0.4, water from these wells are saturated or under saturated with respect to gypsum.

4.2.4 Ca/Mg- Ratio:

Average values of Ca/Mg in Wadi el-Quilt spring group is 1.2 which indicate that the groundwater originates from the carbonate aquifer. The Ca/Mg Values of flood water have the range of 1.0 and 3.9 pointed out of additional source of calcium, which could be the dissolution of gypsum. This water infiltrates with 45.9 mg/L calcium and 17.4 mg/L magnesium into the aquifer and reacts with minerals. In most of the groundwater samples the calcium concentration increase in one hand, the Ca/Mg decrease in the other hand. The source of the additional calcium is the dissolution of the gypsum ($CaSO_4$ $2H_2O$), when free calcium in water, clay minerals absorb the calcium ion and release the magnesium, so through this release the additional magnesium was found in the groundwater with concentration values ranging between 42.1 to 230.6 mg/L. (Fig. 4.16, 4.17 and 4.18) presents the Ca^{2+} concentration, Mg^{2+} concentration, and the Ca^{2+}/Mg^{2+} ratio of the groundwater samples of the study area.

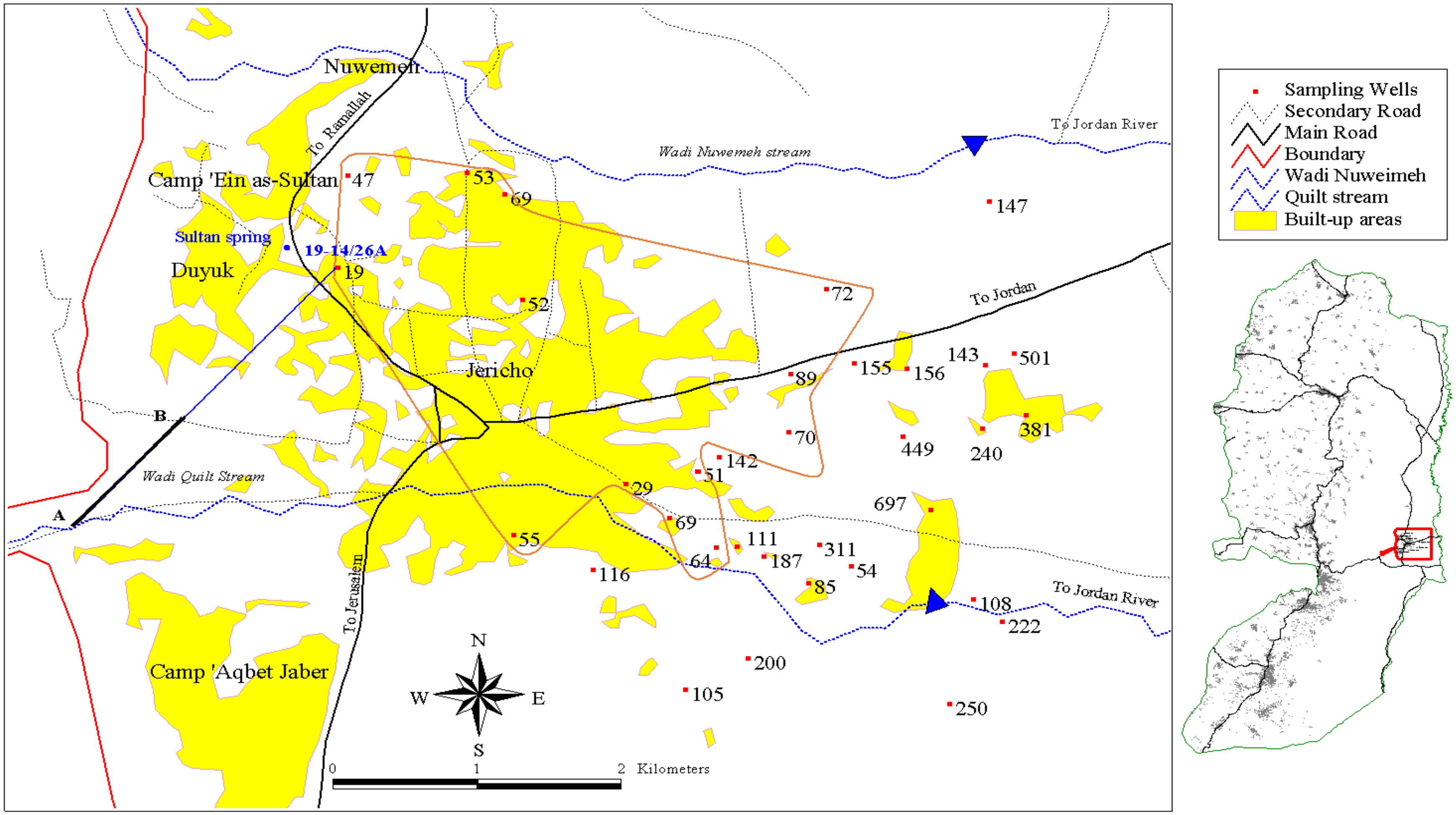

Fig. 4.15: Sulphate contents in groundwater of Jericho area

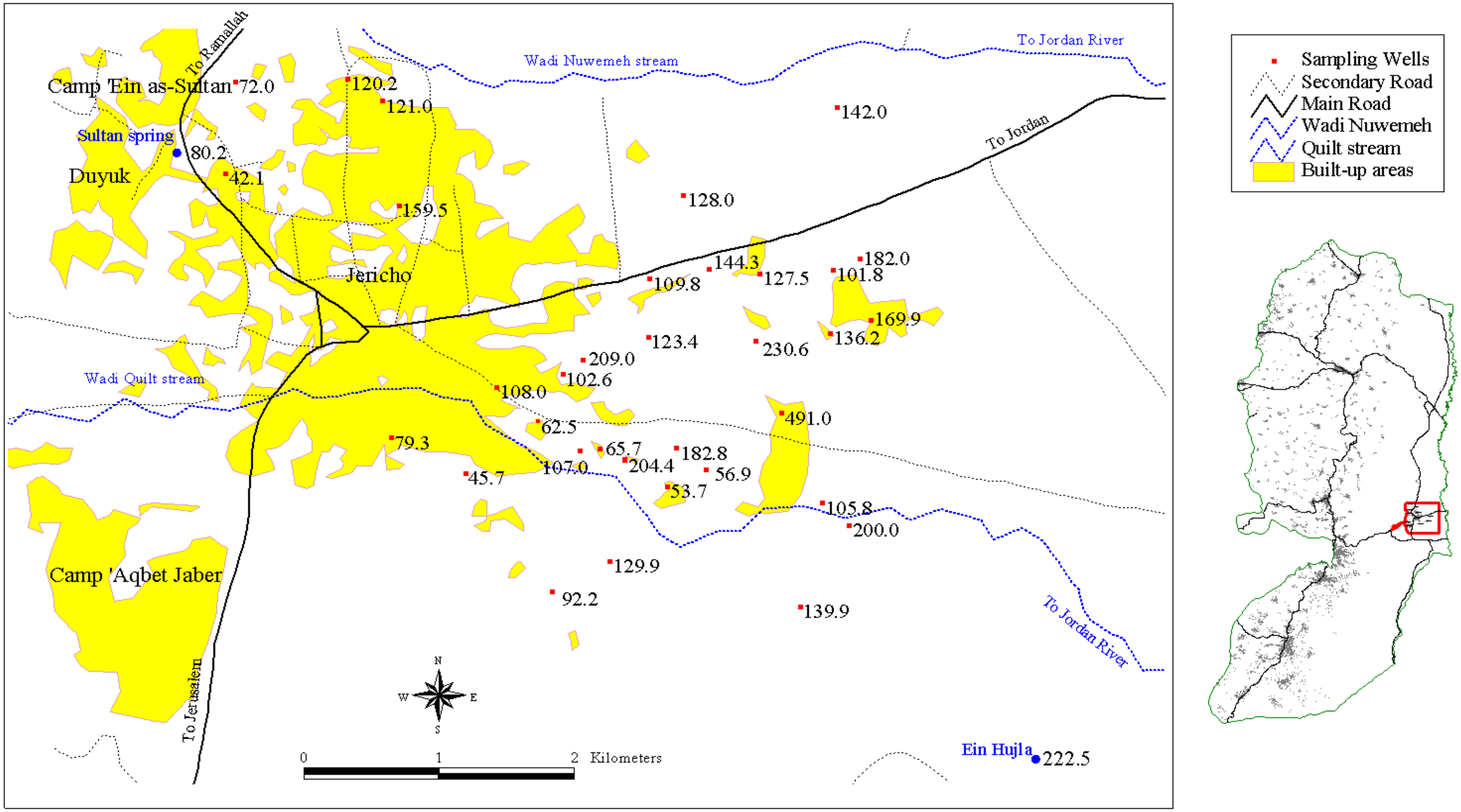

Fig. 4.16: Calcium contents in groundwater of Jericho area

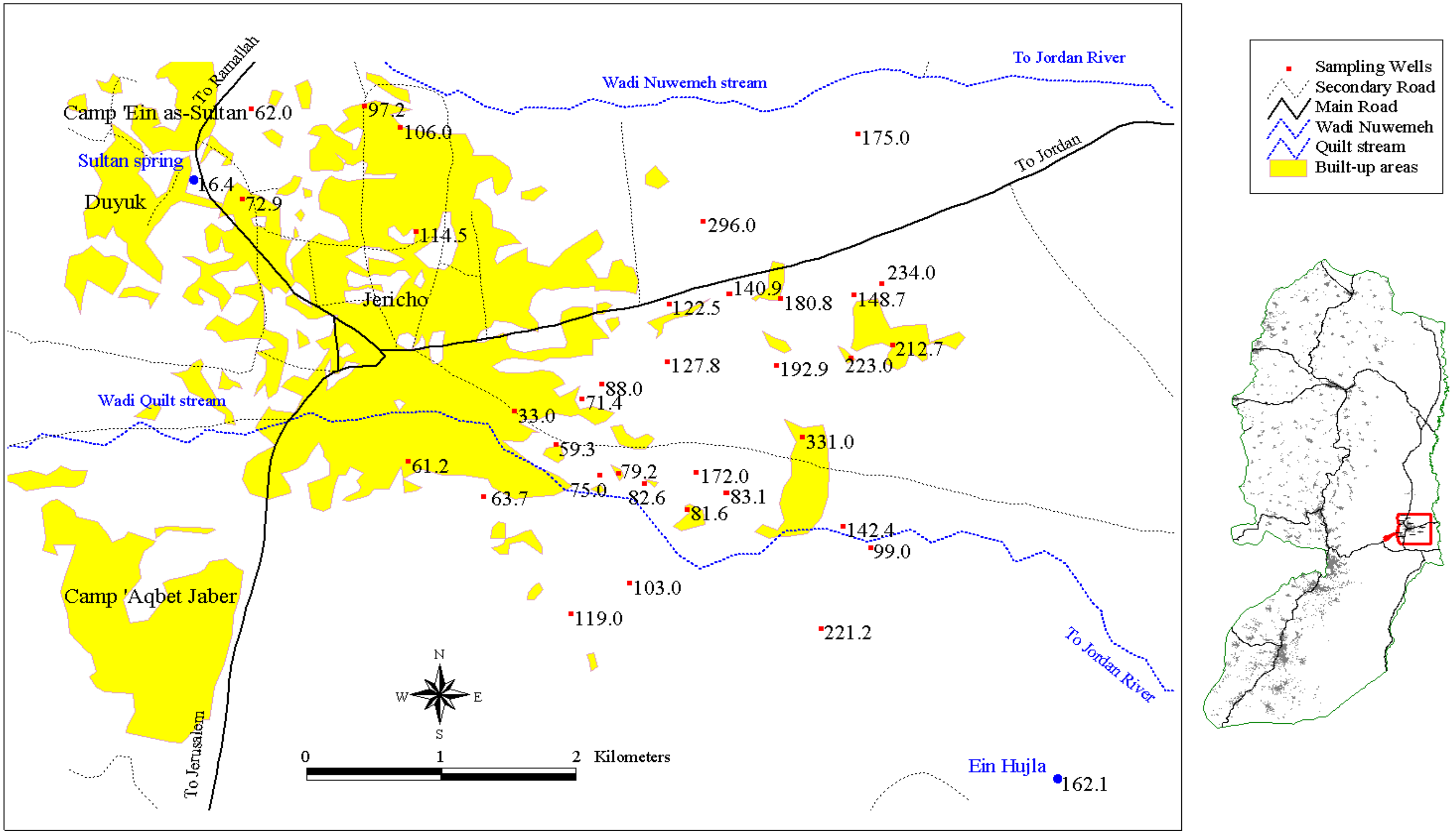

Fig. 4.17: Magnesium contents in groundwater of Jericho area

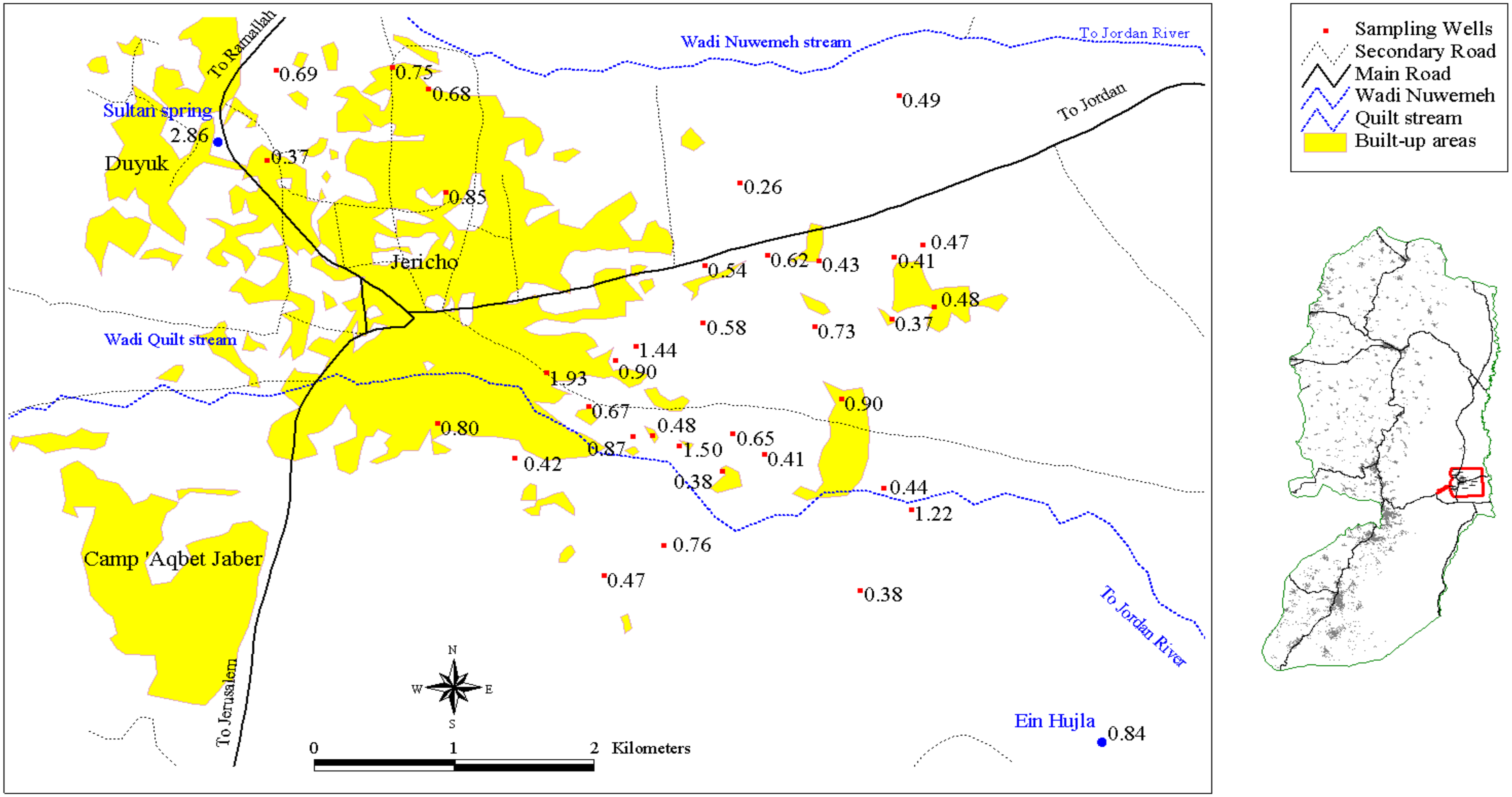

Fig. 4.18: Calcium Magnesium ratios in the groundwater samples of Jericho

The chemical composition of the three springs is identical but differentiates from the chemical composition of the water channel (WQC). The sulfate contents ranges between 5.8 to 10.0 mg/L in springs water (Wolf 1998) and increase up to 14.0 and 28.4 mg/L in the channel water, and the last two values are fitting in the range of the of the flood water.

The initial chemical composition of the spring water flowing into Wadi el-Quilt is Ca-HCO_3 type with low SO_4/Cl ratio (0.07) and changes down stream through the Wadi to Ca-HCO_3-Cl water with increasing SO_4/Cl ratio (0.2). The Na/Cl ratio modifies from the increasing in chloride and sulfate concentration which is related to the dissolution of salt deposits in the Wadi sediments.

The main recharge source of the Plio-Pleistocene aquifer system is taking place through infiltration of flooding freshwater of Wadi el-Quilt. The velocity of the infiltrated water depends on the material of the aquifer system as well as on the material of the covering layer/layers of the unsaturated zone. Fan deposits and sand, silt marl of Samra characterized the western part, while the eastern part is characterized with sand, silt and marl of Samra overlain by the evaporites of Lisan Formation. In both parts the aquifer is phreatic. Consequently, the infiltration velocity in the western part is higher than the eastern part. (Fig. 4.19) present the response of the groundwater body during the wet hydrological year 1991/1992. So the following categories of wells can be recognized:

a- Wells with strong response indicate good hydraulic conductivity with tritium contents values between 2.9 and 3.7 TU, these wells lie in the western part.

b- Wells with week response indicate a low hydraulic conductivity with tritium contents values between 1.1 and 2.0 TU, these wells locate in the eastern part.

The groundwater Table locates at about 319.8 m (b.s.l) in the western part and About 339.3 m (b.s.l) in the eastern part of the aquifer. The block diagrams (Fig. 4.20), present a general view on the geology of the study area. It is to notice that the lithological facieses changed between fan deposits of the Samra Formation in the west and Lisan Formation overlaying Samra Formation in the East. The Relationship between salinity with well distance from the Wadi, between well depth and salinity are not found (Appendix 6.6).

Nasser ed Din 1999, Marie and Vengosh, 2001 and Geyer et. al, 2005 found that the salinity of the groundwater increases eastward. Different hypotheses were suggest as salinity sources, one is up-conning of deep brines due to the over pumping in the eastern part of the area (Nasser ed Din, 1999), second suggestion was related to a mixing process between fresh end member with the chemical composition of spring water emerge from the carbonate aquifer in the west with saline brine (Ca-Cl) water in the east (Geyer et. al, 2005). The last hypotheses is not correct, because springs water (Ein Sultan, Ein Duke and Ein Nuwemeh) issue from the Upper carbonate aquifer system of Upper Cretaceous age and there is no hydraulic connection between this aquifer and the Plio-Pleistocene aquifer system in Jericho, and most of the recharge come through infiltration of Wadi flooding (Golani 1972).

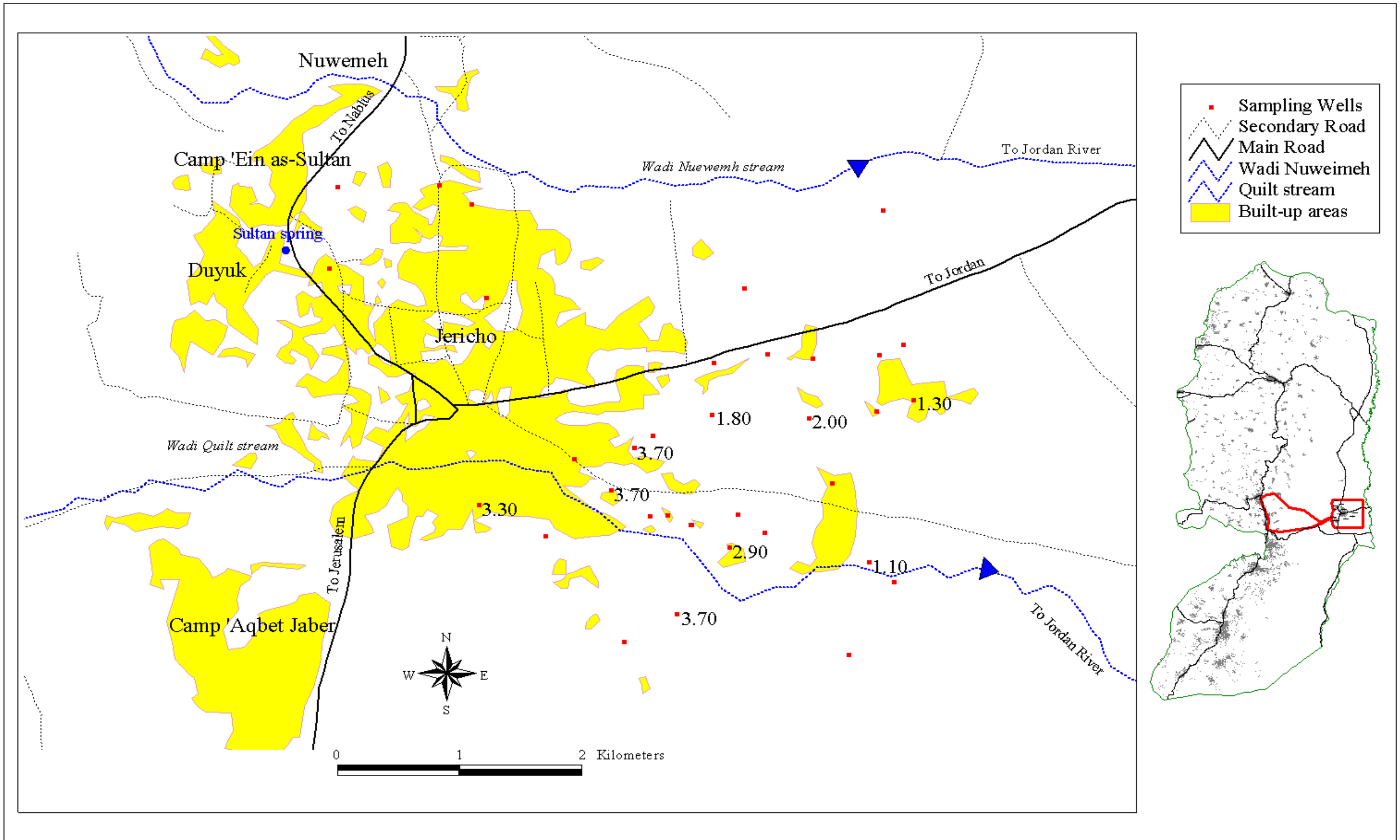

Fig. 4.19: Tritium contents in groundwater of Jericho area.

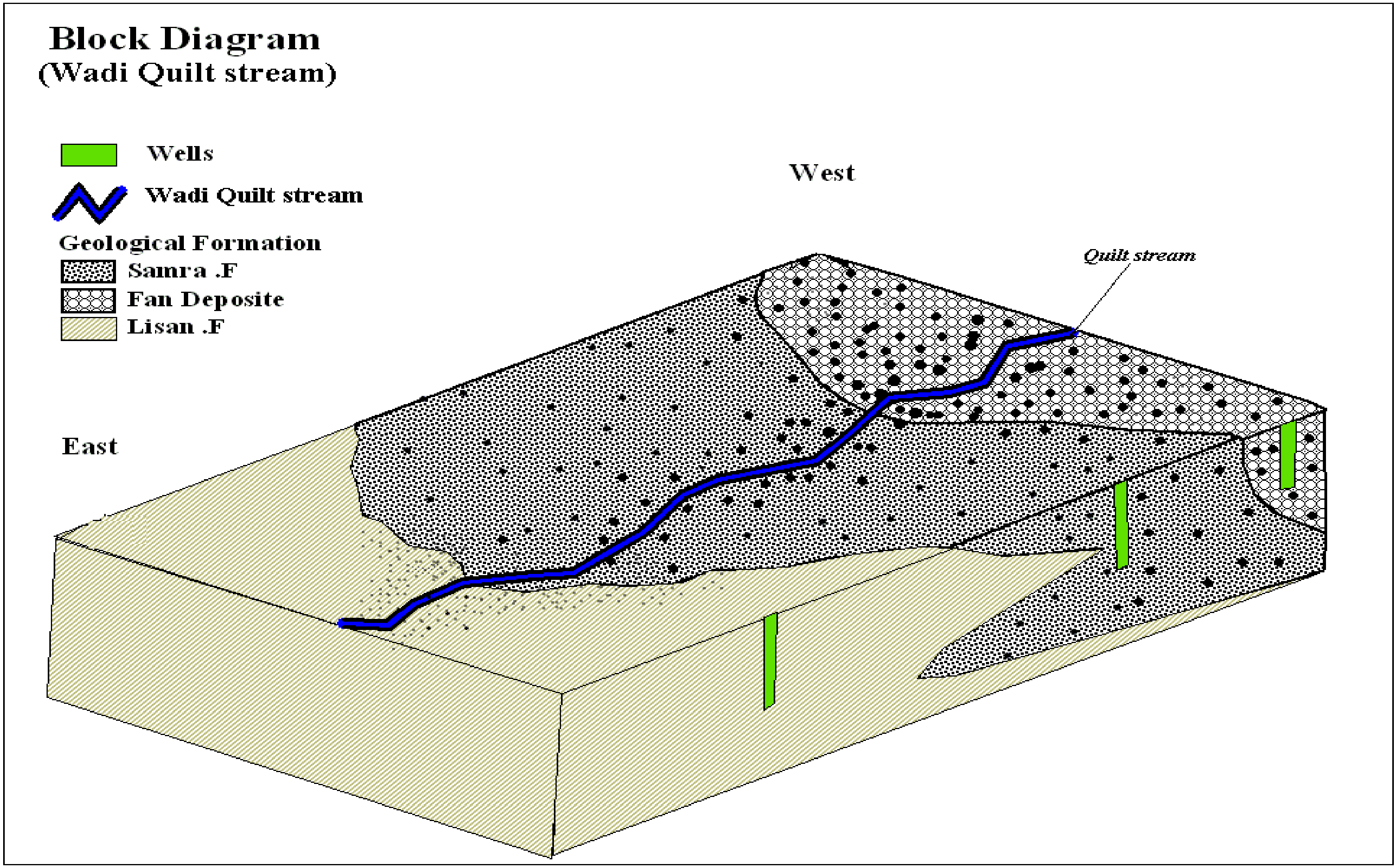

Fig. 4.20: Block diagram of the study area with geological setting.

4.3 Isotopic fingerprinting:

Fig. 4.21 shows the sampling locations for $\delta^{18}O$. The value of $\delta^{18}O$ of the groundwater samples ranges between -5.29 %, and -5.65 %. This narrow range indicate that the groundwater in the Plio-Pleistocene aquifer have the same origin. There is no trend between wells in the West and others in the East. Local affects like salinity increasing or over pumping that could cause up-conning of deep brine is not identified (Appendix 6.7).

Fig 4.22 shows the locations of the groundwater sample comparing with the Local Meteorological Line (Gat, 1972). The $\delta^{18}O$ value indicate enrichment during the infiltration processes that took place relatively quickly in the western part, otherwise the additional enrichment in case the infiltration taken place in the eastern part due to lithological characteristic of the Lisan Formation. It is also to emphasis that $\delta\ ^{18}O$ of Ein Sultan water have the same value of the Plio-Pleistocene aquifer, means that water for both aquifer system have the same origin.

Fig. 4.23 presents the relationship between tritium contents and salinity of the groundwater in the Plio-Pleistocene aquifer in Jericho area. It is clear that the relation is natural logarithmic, so that water with tritium value between 3.5 and 4 TU have less than 500 mg/L chloride, and after about 25 years the tritium content decrease below 1 TU and the salinity rise to more than 1000 mg/L of chloride. This mean that freshwater infiltrated in the western part of the area and replenished in short periods and during the flow pathway eastward become to stagnant due to changing in lithology (from alluvial deposit in the west to evaporites and marl in the east), so the contact time between water and rock forming minerals increase and additional ions added to the groundwater mostly halite and gypsum.

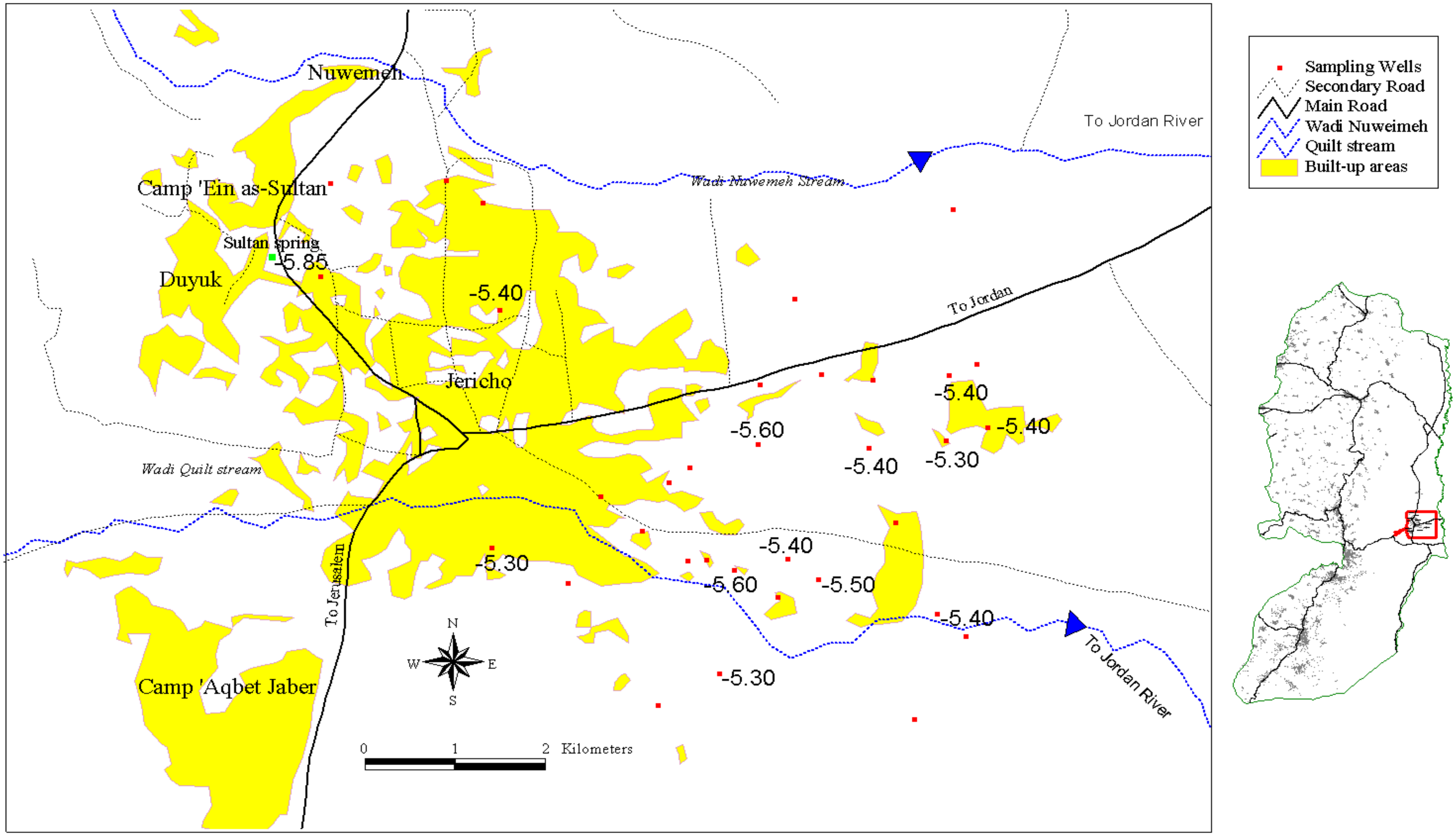

Fig 4.21: $\delta^{18}O$ contents in groundwater of Jericho area.

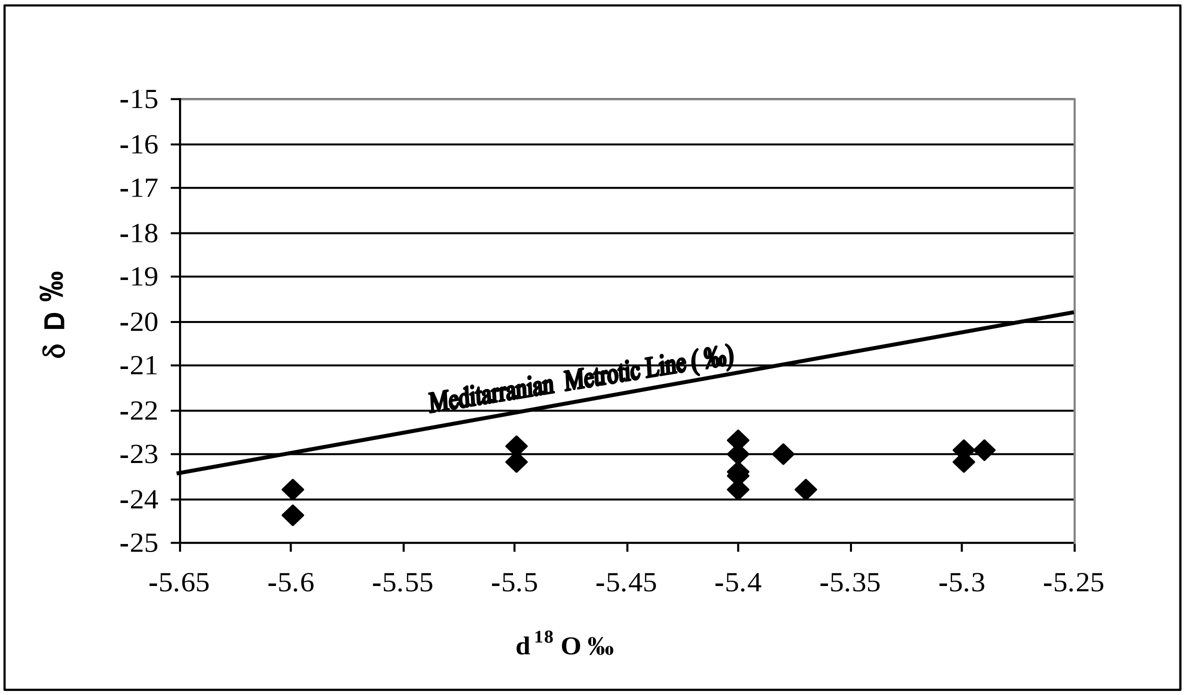

Fig. 4.22: location of the groundwater samples with meteoritic line.

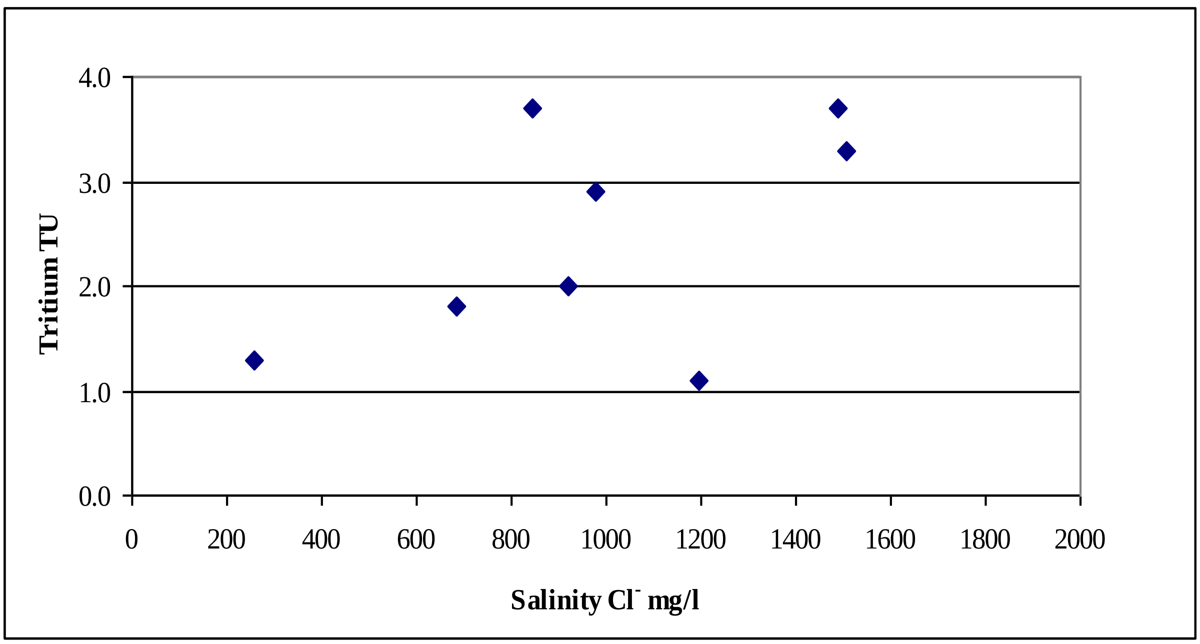

Fig. 4.23: Relation between salinity and tritium contents.

4.4 Mixing Process:

When two different types of water vary in salinity mixed together they produced a new type of water. So we hypothesize two types of water are assumed, one is the freshwater with Cl^- content of 102.8 mg/L (2.9 meq/L) from the well 19-14/019, and the other type is saline water with Cl^- content of 2425 mg/L (68.4 meq/L) from the well 19-14/067 (Arab Developed Project).

So to understand this mixing in the study area two end members is needed. The first end member from the freshwater (less chloride concentration) and the second end member from the saline water, (high chloride concentration). By using the equation of mixing as its bellow:

$$\mathbf{Ax + B\,(1 + x) = C} \qquad \text{(Mazor, E. 1991)}$$

Where:

A = the High chloride concentration from the saline well in meq/L.

B = the low chloride concentration from the fresh well in meq/L.

C = the chloride concentration in the well we need to calculate the mixing in it.

x = the mixing percent from the saline end member.

the result as its clear in the (Table 4.9) and in (Fig. 4.24) showed mixing percentages between freshwater and saline water (different periods mixing), and the mixing contribution percent from the saline water increased toward the east without any changes when two end members were used as in the (Table 4.10) and in (Fig. 4.25) as (one period mixing) or multiple end members as four period mixing, two end members from each season. For the one period, the maximum value is (68.4 meq/L) from the saline groundwater sample. The minimum value is (2.9 meq/L) from the fresh surface water sample.

The four periods mixing depends on the separation of the groundwater samples to four periods, each period have two end members (maximum and minimum chloride values to each period or rainy season) as it explained in Table 4.9 and Fig. 4.24, without a big different or changes from the one period mixing.

Table 4.9: The (Cl^-) whole mixing percentages from fresh and saline water in Jericho groundwater wells. (As different periods).

Period No	Well No	Date of sampling	WELL ID	Cl^- in meq/L	Contributing of Surfacewater %	Contributing of Surfacewater %
First Period	1	12/01/2004	19-13/047	**6.9**	100	0.0
	2	12/01/2004	19-14/023	7.7	98.7	1.3
	3	12/01/2004	19-13/048	12.4	91.1	8.9
	4	12/01/2004	19-13/050	12.8	90.4	9.6
	5	12/01/2004	19-13/020	11.5	92.5	7.5
	6	12/01/2004	19-13/015	13.9	88.6	11.4
	7	12/01/2004	19-14/015	15.6	85.8	14.2
	8	12/01/2004	19-13/006	18.2	81.6	18.4
	9	12/01/2004	19-13/026A	21.4	76.4	23.6
	10	12/01/2004	19-14/052	30.3	62.0	38.0
	11	12/01/2004	19-13/069	29.3	63.6	36.4
	12	12/01/2004	19-13/052	28.9	64.2	35.8
	13	12/01/2004	19-14/019	27.6	66.3	33.7
	14	12/01/2004	19-14/073	38.0	49.4	50.6
	15	12/01/2004	19-14/020	42.0	43.0	57.0
	16	12/01/2004	19-14/066	47.7	33.6	66.4
	17	12/01/2004	19-14/067	**68.4**	0.0	100
Second Period	18	04/12/2004	19-14/037	**24.9**	0.0	100
	19	04/12/2004	19-14/038	14.0	50.5	49.5
	20	04/12/2004	New well	**3.3**	100	0.0
Third Period	21	06/07/2003	19-13/018	**7.3**	100	0.0
	22	06/07/2003	19-14/003	23.8	53.1	46.9
	23	06/07/2003	19-14/066	33.7	25.0	75.0
	25	06/07/2003	19-14/024A	19.4	65.6	34.4
	26	06/07/2003	19-14/073	25.9	47.2	52.8
	27	06/07/2003	19-14/067	**42.5**	0.0	100
Fourth Period	28	1999	19-14/081	**35.4**	0.0	100
	29	1999	19-14/064	30.5	15.1	84.9
	30	1999	19-14/019	18.6	51.7	48.3
	31	1999	19-13/061	27.2	25.2	74.8
	32	1999	19-13/029	12.4	70.8	29.2
	33	1999	19-13/005	8.4	83.1	16.9
	34	1999	19-14/008	11.2	74.5	25.5
	35	1999	19-14/014	**2.9**	100	0.0
	37	1999	19-14/002	11.6	73.2	26.8
	38	1999	19-14/040	10.6	76.3	23.7
	40	1999	19-14/049	16.8	57.2	42.8
	41	1999	19-13/071	13.9	66.2	33.8

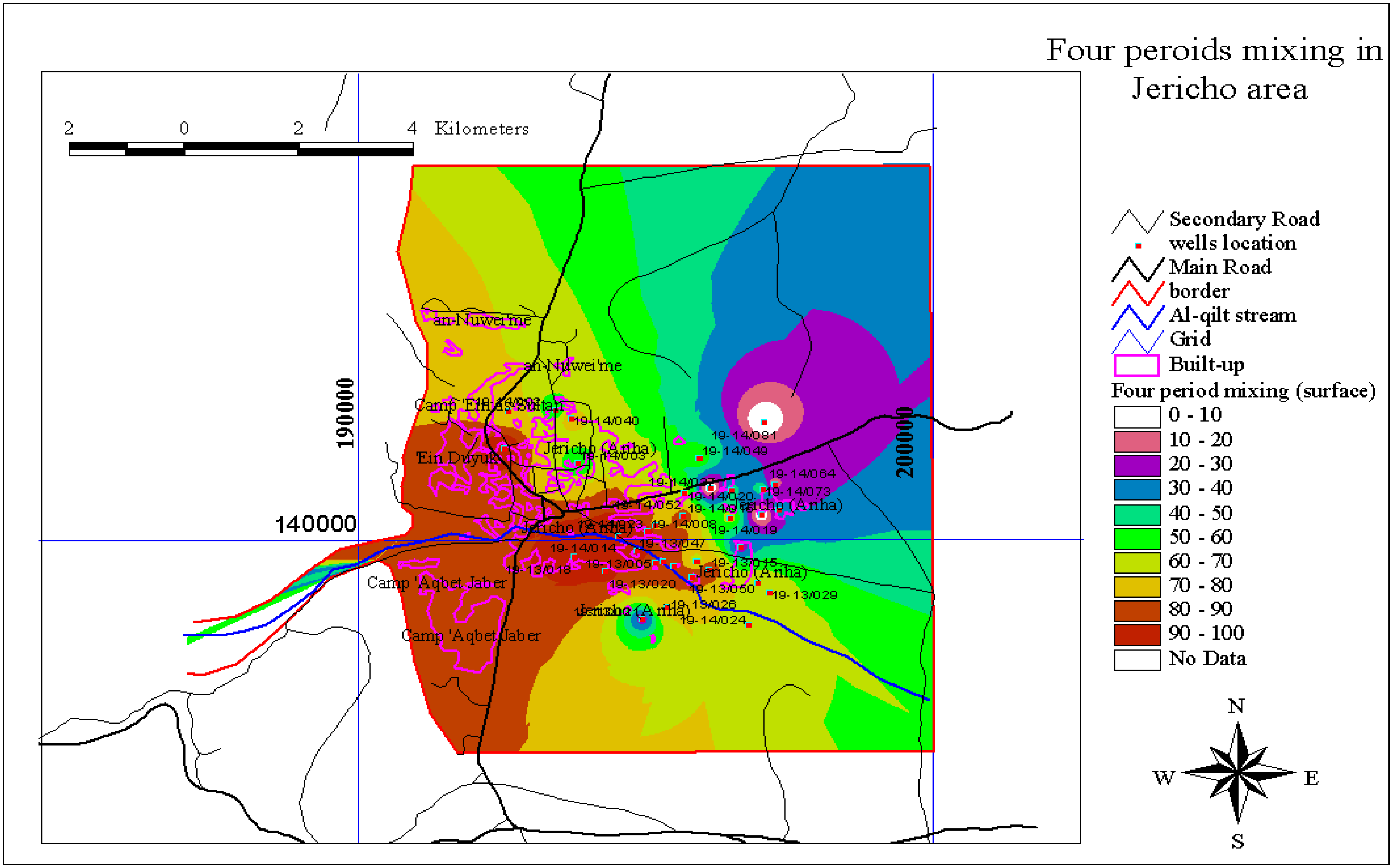

Fig. 4.24: Different periods mixing in Jericho area.

The groundwater mixing interpretation shows that there is a high percentage of surface water infiltration into the groundwater reservoir, and the ratios from surface water input to the groundwater ranging between 70 % up to 100 % in the western part of Jericho area, and decreases eastward faraway from Wadi El-Quilt, and reach 20 % - 10 %, this conclusion conceder by the chemical results of the ground water samples, which show a low content of chloride 260 mg/L in the western part, and increased to 1700 mg/L in the eastern part, in the same direction, the electrical conductivity ranging from 1400 μs/cm up to 6800 μs/cm toward the east.

In the other hand the tritium content rebut this theoretical mixing due to the high content of tritium in the groundwater samples, the tritium content ranging from 1.1 to 3.7 TU which is similar to the tritium content in the surface water, as a strong evidence of tritium enrichment, with respect to the short traveling time from the western to the eastern part of the study area.

Table 4.10: The mixing percentages from surface and saline water in Jericho Groundwater Wells (As one period mixing).

Period No	Well No	Date of sampling	WELL ID	Cl^- in meq/L	Contributing of Surfacewater %	Contributing of Surfacewater %
One Period Mixing	1	12/01/2004	19-13/047	6.9	93.9	6.1
	2	12/01/2004	19-14/023	7.7	92.7	7.3
	3	12/01/2004	19-13/048	12.4	85.8	14.5
	4	12/01/2004	19-13/050	12.8	84.9	15.1
	5	12/01/2004	19-13/020	11.5	86.9	13.1
	6	12/01/2004	19-13/015	13.9	83.2	16.8
	7	12/01/2004	19-14/015	15.6	80.6	19.4
	8	12/01/2004	19-13/006	18.2	76.6	23.4
	9	12/01/2004	19-13/026A	21.4	71.8	28.2
	10	12/01/2004	19-14/052	30.3	58.2	41.8
	11	12/01/2004	19-13/069	29.3	59.7	40.3
	12	12/01/2004	19-13/052	28.9	60.3	39.7
	13	12/01/2004	19-14/019	27.6	62.3	37.7
	14	12/01/2004	19-14/073	38.0	46.4	53.6
	15	12/01/2004	19-14/020	42.0	40.3	59.7
	16	12/01/2004	19-14/066	47.7	31.6	68.4
	17	12/01/2004	19-14/067	**68.4**	0.0	100
	18	04/12/2004	19-14/037	24.9	66.4	33.6
	19	04/12/2004	19-14/038	14.0	83.1	16.9
	20	04/12/2004	New well	3.3	99.4	0.6
	22	06/07/2003	19-13/018	7.3	93.3	6.7
	23	06/07/2003	19-14/003	23.8	68.1	31.9
	24	06/07/2003	19-14/066	33.7	53.0	47.0
	25	06/07/2003	19-14/024A	19.4	74.8	25.2
	26	06/07/2003	19-14/073	25.9	64.9	35.1
	27	06/07/2003	19-14/067	42.5	39.5	60.5
	28	1999	19-14/081	35.4	50.4	49.6
	29	1999	19-14/064	30.5	57.9	42.1
	30	1999	19-14/019	18.6	76.0	24.0
	31	1999	19-13/061	27.2	62.9	37.1
	32	1999	19-13/029	12.4	85.5	14.5
	33	1999	19-13/005	8.4	91.6	8.4
	34	1999	19-14/008	11.2	87.3	12.7
	35	1999	19-14/014	**2.9**	100.0	0.0
	37	1999	19-14/002	11.6	86.7	13.3
	38	1999	19-14/040	10.6	88.2	11.8
	40	1999	19-14/049	16.8	78.8	21.2
	41	1999	19-13/071	13.9	83.2	16.8

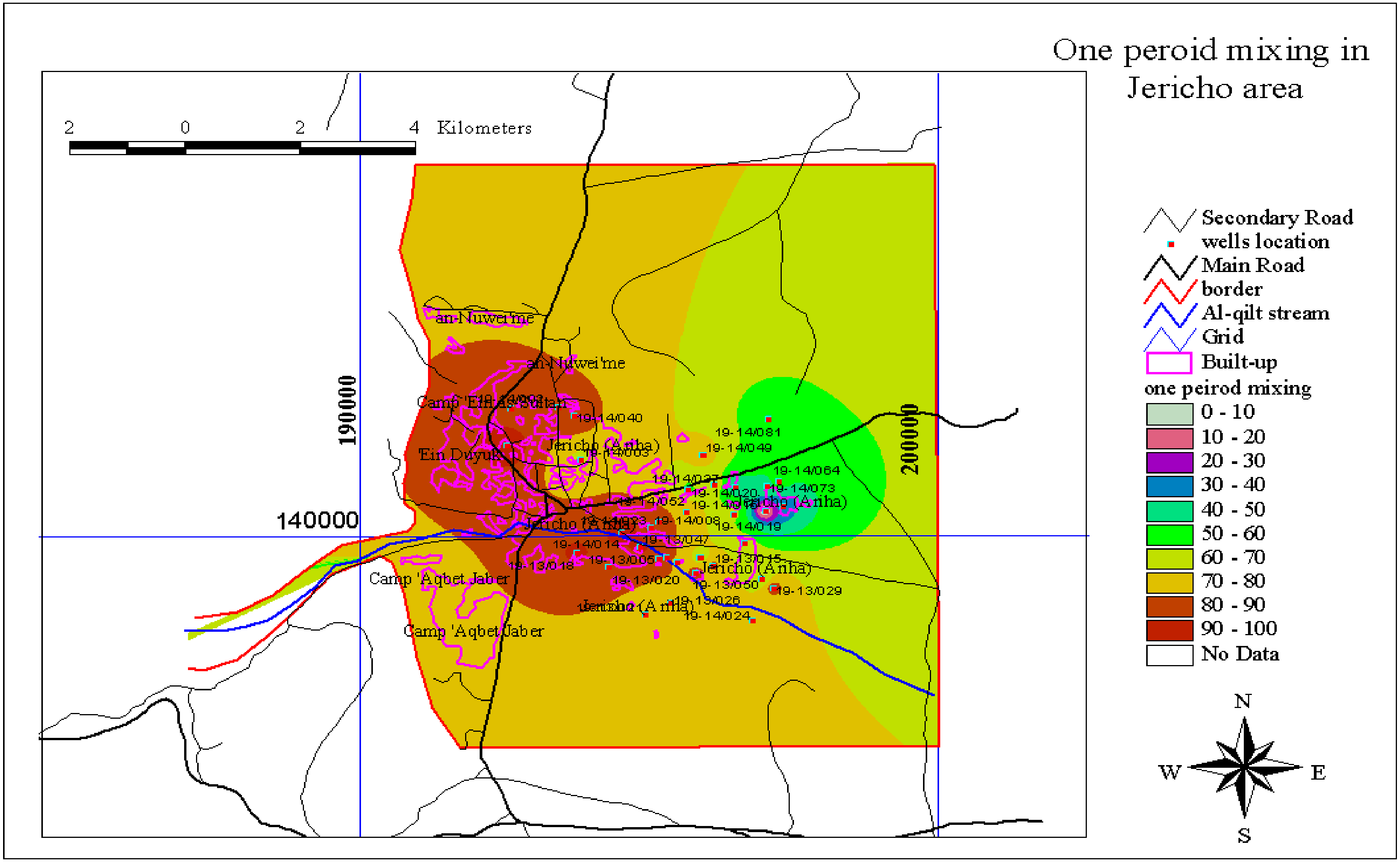

Fig. 4.25: One period mixing in Jericho area.

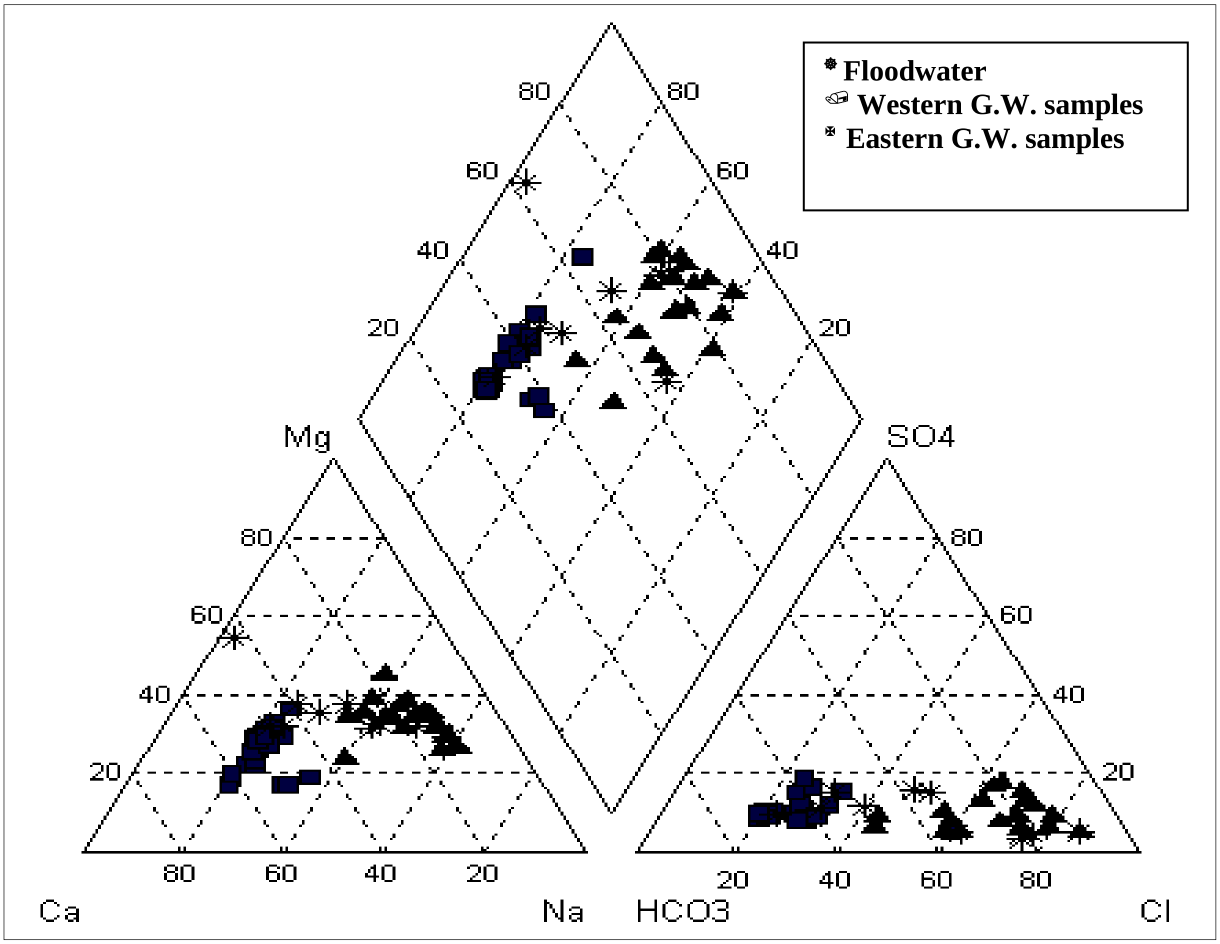

Fig. 4.26: Piper diagram illustrating the results of the analyzed floodwater and groundwater samples of Jericho area

The Fig 4.26 shows that there is no distinguish between the groundwater samples which locate in the western part from the study area from the other samples that locates in the eastern part. And the existence of some groundwater samples at the top of the diamond is characterized by Ca^{2+} + Mg^{2+} and Cl^{-} + $SO4^{2-}$. While the Other groundwater samples that plots near the left corner is rich in Ca^{2+} + Mg^{2+} and HCO_3^- .

Chapter 5

Conclusion and Recommendations

5.1 Conclusion:

The groundwater in Jericho area is very limited, and the quality of the water degraded in the last year due to the decreasing to the recharged water, and the reaching between the infiltrated water and the minerals of the Lisan formation.

The mixing calculations show that there is kind of mixing between the fresh and the brackish water, the contribution percent from the brackish water increased toward the east. However this kind of mixing is theoretical mixing because it depends on calculations, but the isotopic analysis (especially the tritium content rebut such mixing, due to the enrichment of tritium content and the short traveling time.

While the salinity increased toward the east, the Na/Cl ratios decreased duo to the absorption of sodium by the clay minerals. In the other hand, the sulfate content of the groundwater shows an increase of sulfate content due to the dissolution of gypsum from the Lisan Formation. The sulfate content in the groundwater gives a strong indication about the old flow path of Wadi el –Quilt, which could be located in an average 1.5 km and 3.5 km to the north of the present one in the eastern and western part of the study area. In the other hand the calcium magnesium ratios of the groundwater shows an increased of calcium which indicates that the water originate from carbonate aquifer.

As a result of tritium analysis, there is a strong relationship between the hydraulic conductivity and the tritium content, the western part of the study area characterized by high tritium content and good hydraulic conductivity, while the eastern part characterized by low tritium content and weak hydraulic conductivity.

In the other hand the high tritium content is combined by increasing in salinity, as a result of the low hydraulic conductivities which gave along reaching time between the infiltrated water and the saline formations.

The following points are seen important as a main results of this research:

1- The source of the water in Wadi el-Quilt springs and the groundwater of the plio-pleistocene is the same.
2- Wadi el Quilt is the main source of the flooding water in Jericho.

3- There is no clear mixing take place between fresh and brackish water due to the high concentrations of tritium in the groundwater.

4- The salinity in the study area increased towered the east, where the Lisan formation in dominate.

5- The source of salinity is not related to the over pumping, but the long time reaction between freshwater and minerals of the Lisan formation, specially marl and clay.

6- The apparent permeability of the aquifer system is ~1.19 cm/h = (3.3×10^{-5} cm/sec), by using the variations of tritium concentration and the distance between the tow wells that have the lowest and highest tritium content, which support the long time relation.

5.2 Recommendations:

The following recommendations are seen important for future management and preservation of the quality of the groundwater in Jericho area:

1- Looking for using the treated wastewater for irrigation activities is recommended in order to reduce the amount of the needed water.

2- Avoid gave a new license for drilling a new wells, because of the great number of the running well which exceeded 58 well, with an annual discharge 2.5 MCM/y in a small area. And increasing the control in order to reduce the amount of the pumped water, to avoid the over pumping in the future, and the decreasing of the groundwater quality.

3- Transboundary research cooperation to reduce the anthropogenic contamination which caused the degradation of the groundwater quality.

4- An extensive hydrogeological study is needed to identify its actual potential resources, safe yield, the hydrogeological characteristics, groundwater quality, and flow pattern of the aquifer systems.

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6 APPENDICES

Appendix 6.1: Wells taping water from the Shallow aquifer in Jericho area with Abstraction volume.

Well ID	Coordination East North	Aquifer	Well abstractions m^3/a
19-14/067	197,010--140,560	Holocene+ Pleistocene	-----
19-14/073	197,030--141,050	Holocene+ Pleistocene	-----
19-14/066	197,310--140,660	Pleistocene	-----
19-14/024A	196,785--138,449	Pleistocene	86164
19-13/018	193,770--139,750	Holocene	82363
19-14/003	193,830--141,550	Holocene	-----
19-14/020	196,490--141,020	Holocene+ Pleistocene	28800
19-14/019	196,460--140,500	Holocene	152334
19-13/069	196,950--139,250	Holocene+ Pleistocene	209242
19-14/015	195,670--140,530	Holocene	195733
19-13/006	195,500--139,580	Holocene	133464
19-13/047	194,850--139,880	Holocene	108978
19-13/015	196,100--139,510	Holocene+ Pleistocene	43432
19-13/052	195,880--139,670	Holocene+ Pleistocene	94487
19-14/023	195,040--140,240	Holocene	115803
19-13/048	195,310--139,660	Holocene	217235
19-13/050A	195,810--139,380	Holocene	322200
19-14/052	195,680--140,980	Holocene+ Pleistocene	273563
19-13/020	194,320--139,480	Holocene	429509
19-14/067	197.010--140.560	Holocene+ Pleistocene	-----
19-14/026A	192,573--141,834	Pleistocene	-----
19-13/021	194,960--138,560	Holocene	401123
19-14/038	193,450--142,530	Holocene+ Pleistocene	119501
19-14/037	196,120--141,060	Holocene+ Pleistocene	120497

Appendix 6.2: The chemical analysis of the flood water samples in Jericho area during the years 2001-2003

No.	Lab I.D	Date of sampling	Location	EC	pH	Temp.	Ca^{+2}			Mg^{+2}			Na^{+}		
				μS/cm		C°	mg/L	meq/L	mmol/L	mg/L	meq/L	mmol/L	mg/L	meq/L	mmol/L
1	Q1	23/02/2001	Wadi Al- Quilt		8.31		71.70	3.58	1.79	20.50	1.69	0.84	34.10	1.48	1.5
2	Q2	23/02/.2001	Wadi Al- Quilt		8.42		74.70	3.73	1.86	19.70	1.62	0.81	36.38	1.58	1.6
3	Q3	24/02/2001	Wadi Al- Quilt		6.86		67.19	3.35	1.68	19.60	1.61	0.81	30.16	1.31	1.3
4	Q4	24/02/2001	Wadi Al- Quilt		8.01		57.50	2.87	1.43	19.40	1.60	0.80	31.70	1.38	1.4
5	Q5	18/02/2001	Wadi Al- Quilt		7.91		45.50	2.27	1.14	25.00	2.06	1.03	30.00	1.30	1.3
6	Q6	20/02/2001	Wadi Al- Quilt		7.90		41.30	2.06	1.03	24.94	2.05	1.03	29.80	1.30	1.3
7	Q7	26/02/2001	W.Q.CHANNEL		8.34		74.60	3.72	1.86	19.23	1.58	0.79	27.92	1.21	1.2
8	Q8	25/02/2001	Wadi Al- Quilt		7.60		48.50	2.42	1.21	21.50	1.77	0.88	30.87	1.34	1.3
9	Q9	25/02/2001	Wadi Al- Quilt		7.62		31.00	1.55	0.77	18.80	1.55	0.77	29.50	1.28	1.3
10	Q10	10/03/2001	W.Q.CHANNEL		8.01		59.22	2.96	1.48	18.66	1.54	0.77	20.51	0.89	0.9
11	Q11	15/03/2001	W.Q.CHANNEL		7.67		43.26	2.16	1.08	22.69	1.87	0.93	28.82	1.25	1.3
12	Q12	27/04/2001	W.Q.CHANNEL	480			3.03	0.15	0.08	45.91	3.78	1.89	18.01	0.78	0.8
13	Q13	02/05/2001	Wadi Al- Quilt	450			44.68	2.23	1.11	7.54	0.62	0.31	16.96	0.74	0.7
14	Q14	03/05/2001	Wadi Al- Quilt	550			59.80	2.98	1.49	12.03	0.99	0.50	22.35	0.97	1.0
15	Q15	02/01/2002	W.Q.CHANNEL	403	8.5		60.00	2.99	1.50	36.45	3.00	1.50	33.95	1.48	1.5
16	Q45	24/03/2003	Wadi Al- Quilt	464	7.69	23.3	42.80	2.14	1.07	15.20	1.25	0.63	19.30	0.84	0.8
17	Q46	29/03/2003	Wadi Al- Quilt	448	7.69	21.5	41.50	2.07	1.04	14.60	1.20	0.60	18.80	0.82	0.8
18	Q47	04/05/2003	Wadi Al- Quilt	448	7.75	21.7	37.10	1.85	0.93	16.20	1.33	0.67	20.00	0.87	0.9
19	Q48	04/02/2003	Wadi Al- Quilt	460	7.75	27.3	39.70	1.98	0.99	15.80	1.30	0.65	20.40	0.89	0.9
20	Q49	04/07/2003	Wadi Al- Quilt	447	7.77	24.6	37.00	1.85	0.92	16.30	1.34	0.67	20.60	0.90	0.9
21	Q50	31/03/2003	Wadi Al- Quilt	462	7.75	24.2	41.00	2.05	1.02	15.50	1.28	0.64	20.20	0.88	0.9
22	Q51	22/03/2003	Wadi Al- Quilt	471	7.81	24.1	44.30	2.21	1.11	15.10	1.24	0.62	20.00	0.87	0.9
23	Q52	04/02/2003	Wadi Al- Quilt	462	7.72	24.5	39.90	1.99	1.00	15.70	1.29	0.65	19.90	0.87	0.9
24	Q53	17/03/2003	Wadi Al- Quilt	463	7.75	25.1	38.40	1.92	0.96	16.00	1.32	0.66	20.40	0.89	0.9
25	Q54	20/03/2003	Wadi Al- Quilt	489	7.77	25.3	45.70	2.28	1.14	15.50	1.28	0.64	21.40	0.93	0.9
26	Q55	31/03/2003	Wadi Al- Quilt	455	7.76	25.3	40.00	2.00	1.00	14.60	1.20	0.60	20.20	0.88	0.9
27	Q56	17/03/2003	Wadi Al- Quilt	461	7.77	26.2	38.60	1.93	0.96	16.00	1.32	0.66	20.40	0.89	0.9
28	*1	01/12/2002	Wadi Al- Quilt	406.00	8.19	12.70	34.00	1.70	0.85	13.30	1.09	0.55	21.30	0.93	0.9
29	*2	20/01/2002	Wadi Al- Quilt	448.00	7.13	12.00	54.00	2.69	1.35	12.90	1.06	0.53	23.90	1.04	1.0
30	*3	12/11/2001	Wadi Al- Quilt	362.00	7.38	12.30	38.50	1.92	0.96	7.75	0.64	0.32	26.70	1.16	1.2
31	*4	13/01/2002	Wadi Al- Quilt	409.00	7.04	12.20	45.00	2.25	1.12	13.30	1.09	0.55	21.10	0.92	0.9
32	*5	01/12/2001	Wadi Al- Quilt	446.00	8.17	12.50	51.90	2.59	1.29	12.65	1.04	0.52	25.80	1.12	1.1
33	*6	12/12/2001	Wadi Al- Quilt	417.00	7.40	12.30	39.00	1.95	0.97	9.95	0.82	0.41	35.10	1.53	1.5
34	*7	12/07/2001	Wadi Al- Quilt	358.00	7.37	12.50	34.80	1.74	0.87	7.20	0.59	0.30	25.80	1.12	1.1
35	*8	14/01/2002	Wadi Al- Quilt	400.00	8.10	12.20	41.35	2.06	1.03	12.75	1.05	0.52	20.20	0.88	0.9

Appendix 6.2: (continue)

No.	K^+			HCO_3^-			Cl^-			SO_4^{-2}			NO_3^-		
	mg/L	**meq/L**	**mmol/l**	**mg/L**	**meq/L**	**mmol/l**	**mg/L**	**meq/L**	**mmol/l**	**mg/**	**meq/L**	**mmol/l**	**mg/L**	**meq/**	**mmol/l**
1	4.78	0.12	0.12	231.9	3.80	3.8	63.9	1.80	1.8	25.8	0.54	0.27	30.5	0.49	0.49
2	5.1	0.13	0.13	250.2	4.10	4.1	68.5	1.93	1.9	26.8	0.56	0.28	30.3	0.49	0.49
3	4.0	0.10	0.10	219.7	3.60	3.6	55.6	1.57	1.6	22.7	0.47	0.24	24.8	0.40	0.40
4	4.48	0.11	0.11	195.3	3.20	3.2	59.3	1.67	1.7	23.2	0.48	0.24	25.2	0.41	0.41
5	3.1	0.08	0.08	170.9	2.80	2.8	58.0	1.64	1.6	28.7	0.60	0.30	32.3	0.52	0.52
6	3.0	0.08	0.08	183.1	3.00	3.0	57.9	1.63	1.6	28.1	0.59	0.29	32.6	0.53	0.53
7	3.7	0.09	0.09	250.2	4.10	4.1	50.8	1.43	1.4	21.5	0.45	0.22	21.7	0.35	0.35
8	4.8	0.12	0.12	164.8	2.70	2.7	58.2	1.64	1.6	38.1	0.79	0.40	23.6	0.38	0.38
9	4.02	0.10	0.10	122	2.00	2.0	57.7	1.63	1.6	22.7	0.47	0.24	19.2	0.31	0.31
10	2.99	0.08	0.08	138.2	2.26	2.3	36.5	1.03	1.0	18.2	0.38	0.19	13.54	0.22	0.22
11	3.16	0.08	0.08	113.4	1.86	1.9	51.1	1.44	1.4	28.4	0.59	0.30	9.61	0.15	0.16
12	2.83	0.07	0.07	187.12	3.07	3.1	37.7	1.06	1.1	14.8	0.31	0.15	13.2	0.21	0.21
13	5.57	0.14	0.14	130.17	2.13	2.1	31.9	0.90	0.9	34.1	0.71	0.36	15.3	0.25	0.25
14	6.24	0.16	0.16	168.8	2.77	2.8	39.2	1.11	1.1	33.2	0.69	0.35	19.06	0.31	0.31
15	10.03	0.26	0.26	207.42	3.40	3.4	36.8	1.04	1.0	14	0.29	0.15	5.3	0.09	0.09
16	1.5	0.04	0.04	207.47	3.40	3.4	35.3	1.00	1.0	23.3	0.49	0.24	25.3	0.41	0.41
17	1.4	0.04	0.04	207.47	3.40	3.4	34.3	0.97	1.0	23	0.48	0.24	24.3	0.39	0.39
18	1.5	0.04	0.04	207.47	3.40	3.4	38.1	1.07	1.1	22	0.46	0.23	24.3	0.39	0.39
19	1.4	0.04	0.04	207.47	3.40	3.4	38.6	1.09	1.1	24.1	0.50	0.25	25.7	0.41	0.41
20	1.3	0.03	0.03	207.47	3.40	3.4	36.0	1.02	1.0	21	0.44	0.22	23.5	0.38	0.38
21	1.4	0.04	0.04	195.26	3.20	3.2	36.8	1.04	1.0	23.6	0.49	0.25	25.7	0.41	0.41
22	1.5	0.04	0.04	195.26	3.20	3.2	35.4	1.00	1.0	22	0.46	0.23	24.2	0.39	0.39
23	1.2	0.03	0.03	231.88	3.80	3.8	37.0	1.04	1.0	23.3	0.49	0.24	25.4	0.41	0.41
24	1.3	0.03	0.03	231.88	3.80	3.8	38.6	1.09	1.1	22	0.46	0.23	26.2	0.42	0.42
25	1.6	0.04	0.04	219.67	3.60	3.6	39.8	1.12	1.1	22.3	0.46	0.23	26.6	0.43	0.43
26	1.4	0.04	0.04	219.67	3.60	3.6	35.6	1.00	1.0	23.8	0.50	0.25	26	0.42	0.42
27	1.3	0.03	0.03	195.26	3.20	3.2	39.1	1.10	1.1	21.8	0.45	0.23	26.7	0.43	0.43
28	2.08	0.05	0.05	146.45	2.40	2.4	40.0	1.13	1.1	34.0	0.71	0.35	23.90	0.39	0.39
29	2.09	0.05	0.05	268.49	4.40	4.4	45.0	1.27	1.3	31.0	0.65	0.32	23.90	0.39	0.39
30	3.38	0.09	0.09	207.47	3.40	3.4	50.0	1.41	1.4	26.0	0.54	0.27	15.40	0.25	0.25
31	2.03	0.05	0.05	134.24	2.20	2.2	50.0	1.41	1.4	32.0	0.67	0.33	26.00	0.42	0.42
32	2.04	0.05	0.05	256.28	4.20	4.2	40.0	1.13	1.1	29.0	0.60	0.30	28.90	0.47	0.47
33	4.20	0.11	0.11	231.88	3.80	3.8	65.0	1.83	1.8	24.0	0.50	0.25	18.20	0.29	0.29
34	3.28	0.08	0.08	207.47	3.40	3.4	55.0	1.55	1.5	28.0	0.58	0.29	18.40	0.30	0.30
35	1.92	0.05	0.05	219.67	3.60	3.6	55.0	1.55	1.5	34.0	0.71	0.35	27.60	0.45	0.45

Appendix 6.3: The Daily rainfall data (mm/day) of Jericho area from Alberah meteoritic station arranged as seasons 1999/2000, 2000/2001, 2001/2002, 2002/2003

daily rainfall data (mm/day)

station: Jericho / Jericho area   SEASON : 2002/2003

				2002	2003								
DATE	**SEP.**	**OCT.**	**NOV.**	**DEC.**	**JAN.**	**FEB.**	**MAR.**	**APR.**	**MAY.**	**JUN.**	**JUL.**	**AUG.**	**DATE**
1													1
2													2
3													3
4					3.6	2.9							4
5			11.5										5
6							0.2						6
7													7
8			0.2			0.1							8
9			0.2	5.8									9
10				6.0									10
11				5.2			0.5						11
12						1.0	5.3						12
13						1.7							13
14		0.2			3.2	1.9							14
15					0.5	3.4							15
16		7.2		0.8									16
17				8.8	0.5	0.6	2.4						17
18				0.2	2.2	4.1	2.0						18
19					6.0	3.9	0.8						19
20				11.6	12.2	0.5	0.3						20
21				1.4	7.0	3.9	0.2						21
22				0.5		0.9	0.9						22
23			0.7			0.3	11.8						23
24				3.8		11.6	15.1						24
25				0.7		32.3	0.5						25
26				1.3		1.0		2.1					26
27						0.3		0.7					27
28			1.5										28
29			7.3										29
30		13.0		4.2									30
31													31
total	0.0	20.4	21.4	50.3	35.2	70.4	40.0	2.8	0.0	0.0	0.0	0.0	total

Appendix 6.3: (continue)

daily rainfall data (mm/day)

station: Jericho / Jericho area SEASON : 2001/2002

					2001	**2002**							
DATE	**SEP.**	**OCT.**	**NOV.**	**DEC.**	**JAN.**	**FEB.**	**MAR.**	**APR.**	**MAY.**	**JUN.**	**JUL.**	**AUG.**	**DATE**
1													**1**
2					**0.6**								**2**
3													**3**
4				**30.0**									**4**
5				**10.4**									**5**
6			**0.2**										**6**
7					**21.7**								**7**
8					**10.4**								**8**
9					**21.4**								**9**
10					**1.3**	**5.2**			**1.0**				**10**
11						**7.0**							**11**
12				**0.2**		**10.3**							**12**
13						**1.5**			**0.5**				**13**
14				**2.5**									**14**
15													**15**
16			**5.0**										**16**
17			**2.8**										**17**
18				**0.4**									**18**
19				**5.0**			**1.5**						**19**
20				**0.4**	**4.0**		**0.1**						**20**
21			**4.9**		**2.8**								**21**
22					**6.6**								**22**
23													**23**
24													**24**
25													**25**
26													**26**
27					**1.4**		**2.6**						**27**
28					**5.7**		**12.4**						**28**
29					**1.4**		**2.5**						**29**
30			**14.6**										**30**
31													**31**
total	**0.0**	**0.0**	**27.5**	**48.9**	**77.3**	**24.0**	**19.1**	**0.0**	**1.5**	**0.0**	**0.0**	**0.0**	**total**

Appendix 6.3: (continue)

daily rainfall data (mm/day)

station: Jericho / Jericho area SEASON : 2000/2001

				2000	2001								
DATE	**SEP.**	**OCT.**	**NOV.**	**DEC.**	**JAN.**	**FEB.**	**MAR.**	**APR.**	**MAY.**	**JUN.**	**JUL.**	**AUG.**	**DATE**
1									5.5				1
2													2
3						3.8							3
4						4.9		0.2					4
5					0.3	0.8							5
6													6
7						5.2		1.3					7
8				7.2			0.1	0.4					8
9				1.2			1.4						9
10													10
11													11
12													12
13				4.3									13
14		14.8				5.8							14
15						0.3							15
16													16
17						9.5							17
18					4.0								18
19				8.2	5.2								19
20				14.6		1.3							20
21						0.5							21
22					0.2								22
23		0.3			1.4		0.1						23
24					14.2								24
25		2.6			5.6								25
26													26
27													27
28													28
29			1.1										29
30								5.5					30
31													31
total	0.0	17.7	1.1	35.5	30.9	32.1	1.6	7.4	5.5	0.0	0.0	0.0	total

Appendix 6.3: (continue)

daily rainfall data (mm/day)

station: Jericho / Jericho area SEASON : 1999/2000

				1999	2000								
DATE	**SEP.**	**OCT.**	**NOV.**	**DEC.**	**JAN.**	**FEB.**	**MAR.**	**APR.**	**MAY.**	**JUN.**	**JUL.**	**AUG.**	**DATE**
1				1.2			16.9						1
2													2
3													3
4					1.3								4
5					7.6	2.2							5
6					1.2		0.1						6
7							0.6						7
8													8
9					2.2								9
10					0.3								10
11													11
12	0.1			0.3		0.4							12
13				7.6		10.0							13
14						0.2							14
15													15
16						2.6							16
17													17
18					0.1								18
19													19
20					2.7								20
21					0.3		2.2						21
22													22
23							7.3						23
24													24
25					0.6								25
26			0.5	0.1									26
27					35.9	0.5							27
28					2.6								28
29						0.7							29
30			1.1										30
31													31
total	0.1	0.0	1.6	9.2	54.8	16.6	27.1	0.0	0.0	0.0	0.0	0.0	total

Table 6.4: Rainfall, runoff of Ramallah and Abu Dies weather stations.

Station	Year	Rainfall mm/a	Runoff mm/a	Runoff MCM
Ramallah	99/00	491.7	49.2	8659200
	00/01	494.7	94.5	16632000
	01/02	755.9	75.6	13305600
	02/03	1054.3	105.4	18550400
Average			**69.4**	**14286800**
Abu Dies	01/02	459.6	46.0	8096000
	02/03	749.6	75.0	13200000
	03/04	519.0	51.9	9134400
Average			**57.6**	**10143467**

Appendix 6.5: The chemical and isotopic analysis of the groundwater samples in Jericho area during the years 2003, and 2004

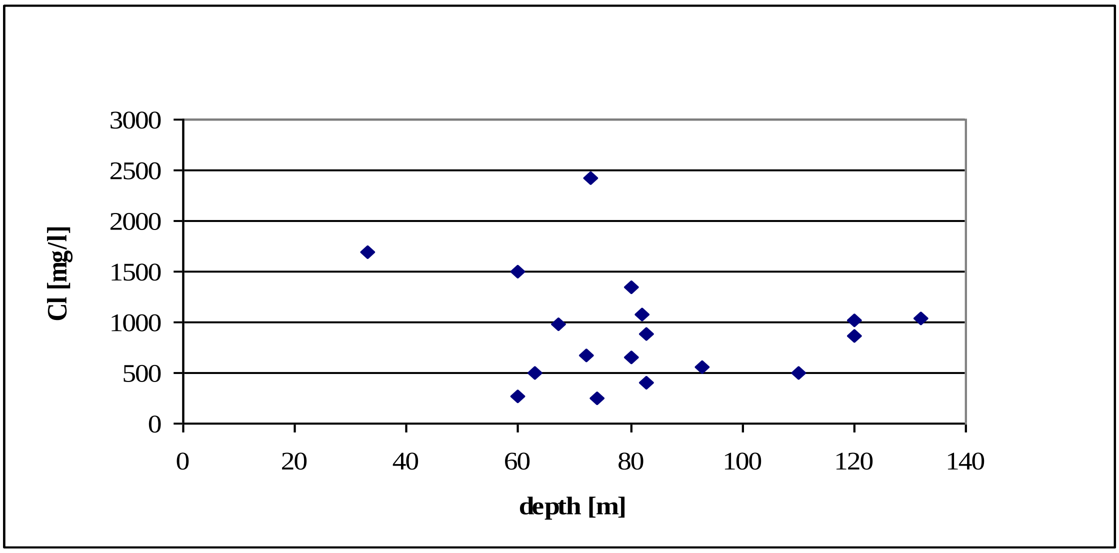
No.	Lab I.D	Well ID	Date of sampling	Location	Coordinates	Elevation	Aquifer	Depth	EC	pH	Temp.
									µS/cm		C°
1	030706G001	19-14/067	06/07/2003	Arab Dev. Project.	197,010--140,560	-308	Holocene+ Pleistocene	73	4930	7.08	26.7
2	030706G002	19-14/073	06/07/2003	Arab Dev. Project.	197,030--141,050	-305	Holocene+ Pleistocene	80	3530	7.03	26.8
3	030706G003	19-14/066	06/07/2003	Arab Dev. Project.	197,310--140,660	-309.88	Pleistocene	33	4790	5.97	26.4
4	030706G005	19-13/024A	06/07/2003	Eghata Zera'eya/CPT	196,785--138,449	-306.85	Pleistocene	65	3150	7.08	26.1
5	030706G006	19-13/018	06/07/2003	Basel Husane	193,770--139,750	-270	Holocene	83	1415	7.30	24.8
6	030706G007	19-14/003	06/07/2003	Abu Fadel Masre/ khaleelia	193,830--141,550	-256	Holocene	120	2970	6.97	29.5
7	040112G179	19-14/020	12/01/2004	Jawdat sha'sha'ah	196,490--141,020	-295	Holocene+ Pleistocene	60	3930	7.19	23.4
8	040112G180	19-14/019	12/01/2004	Jawdat sha'sha'ah	196,460--140,500	-291.85	Holocene	67	3990	6.78	22.0
9	040112G181	19-13/069	12/01/2004	Arab Dev. Project.	196,950--139,250	-315	Holocene+ Pleistocene	132	4060	7.10	25.0
10	040112G183	19-14/015	12/01/2004	Jawdat sha'sha'ah	195,670--140,530	-285	Holocene	93	2350	6.68	22.0
11	040112G185	19-14/066	12/01/2004	Arab Dev. Project.	197.310--140.660	-309.88	Pleistocene	33	5820	6.82	25.0
12	040112G186	19-13/006	12/01/2004	Sbeeru Hanhan &Rantisi	195,500--139,580	-278.99	Holocene	80	2490	6.68	22.4
13	040112G187	19-13/047	12/01/2004	Fahmi Nahas	194,850--139,880	-278.3	Holocene	74	1338	6.91	22.0
14	040112G188	19-13/015	12/01/2004	Fahed Hishmah	196,100--139,510	-292.686	Holocene+ Pleistocene	63	2110	7.05	23.9
15	040112G189	19-13/052	12/01/2004	Zuhdi Hashwah	195,880--139,670	-289	Holocene+ Pleistocene	120	3540	6.87	19.8
16	040112G190	19-14/023	12/01/2004	Musa N.Hattar	195,040--140,240	-295	Holocene	60	1378	6.88	21.6
17	040112G191	19-13/048	12/01/2004	Fahmi Nahas	195,310--139,660	-285	Holocene	57	1448	6.90	22.0
18	040112G192	19-13/050A	12/01/2004	Mahmoud Ikrimawi	195,810--139,380	-290	Holocene	100	1922	7.01	22.9
19	040112G193	19-14/052	12/01/2004	Awni Hijazi	195,680--140,980	-282	Holocene+ Pleistocene	82	2900	6.85	23.0
20	040112G194	19-13/020	12/01/2004	Basel Husane	194,320--139,480	-270	Holocene	83	1574	6.99	22.3
21	040112G195	19-14/067	12/01/2004	Arab Dev. Project.	197.010--140.560	-308	Holocene+ Pleistocene	73	6840	6.80	25.0
22	041204G540	19-14/026A	04/12/2004	Samed	192,573--141,834	-233.47	Pleistocene	90	1134	6.93	22.8
23	041204G541	19-13/021	04/12/2004	Basel Husane+PA	194,960--138,560	-279	Holocene	72	2990	7.34	22.4
24	041204G542	19-14/038	04/12/2004	Mohammad Al Masri	193,450--142,530	-244	Holocene+ Pleistocene	110	2240	6.98	25.5
25	041204G543	19-14/037	04/12/2004	Awni Hijazi	196,120--141,060	-287.3	Holocene+ Pleistocene	83	3610	6.98	24.5
26	041204G544	19-14/003	04/12/2004	Abu Fadel Masre	193,830--141,550	-256	Holocene	120	3210	7.01	26.0

Appendix 6.5: (continue)

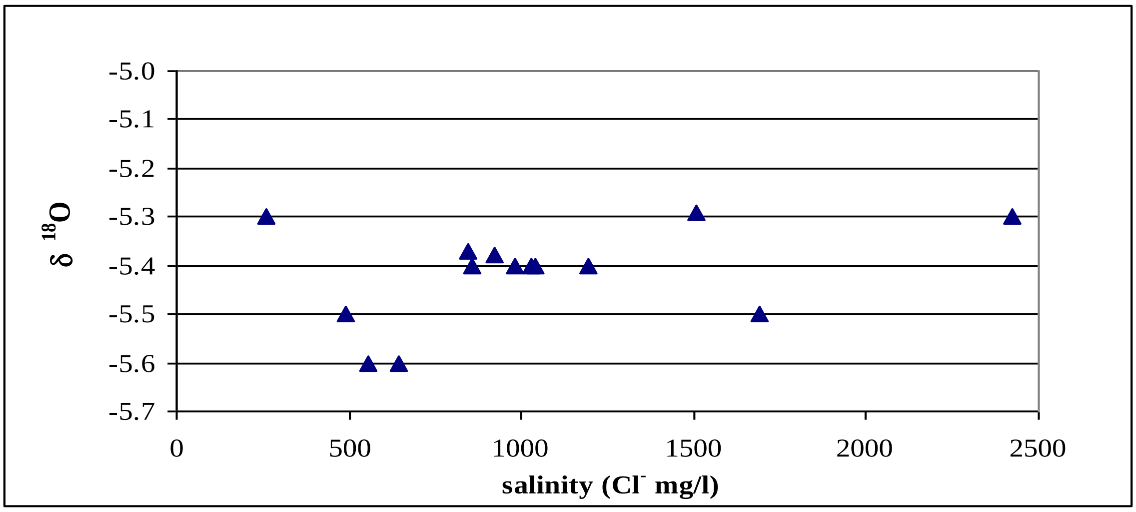
No.	Ca^{+2}			Mg^{+2}			Na^{+}			K^{+}			HCO_3^{-}		
	mg/L	meq/L	mmol/L	mg/L	meq/L	mmol/L	mg/L	meq/L	mmol/L	mg/L	meq/L	mmol/L	mg/L	meq/L	mmol/L
1	136.20	6.80	3.40	223.00	18.34	9.18	614.09	26.71	26.71	94.00	2.40	2.40	414.00	6.79	6.78
2	101.80	5.08	2.54	148.70	12.23	6.12	414.40	18.02	18.02	77.66	1.99	1.99	439.30	7.20	7.20
3	169.90	8.48	4.24	212.70	17.50	8.75	579.10	25.19	25.19	71.53	1.83	1.83	463.80	7.60	7.60
4	139.40	6.96	3.48	221.20	18.20	9.10	349.50	15.20	15.20	41.55	1.06	1.06	390.50	6.40	6.40
5	79.30	3.96	1.98	61.20	5.03	2.52	147.00	6.39	6.39	24.53	0.63	0.63	341.70	5.60	5.60
6	159.50	7.96	3.98	114.60	9.43	4.72	284.00	12.35	12.35	34.06	0.87	0.87	414.90	6.80	6.80
7	127.45	6.36	3.18	180.79	14.87	7.44	406.20	17.67	17.67	91.54	2.34	2.34	488.16	8.00	8.00
8	230.61	11.51	5.75	192.94	15.87	7.94	391.80	17.04	17.04	56.81	1.45	1.45	488.16	8.00	8.00
9	105.81	5.28	2.64	142.40	11.71	5.86	618.30	26.89	26.89	85.22	2.18	2.18	506.47	8.30	8.30
10	123.45	6.16	3.08	127.82	10.51	5.26	237.30	10.32	10.32	18.49	0.47	0.47	579.69	9.50	9.50
11	186.77	9.32	4.66	188.57	15.51	7.76	801.60	34.87	34.87	89.96	2.30	2.30	591.89	9.70	9.70
12	204.41	10.20	5.10	82.62	6.80	3.40	266.00	11.57	11.57	7.90	0.20	0.20	439.34	7.20	7.20
13	62.53	3.12	1.56	59.29	4.88	2.44	172.50	7.50	7.50	11.04	0.28	0.28	457.65	7.50	7.50
14	56.91	2.84	1.42	83.11	6.84	3.42	266.00	11.57	11.57	33.14	0.85	0.85	451.55	7.40	7.40
15	182.77	9.12	4.56	172.04	14.15	7.08	406.20	17.67	17.67	33.14	0.85	0.85	396.63	6.50	6.50
16	102.61	5.12	2.56	71.44	5.88	2.94	140.20	6.10	6.10	14.20	0.36	0.36	518.67	8.50	8.50
17	65.73	3.28	1.64	79.22	6.52	3.26	179.70	7.82	7.82	14.20	0.36	0.36	451.55	7.40	7.40
18	53.71	2.68	1.34	81.65	6.72	3.36	219.30	9.54	9.54	33.14	0.85	0.85	445.45	7.30	7.30
19	109.82	5.48	2.74	122.47	10.08	5.04	366.70	15.95	15.95	33.14	0.85	0.85	518.67	8.50	8.50
20	45.69	2.28	1.14	63.18	5.20	2.60	222.90	9.70	9.70	15.78	0.40	0.40	463.75	7.60	7.60
21	177.15	8.84	4.42	249.32	20.51	10.26	938.20	40.81	40.81	116.79	2.99	2.99	451.55	7.40	7.40
22	42.10	2.10	1.05	72.90	6.00	3.00	71.00	3.09	3.09	6.00	0.15	0.15	512.60	8.40	8.40
23	92.20	4.60	2.30	119.00	9.79	4.90	317.00	13.79	13.79	54.00	1.38	1.38	402.70	6.60	6.60
24	120.20	6.00	3.00	97.20	8.00	4.00	166.00	7.22	7.22	19.00	0.49	0.49	457.70	7.50	7.50
25	144.30	7.20	3.60	140.90	11.59	5.80	349.00	15.18	15.18	43.00	1.10	1.10	418.00	6.85	6.85
26	144.30	7.20	3.60	116.60	9.59	4.80	289.00	12.57	12.57	21.00	0.54	0.54	366.00	6.00	6.00

Appendix 6.5: (continue)

No.	Cl^-			SO_4^{-2}			NO_3^-			$\delta^{18}O$	δ^2H	(TU)	uncertainty (TU)	Na/Cl	SO_4/Cl	Ca/Mg
	mg/L	meq/L	mmol/L	mg/L	meq/L	mmol/L	mg/L	meq/L	mmol/L	[‰]	[‰]			mmol/mmol	mmol/mmol	mmol/mmol
1	1505.00	42.45	42.35	240.00	5.00	2.50	34.50	0.56	0.56	-5.29	-22.9			0.63	0.06	0.37
2	920.00	25.95	25.89	100.00	2.08	1.04	25.55	0.41	0.41	-5.38	-23			0.70	0.04	0.42
3	1195.00	33.71	33.62	300.00	6.25	3.13	20.23	0.33	0.33	-5.4	-23.4			0.75	0.09	0.48
4	686.50	19.36	19.32	250.00	5.21	2.60	32.18	0.52	0.52					0.79	0.13	0.38
5	258.30	7.29	7.27	116.00	2.42	1.21	23.50	0.38	0.38	-5.3	-23.2	3.3	0.4	0.88	0.17	0.79
6	843.00	23.78	23.72	52.00	1.08	0.54	9.10	0.15	0.15	-5.37	-23.8			0.52	0.02	0.84
7	1489.10	42.00	41.90	155.80	3.24	1.62	61.45	0.99	0.99					0.42	0.04	0.43
8	978.90	27.61	27.54	368.10	7.66	3.83	71.10	1.15	1.15	-5.4	-22.7	2	0.4	0.62	0.14	0.72
9	1039.80	29.33	29.26	108.30	2.25	1.13	27.20	0.44	0.44	-5.4	-23.5	1.1	0.4	0.92	0.04	0.45
10	554.60	15.64	15.60	69.90	1.46	0.73	57.40	0.93	0.93	-5.6	-24.4	1.8	0.4	0.66	0.05	0.59
11	1691.60	47.71	47.60	383.80	7.99	4.00	44.90	0.72	0.72	-5.5	-22.8	1.3	0.4	0.73	0.08	0.60
12	645.70	18.21	18.17	186.70	3.89	1.94	75.90	1.22	1.22	-5.6	-23.8			0.64	0.11	1.50
13	245.30	6.92	6.90	68.60	1.43	0.71	33.50	0.54	0.54			3.7	0.4	1.09	0.10	0.64
14	493.00	13.91	13.87	54.30	1.13	0.57	32.70	0.53	0.53	-5.5	-23.2			0.83	0.04	0.42
15	1025.50	28.93	28.85	311.00	6.48	3.24	61.30	0.99	0.99	-5.4	-23			0.61	0.11	0.64
16	271.60	7.66	7.64	51.30	1.07	0.53	87.40	1.41	1.41			3.7	0.4	0.80	0.07	0.87
17	438.20	12.36	12.33	111.20	2.32	1.16	54.90	0.89	0.89					0.63	0.09	0.50
18	452.40	12.76	12.73	85.40	1.78	0.89	40.80	0.66	0.66			2.9	0.4	0.75	0.07	0.40
19	1073.00	30.27	30.19	89.21	1.86	0.93	45.00	0.73	0.73					0.53	0.03	0.54
20	407.50	11.49	11.47	161.30	3.36	1.68	58.90	0.95	0.95					0.85	0.15	0.44
21	2423.70	68.36	68.20	190.40	3.96	1.98	55.20	0.89	0.89	-5.3	22.9			0.60	0.03	0.43
22	117.00	3.30	3.29	19.00	0.40	0.20	16.90	0.27	0.27					0.94	0.06	0.35
23	680.60	19.20	19.15	105.00	2.19	1.09	31.60	0.51	0.51					0.72	0.06	0.47
24	496.30	14.00	13.96	53.00	1.10	0.55	9.40	0.15	0.15					0.52	0.04	0.75
25	882.70	24.90	24.84	155.00	3.23	1.61	21.50	0.35	0.35					0.61	0.07	0.62
26	857.90	24.20	24.14	64.00	1.33	0.67	6.80	0.11	0.11	-5.4	-23.8			0.52	0.03	0.75



Appendix 6.6: Relation between wells depth and salinity.



Appendix 6.7: Relation between $\delta^{18}O$ and salinity Cl^- (mg/l).