HYDROCHEMISTRY OF THE NATUF DRAINAGE BASIN RAMALLAH/ WEST BANK

By

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Supervisor

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1025117

This thesis was prepared under the supervision of Dr. Marwan Ghanem and has been approved by all members of the Examination Committee

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The findings, interpretations and conclusions expressed in this study do not necessarily express the views of Birzeit University, the views of the individual members of the examination committee.

Abstract

This study contains hydrochemical data on the Natuf drainage basin conducted between dry seasons of 2003 to wet season of 2005. The Natuf drainage basin located in the western hill of Ramallah district is about $200km^2$. The area contains many springs that emerge from local perched aquifers and outcrops from a limestone and dolomite limestone formations. This study aims to add more information about hydrochemical parameters and the chemical changes in the spring's water between dry and wet seasons and to locate possible sources of pollution and their effect on the water quality of spring's water for domestic and agricultural uses.

The study involved collection and analysis by conventional and available instrumental methods for the hydrochemical parameters of water from twelve springs before and after recharge. Water samples of runoff from two places in eastern and western parts of the study area were collected and analyzed as well.

Most of the springs in the study area are of good water quality for domestic and agricultural uses. Variations in the chemical composition between dry and wet seasons, and from one spring to another, were observed. Springs located near populated areas and close to agricultural activities show higher values of EC, SSP, SAR and TH. These springs contain uncountable colonies of TC and FC.

Trace amounts, within the Palestinian standard limits, of cadmium, chromium, cobalt and lead are found in some springs; while concentrations of iron and zinc that were detected in springs located near populated areas are higher, but within the Palestinian standard limits, than other springs.

Water types of Ein Musbah, Al Alaq and Ein Arik El Tehta are of earth alkaline with increased portion of alkalis with prevailing bicarbonate and chloride in wet and dry seasons. Other springs show variation in water type between earth alkaline with prevailing bicarbonate in the wet seasons to earth alkaline with prevailing bicarbonate and chloride in the dry seasons.

Water genesis in the springs of the Natuf drainage basin is affected mainly by water-rock between water with the mineral phase of calcite, dolomite and aragonite, which are the main constituents of the lithological formations of the recharge area. Water genesis in springs located near populated areas is affected also by mixing with wastewater.

كيمياء المياه في منطقة الناطوف في محافظة رام الله/ الضفة الغربية

الخلاصة

تحتوي هذه الدراسة على بيانات عن كيمياء المياه جمعت خلال الفترة 2003-2005 في منطقة الناطوف التي تقع في الجبال الغربية لمحافظة رام الله . تبلغ مساحة المنطقة حوالي مائتي كيلو متر مربع ويسكن فيها حوالي مائة ألف نسمة من الفلسطينيين وتحتوي المنطقة على العديد من الينابيع التي تنبثق من أحواض مائية محلية معلقة و تتغذى من منطقة صخرية ذات طابع كلسي وكلسي دولومايتي.

تهدف الدراسة إلى زيادة المعلومات عن كيمياء المياه والتغيرات الكيميائية التي تحصل على مياه الينابيع في منطقة الناطوف، وإلى تحديد مصادر التلوث وتأثيرها على جودة مياه الينابيع واستعمالاتها للأغراض الشرب والزراعة.

شملت الدراسة على جمع عينات مياه وتحليلها كيميائياً، بالطرق التقليدية والتحليل الآلي المتوفر، قبل نزول المطر وبعد نزوله، خلال فترة الدراسة، من اثنتا عشرة عيناً ومن مياه الجريان السطحي في منطقتين تقعان شرقي منطقة الناطوف وغربيها.

تبين من نتائج التحليل الكيميائي لعينات المياه من الينابيع أن معظم هذه الينابيع تتمتع بجودة مياه جيدة صالحة للاستهلاك البشري وفي الزراعة. و وجد أن المياه في ينابيع عين مصباح في رام الله، وعين العلق في أبوشخيدم وعين أيوب في راس كركر، ملوثة بالبكتيريا البرازية وتحتوي على تراكيز عالية من النترات والكلوريد، إضافة إلى تركيز عال في بقية الأيونات السالبة والموجبة مما يؤدي إلى ارتفاع في التوصيلية الكهربائية، و تركيز الصوديوم وعسر الماء الدائم. وقد يرجع سبب ذلك إلى قرب هذه الينابيع من التجمعات السكنية واحتمال تلوثها بمياه الصرف الصحي ومخلفات الأنشطة الزراعية.

لقد وجدت كميات قليلة، لا تشكل خطراً في الوقت الحاضر، وتقع ضمن معايير جودة المياه الفلسطينية، من المعادن الثقيلة مثل الكادميوم والكروم والنحاس والكوبالت والرصاص قي مياه الينابيع في المنطقة، ووجدت كميات أكبر من الحديد والزنك في الينابيع القريبة من التجمعات السكنية، ولكن ضمن معايير جودة المياه الفلسطينية.

تدل نتائج التحليل الكيميائي أن سمة المياه في ينابيع العلق وعين عريك التحتا وعين مصباح ذات سمة قلوية/ ترابية مع زيادة في القلويات وسيطرة ايونات البايكربونات والكلوريد في جميع الفصول، بينما تتغير سمة المياه في باقي الينابيع من سمة قلوية ترابية وسيطرة للبايكربونات في الفصول الماطرة، إلى سمة قلوية ترابية مع سيطرة للبايكربونات والكلوريد في الفصول الجافة.

وتدل نتائج التحليل أن سحنة المياه في ينابيع منطقة الناطوف تتأثر بشكل أساسي بالتلامس بين الماء ومعادن الكلسيت والدولومايت والأراغونايت والتي تشكل العناصر الأساسية من مناطق التغذية المائية للينابيع في المنطق. أما سحنة المياه في الينابيع القريبة من التجمعات السكنية والأنشطة الزراعية ، فإنها تتأثر بالتسريبات من مياه الصرف الصحي ومياه الجريان السطحي.

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Abbreviations

a.s.l.:	Above Sea Level
aq:	Aqueous
anhyd:	Anhydrite
arag:	Aragonite
ARIJ:	Applied Research Institute in Jerusalem
BZU:	Birzeit University
cm:	Centimeter
calc:	Calcite
D	Dry Season
dol:	Dolomite
EC:	Electrical Conductance
Eq.	Equation
EUC:	European Community
FC:	Faecal Coliform
g:	Gram
GIS:	Geographical Information System
Gyp:	Gypsum
H	Hour
Km^2	Squared Kilometer
M:	Molar concentration
MAC:	Maximum Allowable Concentration
mcm:	Million Cubic Meter
mg/L:	Milligram/Liter
MOPIC:	Ministry of Planning and International Cooperation

PCBS:	Palestinian Central Bureau of Statistics
PGE:	Palestinian Grid East
PGN:	Palestinian Grid North
PHG	Palestinian Hydrology Group
PWA:	Palestinian Water Authority
R:	Correlation Coefficient
$R^{\wedge 2}$:	Square Correlation Coefficient
S:	Siemens
SAR:	Sodium Adsorption Ratio
SMVOC	Semi-Volatile Organic Compounds
SSP:	Soluble Sodium Percentage
SUSMAQ:	Sustainable Management of the West Bank and Gaza Aquifers
T:	Temperature
TC:	Total Coliform
TDI:	Total Dissolved Ions
TDS:	Total Dissolved Solids
TH:	Total Hardness
µ:	Micro
VOC	Volatile Organic Compounds
W	Wet Season
WAB:	Western Aquifer Basin
WB:	West Bank
WHO:	World Health Organization
Y:	Year
^{o}C:	Degrees Celsius

Chapter one
Introduction

1.1 Background

Water is the most precious natural resource in Palestine. The continuous supply of high quality water is essential for economic growth, quality of life, environmental sustainability and survival. The quantity and quality of potable water varies over time and space, and is influenced by natural and man-made factors including climate, hydrogeology management practices and pollution. In the West Bank, the demand for potable water for domestic uses has increased in the last few decades because of the rapid increase of population in the West Bank, which is due to natural growth and to the increase of the Israeli settlements in the area.

Groundwater is the major source of fresh water in the West Bank (WB). The only source of groundwater in the West Bank is recharged from the mountainous area, and divided into three aquifers; the Northeastern, Western and Eastern (Fig.1.1).

The Natuf drainage basin, which is part of the Auja-Tamaseeh sub-basin in the Western subsurface drainage basin, like other areas in the West Bank, suffers from the scarcity of water. People in the study area are forced to use unprotected water from springs and rainfall harvesting (cisterns), or they have to pay double and sometimes triple the price for tank water supply for their daily use. The scarcity of water in the study area has limited land use for agricultural purposes

Heavy exploitation of groundwater by Israelis, the growing demand of Palestinians, the shortage of sewer systems, the wide distribution of cesspits, and septic tanks, the common practice of wastewater disposal into gardens and road ditches, and the uncontrolled disposal of untreated municipal sewage into wadis may cause rapid contamination of aquifer systems through karstic conduits in the area. In 2003, during the period of the work of olive mills, the water supplied to inhabitants by trucks was red in color; it was found out that this water was contaminated by olive mills wastewater from the nearby mills in Jammalah and Deir Ammar villages, which indicates the presence of karstification process the area. The lack of information about water quality in the area and the deterioration factors form one of the bases for any water resources management and planning strategy. Therefore, a need to investigate the chemical and biological pollutants in water is essential to determine the sources of pollution, which will assist the Authorities plan and implement the water resources management as well as the master plans for the area.

1.2 Location and Geography of the Natuf Drainage Basin

The Natuf drainage basin is located in the western part of the West Bank between 34^{o} 98’ W and 35 ^{o} 26’ E (East coordinates PGE 150.5-169 and the North coordinates PGN 147-158) (Fig.1.2); it is about 204 km^2, and it drains from the mountains of western Ramallah into the coastal plain of Palestine.

The Natuf drainage basin borders are: Sarida drainage basin from the North, Quilt and Sarida drainage basins from the East, Salman and Soreq drainage basins from the South and coastal plain from the West (Abed and Wishahi, 1999). The part of the Natuf drainage basin, which extends to the Mediterranean Sea near Jaffa / Tel-Aviv, is not of concern to this study because of the political situation. The Palestinian inhabitants in the study area are about seventy thousand; they are distributed over twenty eight villages and some parts of Ramallah city. Twelve Israeli settlements have been built in the area since 1967; these are Dolev, Qiryat Sefer, Mattityaho, Talmon, Talmon B, Talmon C, Halamish, Nili, Na'ate, Nahliel, Ateret, and Nevi Tsouf (Peace now, 2005).

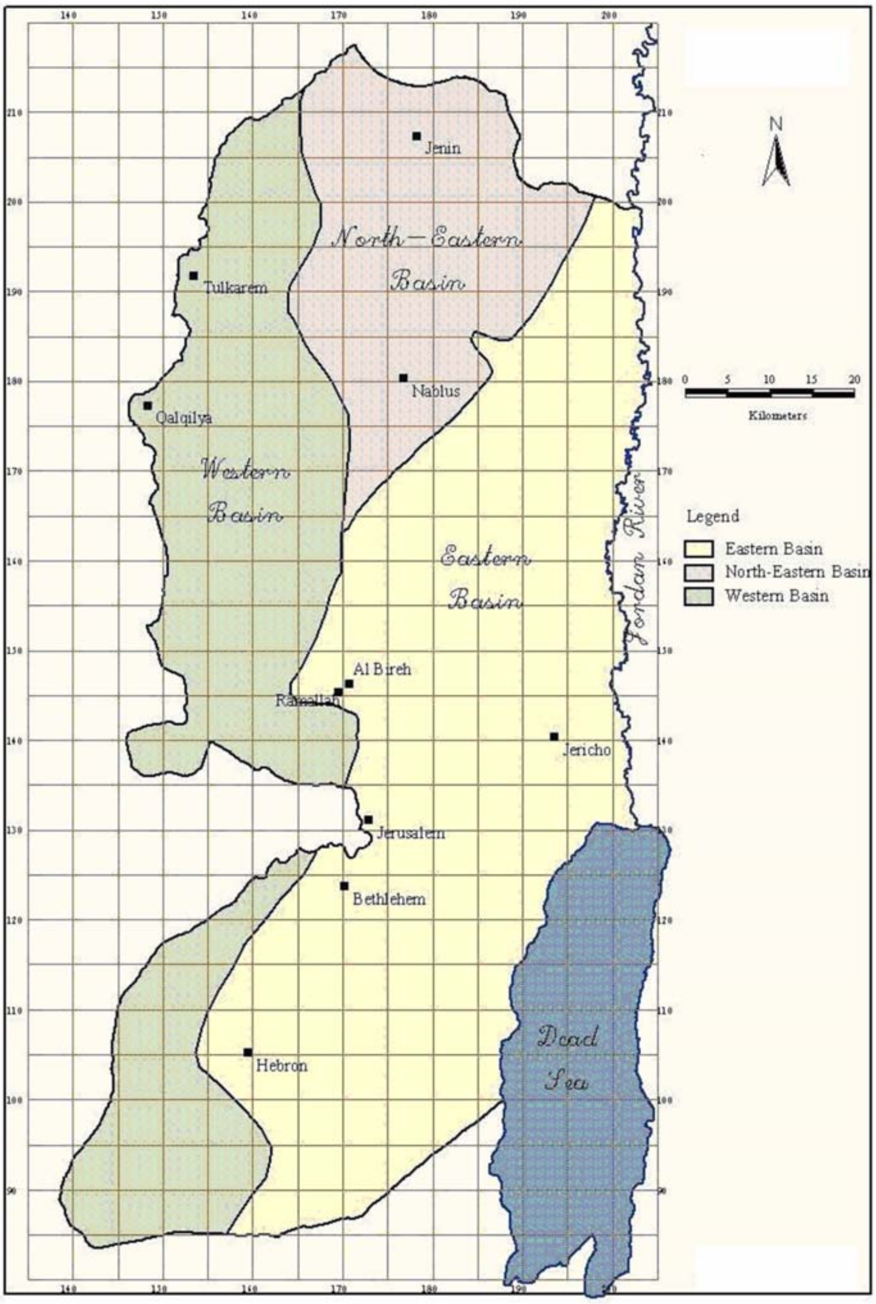

Figure 1.1: Groundwater basins in the West Bank (Modified after PHG, 2004)

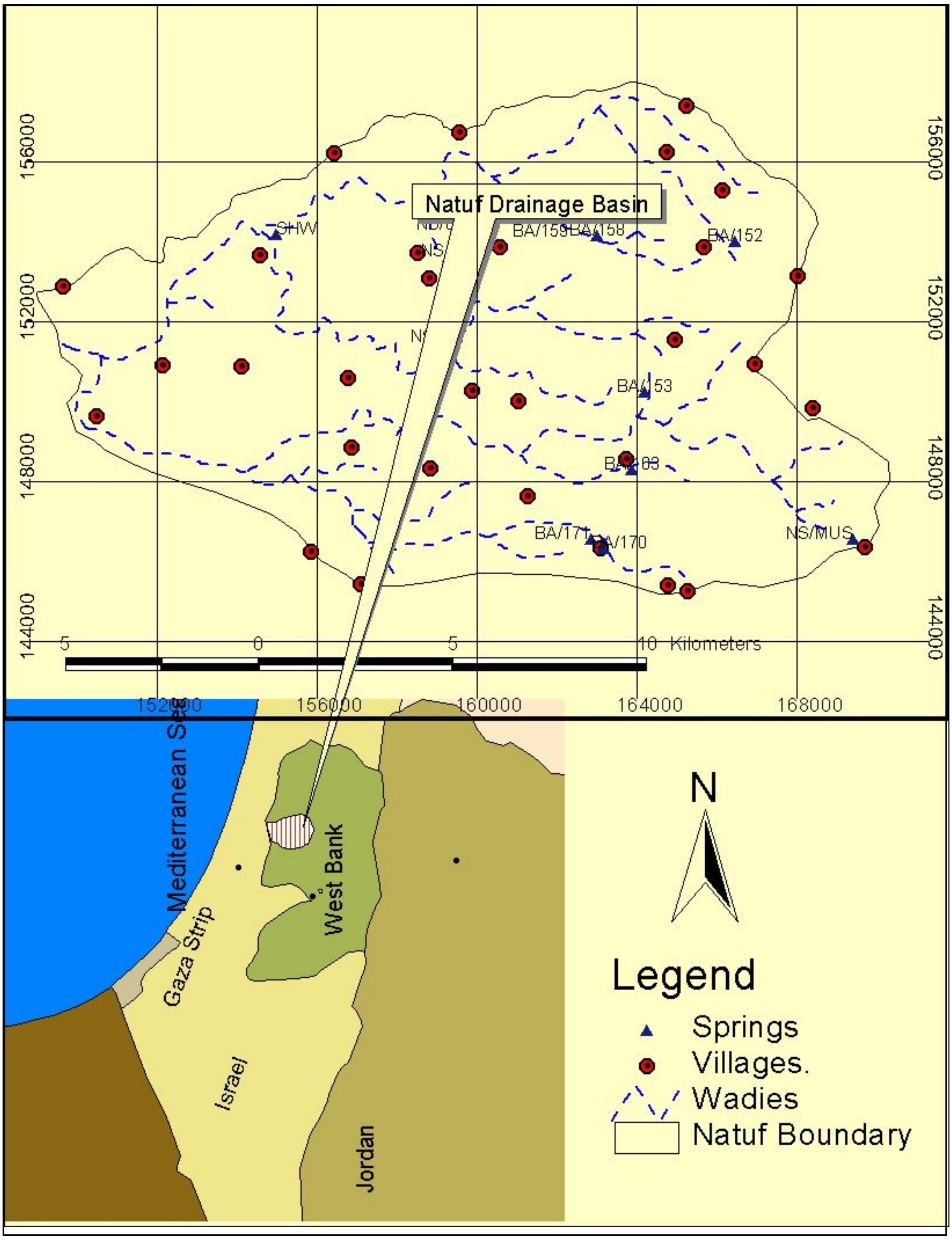

Figure 1.2: Location map of the Natuf drainage basin including wadis and springs

1.3 Importance of Natuf Drainage Basin

The Natuf drainage basin, as an outcrop for recharging the Western Aquifer Basin (WAB), is located within the sensitive areas for pollution of water resources (Fig.

1.3). It has a cultural value as one of the oldest world cultures, where man kind had the first domestic agricultural community; ten thousand years ago. The area would be listed by UNESCO as one of the world's cultural reserves in Palestine for its historical and cultural heritage (Ministry of Archeology and Tourism, Palestine, 2004).

1.4 Climate

The West Bank is located within the Mediterranean climate, which is considered to be semi – arid to arid climate, with dry and wet seasons. The wet season starts approximately in early November and extends to late April. The average precipitation in the study area ranges between 400 and 900mm. Out of the rainfall quantity, it is believed that 2-13% returns to sea as surface runoff, 20-26% infiltrates to groundwater aquifers and the rest is lost by evapotranspiration (Rofe & Raffety, 1965).

The study area is part of the Hill Regions in the West Bank which has lower temperatures than other places in the West Bank. The temperature of the coldest month (January) is in the range of 6-13 ^{o}C while the hottest month (August) temperature ranges between 22-27 ^{o}C. The highest average temperature was 37.5 ^{o}C in May 1995, and the lowest average temperature was 1.2 ^{o}C in February 1995. The mean annual temperature ranges between 15-20 ^{o}C (Applied Research Institute in Jerusalem, 1996).

1.5 Previous Studies

The study of water resources and water quality in Palestine was of concern to many scientists and researchers since the British Mandate in 1917.

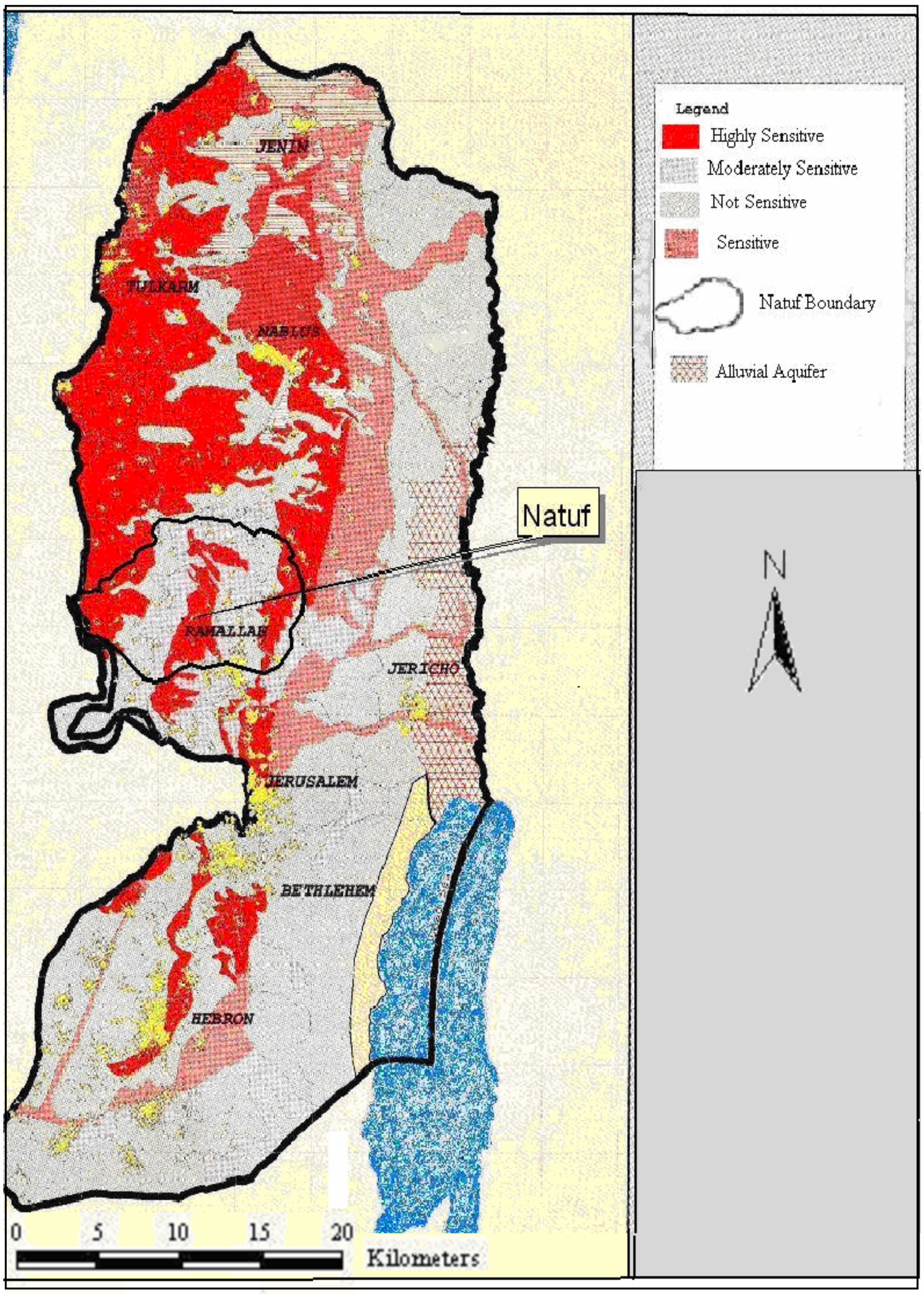

Figure 1.3: Sensitive Areas for Water Resources Pollution in the West Bank (Modified after MOPIC, 1998)

The topography, stratigraphy, hydrology and geology of Palestine including the study area was investigated by G.S. Blake in 1924, the report was modified and published by Goldschmidt in 1947 after Blake's murder. Ein Arik, located in the Natuf drainage basin, was described in the report as a "sweet spring, with a flow of 250,000 gallons/ day" (Blake, 1947).

Chemical analysis of water from rivers, springs and wells in addition to geographical co-ordinates of springs and wells in Palestine was reported by the Department of Land and Settlement and Water Commission in the Government of Palestine in 1940. Water samples from Ein Arik El Fuqa and Ein Qinia were tested for chloride, TDS, total hardness and pH. Ein Arik El Fuqa had 22 mg/L Cl^- , 280 mg/L TDS, 224 mg/L total hardness and pH of 7.3; while Ein Qinia had 26 mg/L Cl^- , 320 mg/L TDS, 244 mg/L total hardness and pH of 7.3 (Government of Palestine, 1948).

Since 1992, the Palestinian Water Authority (PWA) has taken the responsibility for monitoring the water quality supplied to Palestinian people, so as to ensure suitability of water supplies for domestic uses. Many other Non-Governmental Organizations (NGO's) and research centers in the West Bank, such as Palestinian Hydrological Group (PHG) and Sustainable Management of the West Bank and Gaza Aquifers (Susmaq Project- PWA, 2004) also have established programs for monitoring water quality in many areas in the West Bank.

Applied Research Institute in Jerusalem (ARIJ) has published an environmental profile about Ramallah district in 1996. The report describes the geological settings of Ramallah district, hydrology and hydrogeology of water resources in the area. Analysis of chloride and nitrate during 1995 in Harrashah, Ein Arik Al Fuqa and Ein Arik El Tehta springs, which are located in Natuf drainage basin, was reported in the profile. Nitrate concentration was about 1mg/L in each of Harrashah and Ein Arik Al

Fuqa samples, while it was about 21 mg/L in Ein Arik El Tehta. Results from the analysis of water samples from Harrashah, Ein Arik Al Fuqa and Ein Arik El Tehta springs for chloride concentration, were 22, 24 and 37mg/L respectively (Applied Research Institute in Jerusalem, 1996)

Abed Rabbo *et.al* studied water quality of springs in the West Bank including some springs in the Natuf drainage basin. And the analysis of major cations and anions, EC, TDS and pH, were done on water samples from major springs in the West Bank. Ein Qinia, Ein Arik El Fuqa and Ein Ayoub and Zerqa springs, located in the Natuf drainage basin, were mentioned in the study. The study showed that water type of Ein Qinia, using Piper diagram, is of the earth alkaline with prevailing bicarbonate. The study showed that water quality for agricultural purposes in Ein Arik El Fuqa and Ein Qinia is of medium salinity according to Wilcox EC-SAR classification, the study also showed that springs of Ramallah district, including those in the Natuf drainage basin, are all saturated with respect to calcite, dolomite and quartz, and under saturated with respect to gypsum, magnetite and anhydrite. Only Ein Ayoub spring in the Natuf drainage basin showed unde-rsaturation with respect to aragonite. The study concluded that all springs were from one recharge area, only Ein Ayoub had shifted from recharge area, which was a result of mixing with wastewater. (Abed Rabbo, *et al*. 1999).

Flow data were collected by SUSMAQ Project for some springs and Shibteen well in the Natuf drainage basin. These data were used for developing a recharge model for WAB including the study area (Susmaq, 2003).

A water quality report of the springs and groundwater wells in the West Bank, including the Natuf drainage basin, was published by the Ministry of Planning and International Cooperation (MOPIC, 1998). The report includes maps on the geographical location of springs and wells, and a map on sensitive areas for water resources pollution. The values of the Nitrate concentrations in the four springs of Al-Alaq, Ein Arik El Fuqa, Ein Arik El Tehta and Harrashah, which are located in the Natuf drainage basin, were 43, 1, 27 and 1 mg/L respectively; while chloride concentrations were 38, 24, 37 and 22 mg/L for the same springs (MOPIC, 1998).

Nuseibeh and Nasser Eddin listed hydrochemical and discharge data for the period 1970-1994 for about 113 springs in the West Bank, including some springs in the Natuf drainage basin. The data shows concentrations of nitrate and chloride, as a hydrochemical parameter in Al Alaq, Ein Arik El Fuqa, Ein Arik El Tehta Harrashah and Ein Qinia, which are located in the Natuf drainage basin. Nitrate concentrations in the five springs were 43, 1, 21, 1 and 1 mg/L respectively; while chloride concentrations were 38, 24, 37, 22 and 24 mg/L respectively for the same springs (Nuseibeh &Nasser Eddin, 1995).

Graphical data of nitrate and chloride for wells and springs in the West Bank, including five springs in the Natuf drainage basin, are listed in the study of Palestinian Hydrologic data 2000. Al Alaq spring showed fluctuation in chloride and nitrate concentrations from 30 to 80mg/L during the period of 1970 to 2000. The mean values of chloride and nitrate were 48 and 42mg/L respectively. Harrashah, Ein Qinia Al Balad, Ein Arik Al Fuqa and Ein Arik El Tehta showed lower concentrations of chloride and nitrate. The report contains statistical values of other major cations and anions, TDS and the measured discharge in liter/sec over two different years (Palestinian Water Authority, 2000)

Interpretation for some of hydrochemical parameters for the West Bank recorded by PWA was published in a report for the British Geological Survey (2003). The report includes maps for the distribution of sulfate, TDS and nitrate concentrations in groundwater across the West Bank. It shows the location of rainfall collection stations in the West Bank with rainfall chemistry data based on studies done by some Israeli scientists in 1987 and 1992 (British Geological Survey, 2003).

A model of the monthly recharge estimates for the groundwater at Al Auja-Tamaseeh catchment in WAB, which includes the Natuf drainage basin within its boundaries, was the subject of an MSc thesis. The study was based on the hydrological observations by analysis of rainfall quantities and their effect on groundwater level rise inside the aquifer. Twenty one percent of rainfall was calculated by the model as a recharge volume in the Auja-Tamaseeh catchment (Asbah, 2004).

Investigation of the hydrological parameters in the Auja – Tamaseeh catchment area, which includes the Natuf drainage basin, was the subject of an MSc thesis. Analysis and evaluation of the existing rainfall data as well as the discharge of the springs located within the area were used in the estimation of surface runoff and thereafter for hydrological modeling of the area (Yasin, 2004).

1.6 Objectives

The main objectives of this study are:

1- Determining the suitability of the spring's water for domestic and agricultural uses through monitoring the physical, chemical and biological parameters
2- Understanding the water types of the spring's water by interpretation of hydrochemical parameters using Aquachem software.
3- Understanding water genesis of the spring's water and the possible water rock interactions by calculating saturation indices using PhreeqC, indicating recharge areas and interpretation of hydrochemical parameters using Durov diagrams.

1.7 Thesis Structure

Chapter two of this thesis describes the general features of the study area, geology, hydrology and land use. Chapter three describes the methodology followed in the study; it describes the sampling and sampling procedure, methods used in laboratory tests and statistical analysis of the data.

Chapter four deals with the hydrochemistry and interpretation of hydrochemical data collected and calculated for water samples from springs in the study area.

Chapter five deals with conclusions deduced from the study and lists recommendations to overcome pollution risks and water quality problems in the study area.

Chapter two

General Features of Study Area

2.1 Geological Settings of the Study Area

The geological formations of the West Bank start from the Jurassic to the Quaternary periods. Before the Jurassic period, no formations were observed in the West Bank (Abed and Wishahi, 1999). (Fig. 2.1)

The Natuf drainage basin is located within the WAB; it is part of the Auja –Tamaseeh catchment area. The basin is composed of thick sequences of layered limestone, dolomite, chalk and marl. The main outcrop formations belong to formations of the Albian to Turonian age (Susmaq, 2003).

Most of the springs are located in the center of the study area near Beitillu and Dir Ammar, where Yatta formation, which is an Aquiclude, is dominant (Fig.2.2.). The flow discharge of these springs is only affected by the intensity of precipitation, and not affected by the heavy withdrawal ($80m^3/h$) of Shibteen productive well in the upper aquifer, located down stream of Natuf Wadi, which proves that the springs in the study emerge from perched aquifers distributed over Yatta and Abu Dis Aquiclude formations.

The geological formations found in the Natuf drainage basin are classified, from recent to old, as follows (Abed and Wishahi, 1999, Susmaq, 2003):

I. Senonian:

A. The exposed rocks of this formation are referred to Abu Dis group (Mount. Scopus). This formation is part of the Eocene- Senonian ages; it consists of chalk and in some places chert is found, which makes it an Aquiclude. It is found in the lower western part of the Natuf drainage basin

II. Turonian:

A. Jerusalem Formation (Bi'na formation)

This formation is widely spread in the West Bank; it is formed from hard white creamy limestone which makes it useful for building material. It is highly karstified and thus has high hydraulic conductivity.

III. Cennomanian:.

This age is divided into two parts:

A. Upper Cennomanian. The formation of this age that are found in the Natuf drainage basin are:

1. Bethlehem Formation (Kefar Sha'ul and Wiradim), which is divided into the Upper and Lower Bethlehem: the rocks of this formation are exposed in many places in the West Bank, in Jerusalem, Nablus, Ein Qinia, and other places. The rocks of this formation are formed from chalky limestone and chalk, which forms an aquifer.

B. Lower Cennomanian. The exposed rocks of this formation are divided into two parts:

1. Hebron formation (Ằmminadav). This formation is widely spread in Jerusalem Mountains, Hebron and in the northern parts of the West Bank. It is characterized by sequences of hard rocks of limestone and dolomite. This formation can be a good aquifer with a good permeability because of the conduits and karstic systems.

2. Yatta formation: The rocks of this formation are exposed in many places in the West Bank, near the Dead Sea, Nablus, western heights of Ramallah, Al-

Faria and other places. The main characteristic of this formation is that it is formed from marl layers with some layers of limestone in between, which makes it a good Aquiclude.

IV. Albian formation:

The rocks of this age are divided into two parts:

A. Upper Beit Kahil formation (Soreq and Kesalon):

This formation is found in many places in the north and the middle of the West Bank. It consists of layers of limestone with marl layers in between. The presence of marl and chalk in this formation makes it an Aquiclude.

B. Lower Beit Kahil Formation (Kefria and Giv'at Ye'arim):

The rocks of this formation are exposed in Ein Qinia in the Natuf drainage basin and in Surif in the south, in Al-Faria and Beit Forik in the Northern parts of the West Bank. It is formed from dolomitic limestone with little marl and marly limestone and shale. It forms an aquifer.

V. Lower Cretaceous (Albian- Abtian):

The exposed rocks of this age that are found in the Natuf drainage basin are divided into two parts:

A. Qatanna rocks, which are made of marl and clay, and they are described as Aquitard.

B. Ein Qinia rocks, which are made of marl and marly limestone, they are described as an Aquitard.

2.2 Topography of the Natuf Drainage Basin

The Natuf drainage basin, located in the western part of Ramallah district, starts from the mountain crests which form the watershed line that separates the eastern and

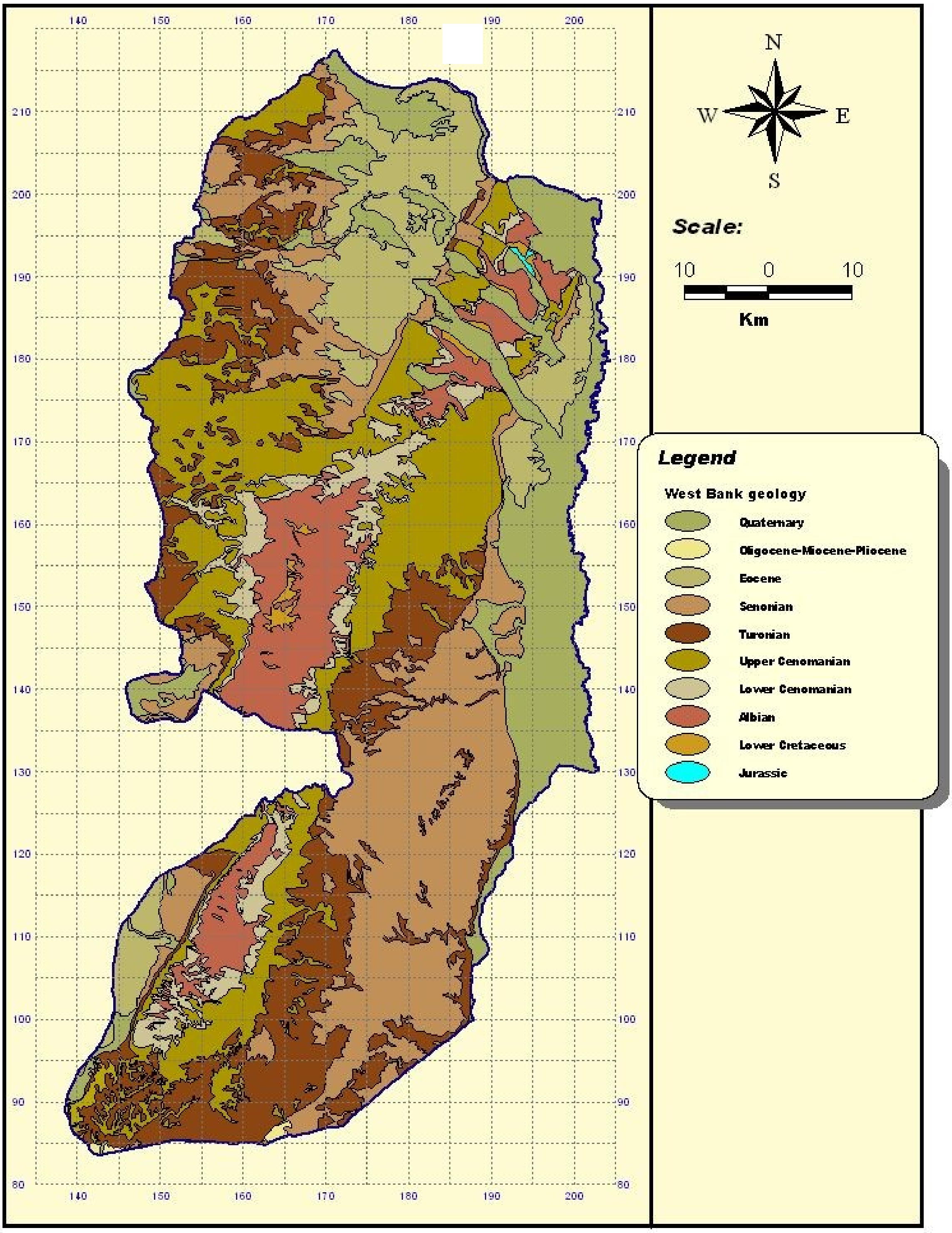

Figure 2.1: Geological map of the West Bank (Modified after the PWA, 2006)

western slopes (Applied Research Institute in Jerusalem, 1996), and extends to the west near 1967 political boarders between Israel and West Bank.

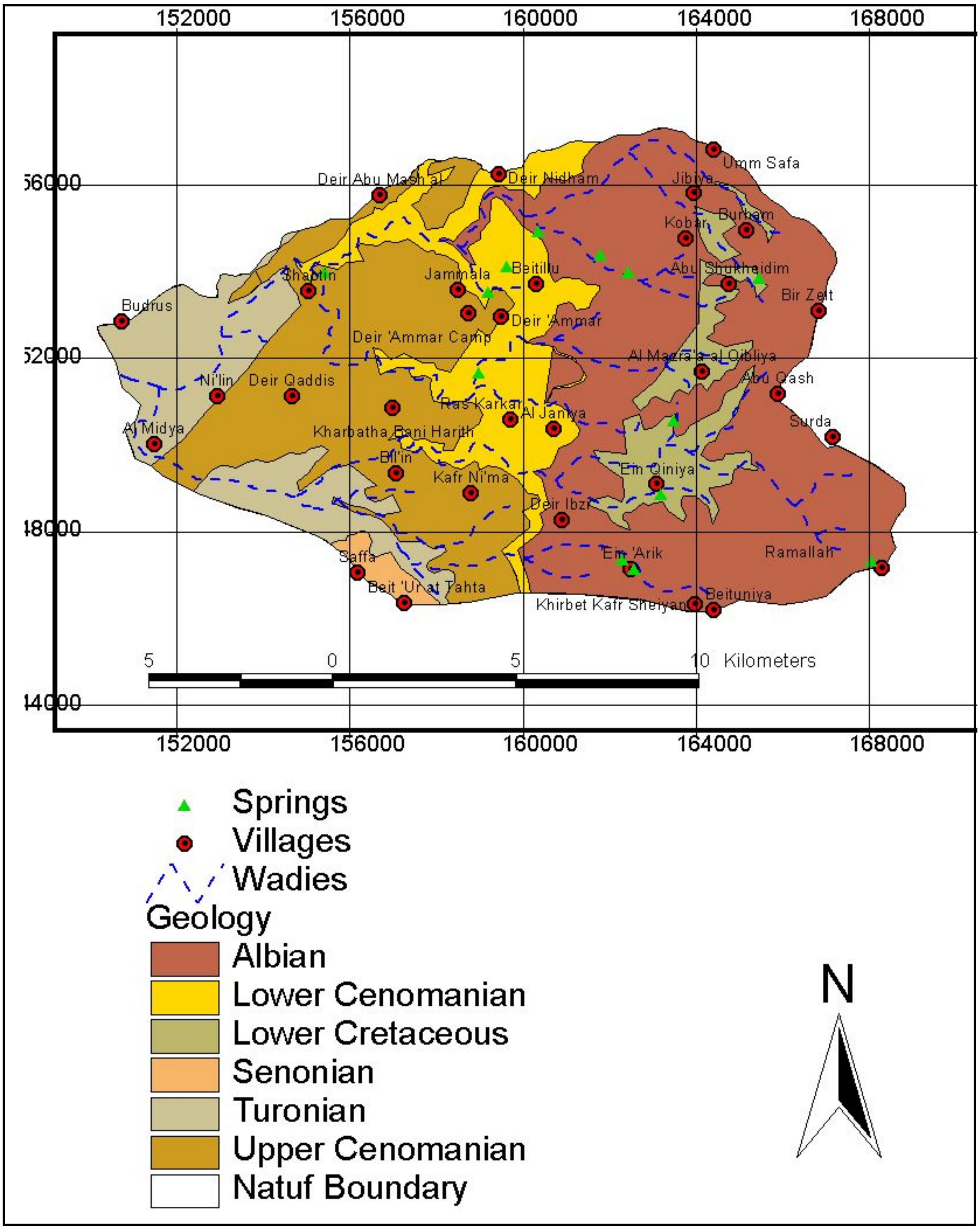

Figure 2.2: Geological formations in the Natuf drainage basin
(Modified after the PHG, 2004)

The western slopes are characterized by their gentle slopes, and they have elevations of about 850m a.s.l in the Eastern hills near Birzeit and Ramallah, and drop to about 200m a.s.l in the western hills near Ne'lin village on 1967 borders.(Fig. 2.3)

The drainage system runs to the west towards the Mediterranean Sea. The area does not contain apparent surface water bodies; there are three major wadis named locally as Al-Natuf, Ein Arik and Al-Dilb. (Fig. 2.4)

2.3 Land Use in the Natuf Drainage Basin

The Natuf drainage basin includes within its boundaries all or part of the following Palestinian communities: Ramallah city, Beituniya, Ein ‘Arik, Ein Qinia, Deir Ibzi’, Kafr Ni’mih, Bil’in, Ras Karkar, Al-Janiya, Kharbatha Al-Harethiya, Deir Quaddis, Ne’lin, Shibteen, Shuqba, Deir Abu Mash’al, Deir Nidham, Kobar, Burham, Jebiya, Abu Shekhedem, Al Mazr’a Al Quibliya, Birzeit, Um Safa, Abu Quash, Deir Ammar, Jammalah, Beitillu, Deir Ammar Refugee Camp (PCBS, 1999), and Twelve Israeli settlements (Peace now, 2005).

Like other parts in Ramallah district, land use in the Natuf drainage basin is distributed among agricultural lands fed by rainfall, Palestinian Built-up land, Israel settlements Built-up and other areas (Table 2.1).

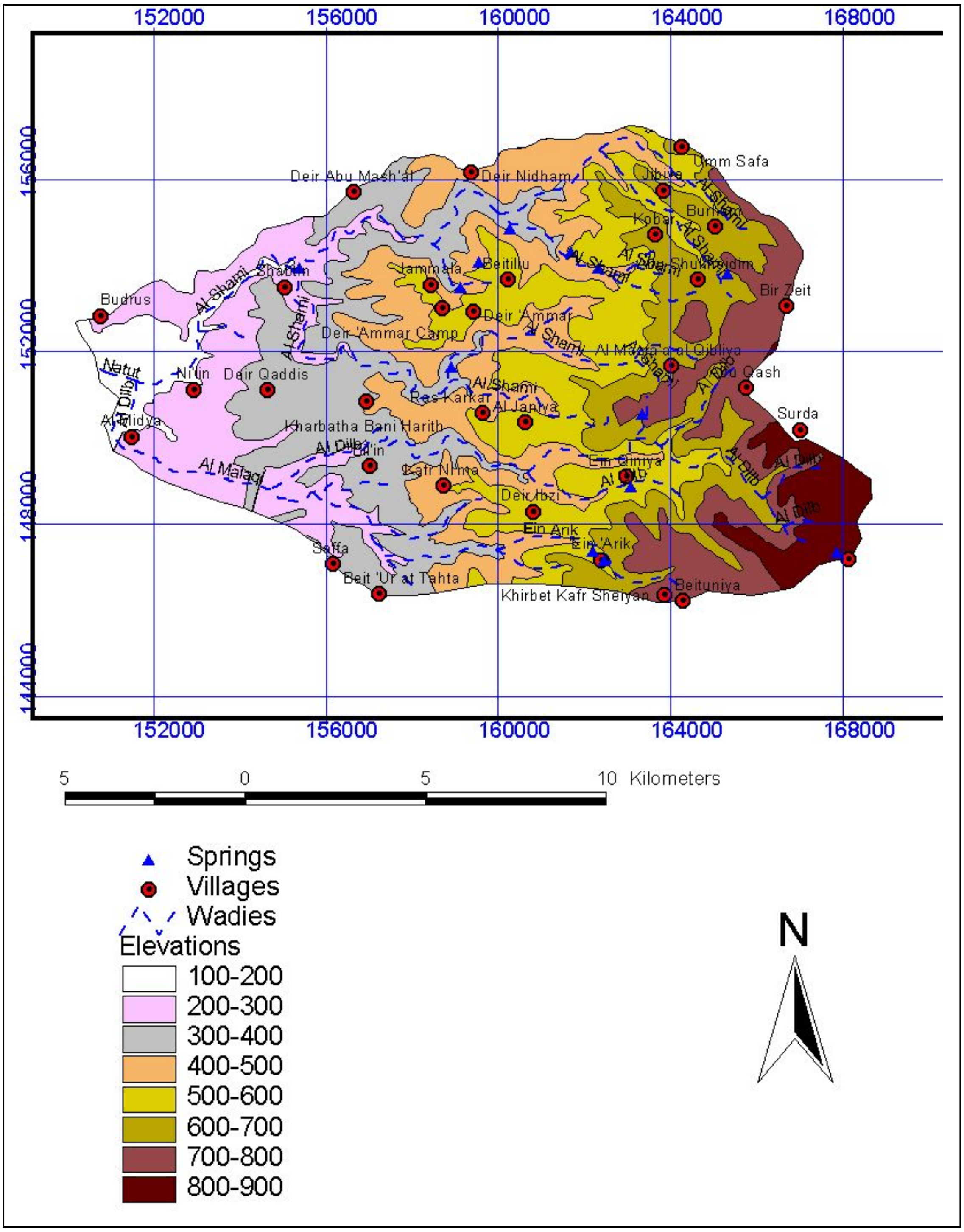

Figure 2.3: Elevations of the Natuf drainage basin (Modified after the PHG, 2004)

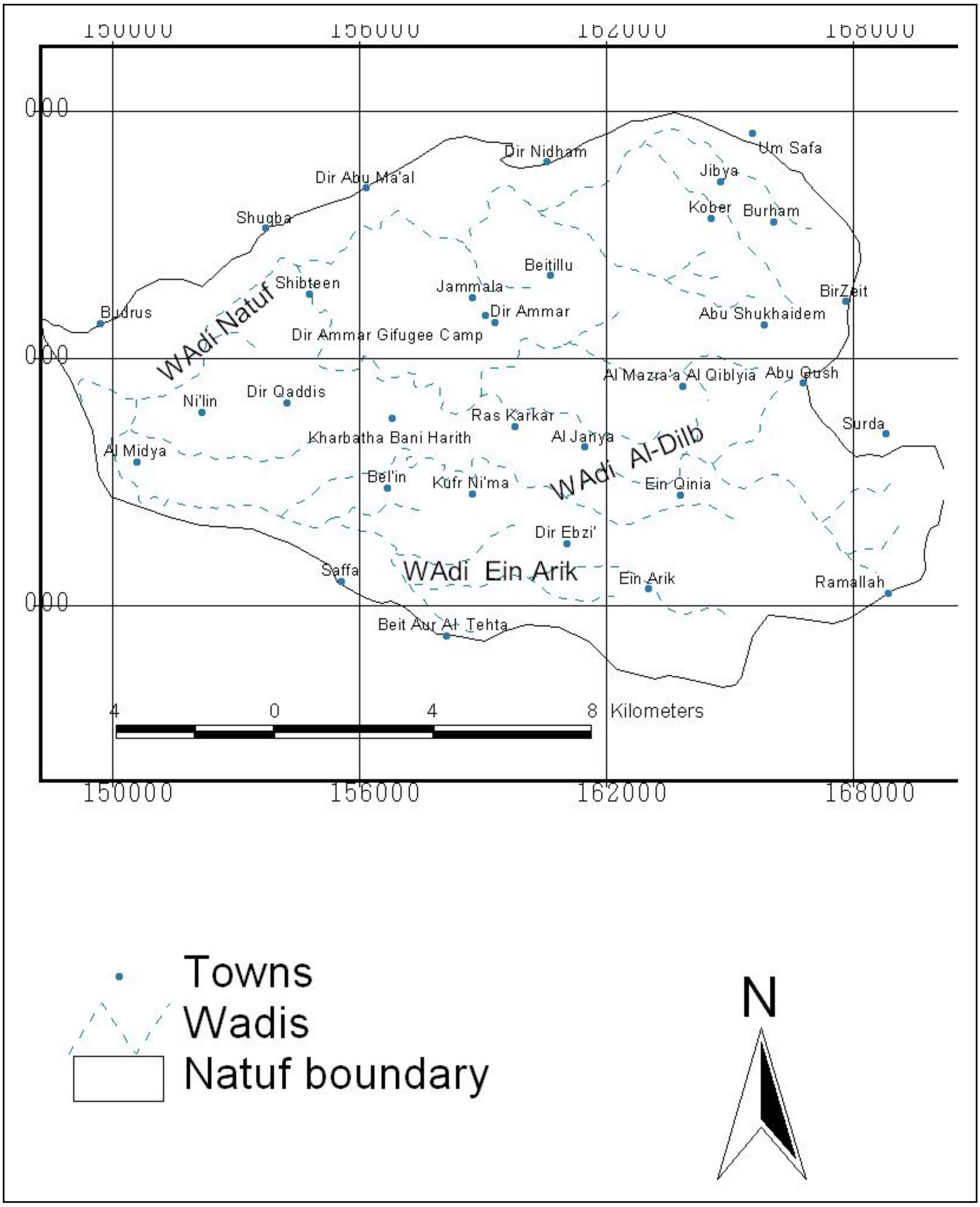

Figure 2.4: Wadis in the Natuf drainage basin (Modified after the PHG, 2004)

There is a lack of specialized agriculture in Ramallah district in general and in the Natuf drainage basin in specific, which spreads widely in the areas that are empty of any cultivation except for olive trees on some hilly areas and some seasonal crops near the springs in the area. (Fig. 2.5)

Table 2.1: Land use in Ramallah district (Modified after PCBS, 2002)

Agricultural land(km^2)	Forests and wooded land (km^2)	Palestinian Built-up land (km^2)	Built-up land in Israeli Settlements (km^2)	Other land * (km^2)	**Total (km^2)**
174.0 **20.35%**	**2.1** **0.25%**	**86.6** **10.13%**	**22.7** **2.65%**	**569.6** **66.62%**	**855.0** **100%**

*Includes: heath, meadows, fallow land, pastures, roads and others

2.4 Hydrology

Water resources in the Natuf drainage basin originates from rainfall in the winter season and from snowmelt which falls occasionally for a few days on the eastern parts of the study area near Ramallah and Birzeit hills.

The Natuf drainage basin is underlain by the Western aquifer; many springs are spread in the study area (Fig. 1.2), with an average annual discharge of 0.3-0.6 million cubic meters (mcm) of fresh water, which is used for domestic and agricultural purposes for the Palestinian people living in the area. There is only one groundwater well from the lower aquifer located near Shibteen village downstream Natuf Wadi; it is completely controlled by the Israeli Water Authority (Mekarot) and supplies about 0.7 mcm /year of fresh water to the Palestinian villages and Israeli settlements in the area.

2.4.1 Rainfall in the West Bank

The West Bank is characterized by a Mediterranean climate type, which is characterized by a long dry season in summer and a short wet season in winter (early

Figure 2.5: Land use in Ramallah district including Natuf drainage basin
(Modified after PWA, 2006)

November to late April) with a mean number of rainy days varies from 30-55days(Ghanem, 1999).

The quantity of rainfall differs from one area to another in the West Bank; it shows the highest value in the hilly areas in the central parts with an average of 740mm/year (Sabbah, 2004)

2.4.2 Rainfall in the Natuf Drainage Basin

The Natuf drainage basin lies in the central part of the West Bank, which has an average rainfall of 540-740mm/year. The rainfall intensity decreases from East (Ramallah and Birzeit town) to West (Ne'lin village) (Fig. 2.6). A total amount of 840mm was recorded at BZU rainfall station during 2004.

2.5 Hydrogeology and Aquifer System of the Study Area

The Western Aquifer outcrops from the flanks of the major anticline structure that builds up the West Bank (Susmaq, 2003). Two major aquifer systems can be differentiated (Fig. 2.7), they are divided by a series of impermeable lithologies, such as marl, clay and chalk (Appendix A). The Natuf drainage basin is located within the western aquifer which is geologically described as the Cennomanian – Turonian Limestone aquifer or what is called "Judea Group" (Issar, 2000). This aquifer is composed of permeable limestone. The permeability of this formation is a function of dissolution of limestone system over years by chemical and biological processes; this is known as karstic processes. The water infiltrates vertically until it reaches the saturated part of the permeable limestone, and then it flows in a sub- horizontal direction as groundwater. In many places the water is discharged through small springs due to the formation of local perched aquifers on marl layers. In some places the marl layers are thick and cover wide areas where springs flow allover the yearThe Judea group is divided into three main hydrological parts (Issar, 2000, Susmaq, 2003). (Fig.2.8)

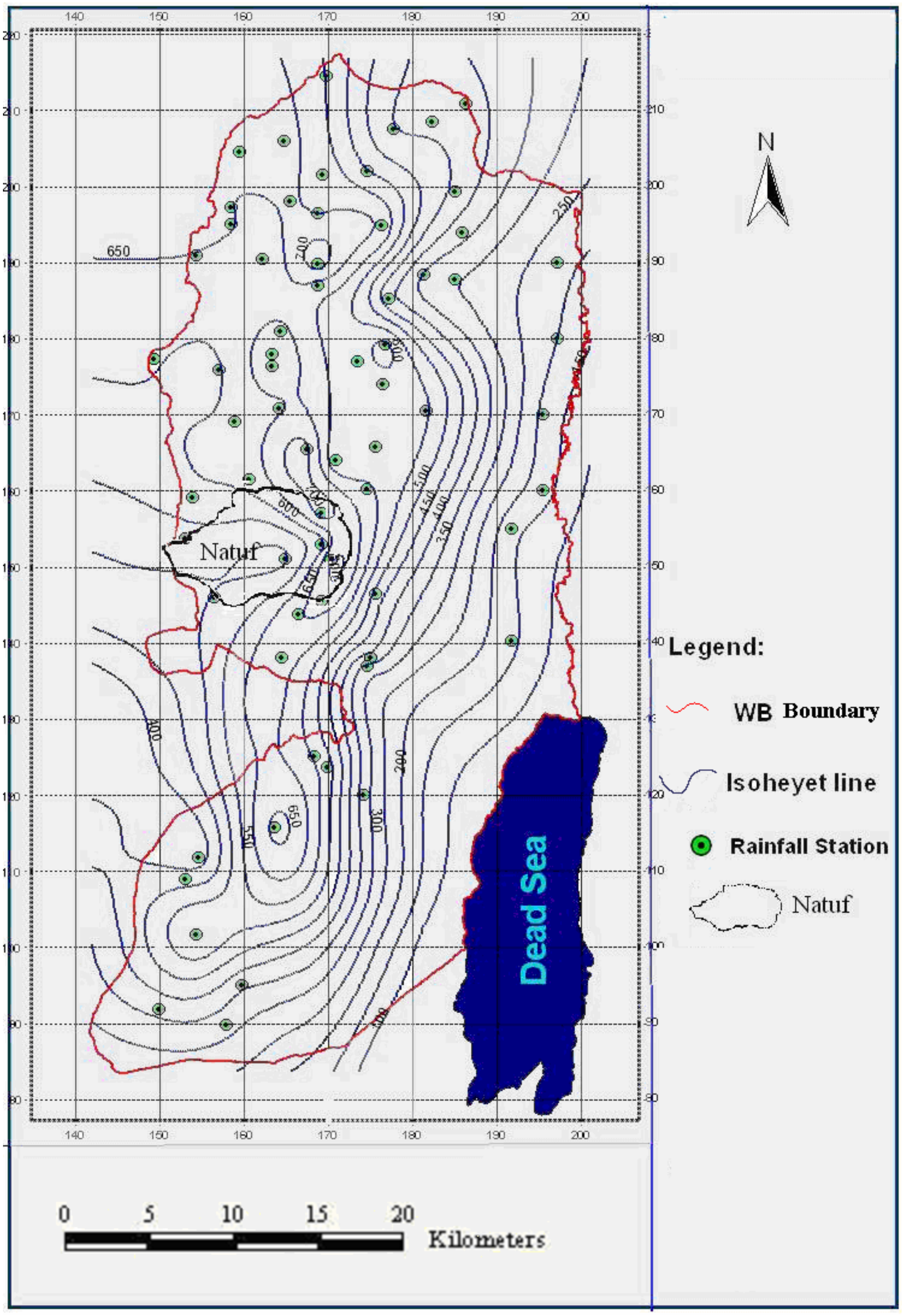

Figure 2.6: Precipitation in the West Bank and the Natuf drainage basin during 2004 (Modified after PWA, 2005)

1- Upper aquifer in the Turonian- Upper Cennomanian part which is built of highly permeable limestone, its thickness is about 150m. The lower part of the aquifer is built up of Bethlehem formation, while Jerusalem formation forms the upper part of the aquifer. The top cover of the aquifer is overlain by Senonian impermeable chalks of Abu Dis group.

2- Mid. Cennomanian Aquiclude Yatta formation which separates the upper aquifer from the lower aquifer. The upper part of this formation is made of yellowish marls and in some places clay. The lower part consists of dolomite, limestone, marl, chalk, quartzolite and chert. Its thickness is about 110m. Perched springs are found in this formation.

3- Lower aquifer in the Cennomanian to Albian age or upper and lower Beit Kahil. These formations are about 340m thick. Upper Beit Kahil consists of yellowish dolomite with thick marly layers. Lower Beit Kahil is about 240m of karstified carbonates with about 70m of hard dolomite underlain by hard limestone and dolomite. There is an increase of marly layers towards the bottom of the formation. Many springs emerge within the recharge area of the aquifer, fed by a perched water table within upper Beit Kahil.

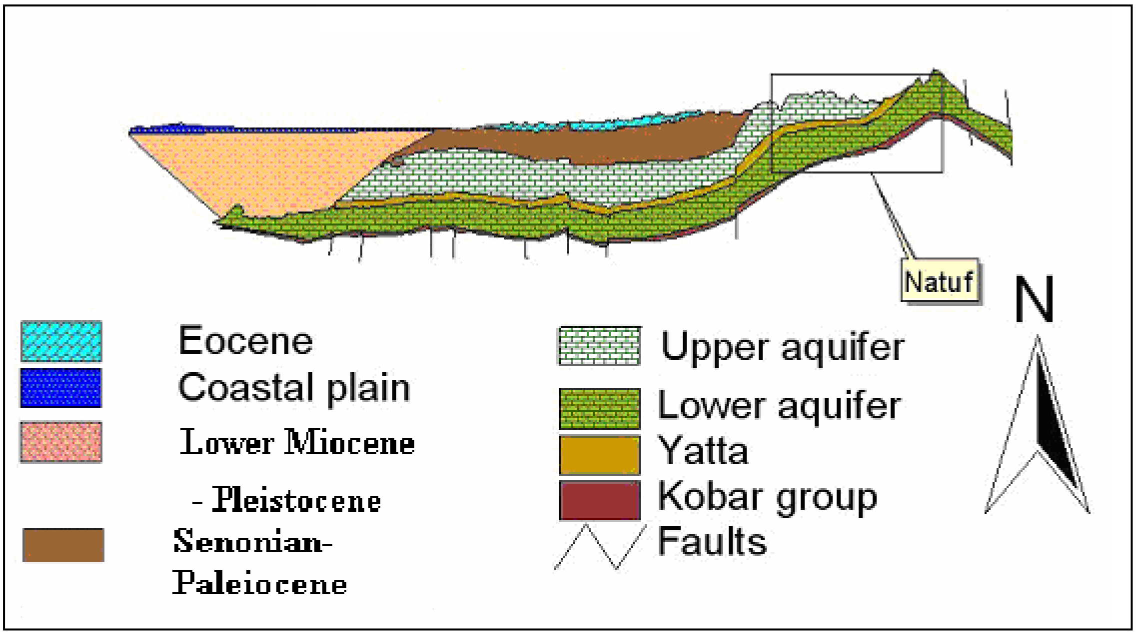

Figure 2.7: Stratigraphic sections of West Bank (Modified after: PWA, 2004)

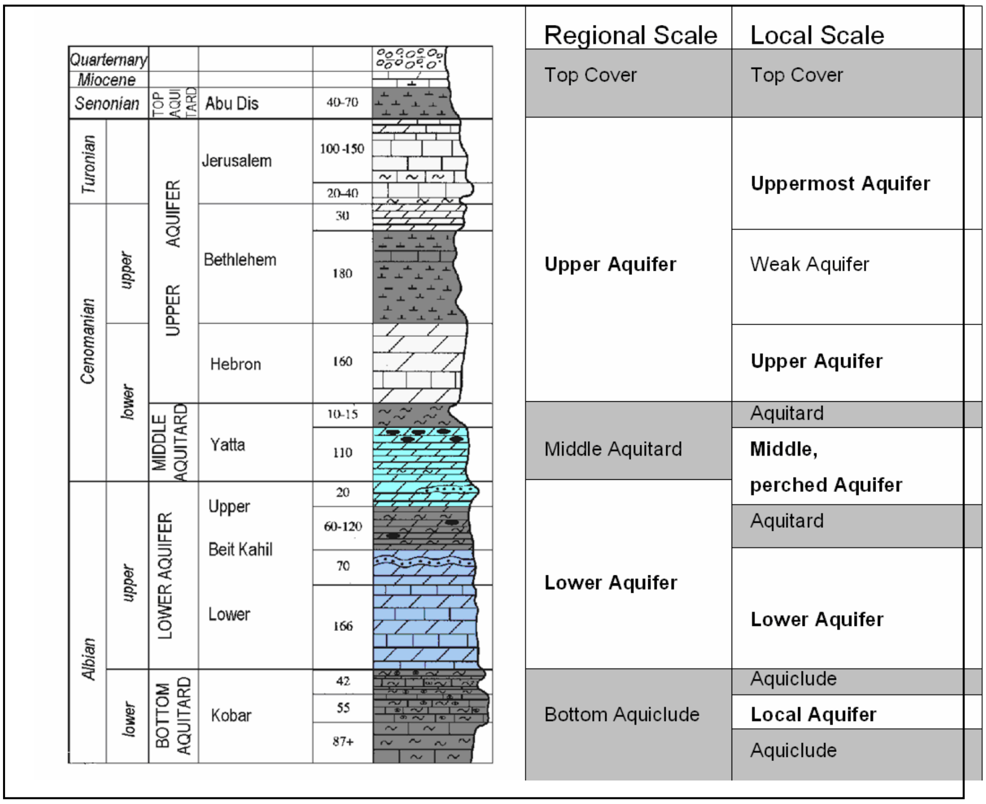

Figure 2.8: Lithology and Stratigraphy of Natuf drainage basin
(Modified after: Messerschmid, 2004)

Chapter Three

Methodology

3.1 Sampling Procedures

The sampling procedures was carried out during the wet and dry seasons, starting from Nov. - 2003 to May- 2005, in which 47 samples were collected. Twelve major springs were the target of the sampling (Table 3.1). Two samples from Shibteen well, a runoff sample during winter 2005 from Wadi Natuf near Shibteen village and one sample from Al- Fawarah (Seasonal Base flow from Wadi Natuf) were also collected, the total number of was 51 samples. Samples of runoff, rainfall were collected at Birzeit University campus in 2004 / 2005.

Table 3.1: Sampling Procedure (2003-2005)

Year	**Dry season Oct. - Nov**	**Wet season April - June**	**No. of Springs**	**Other Locations**	Total
2003	12	0	12	0	**12**
2004	12	9	12	2	**23**
2005		12	12	4	**16**
Total Number of samples					**51**

3.2 Sampling and Sample Treatment

The samples were collected from springs, listed in table 3.2, in a 1 Liter Polyethylene bottles, stored in an icebox and refrigerated in the lab. at 2ºC for further analyses. Onsite tests for pH, Total Dissolved Solids (TDS), Electrical conductance (EC) and Temperature (T) were carried out using Hanna Field Multimode Meter.

Table 3.2: List of springs in the Natuf drainage basin

No.	Spring Code	East	North	Spring Name	Location	Formation
1-	BA/152	166.775	152.575	Al- Alaq	Abu Shekhedem	Qatana
2-	BA/153	164,700	149,900	Harrashah	Al-Mazr'a Al-Quibliya	Qatana
3-	BA/157	159.100	155.410	Akari	Beitillu	Bottom UUBK
4-	BA/158	161.440	153.700	Al- Balad	Beitillu	Bottom Lower Yatta
5-	BA/159	161.400	154.140	Al-Quos	Beitillu	UUBK
6-	BA/163	165.000	148.680	Old JWU well	Ein Qinia	Lower Ein Qinia
7-	BA/170	163.600	145.850	Ein Arik Al-Fuqa	Ein Arik	LLBK
8-	BA/171	163.400	146.180	Ein Arik Al-Tehta	Ein Arik	LLBK
9-	NS/007	159.130	150.580	Ein Ayoub	Ras Karkar	Hebron**
10-	NS/040	159.410	153.440	Al- Tina	Jammalah	Lower Yatta
11-	NS/041	159.740	153.600	Al-Shakhariq	Deir Ammar	Lower Yatta
12-	NS/MUS	169.380	146.275	Ein Musbah	Ramallah	LUBK
13-	SHW	155,220	153.250	Shibteen Well	Shibteen	Hebron

**: The formation in this site is more likely alluvial

Three sites, Ein Musbah, Harrashah and Al Alaq, were chosen for microbiological tests: Total Coliform (TC) and Faecal Coliform (FC). Samples for these tests were collected in sterile 100ml. glass bottles, cooled in an icebox and transferred to the laboratory on the same day for biological tests.

3.3 Laboratory Tests

Conventional instrumental and chemical tests (Table 3.3) were carried out for each sample on the same day of collection. About 100ml of each collected sample were acidified with Aristar Concentrated 69% Nitric acid (14.4M HNO_3) and stored refrigerated for trace elements analysis.

3.4 Validation

For the validation of data, Electrical balance was conducted for all samples using the following formula (Freeze, 1979):

$$\text{Electrical Balance} = \left[\frac{\sum cations - \sum anions}{\sum cations + \sum anions}\right] * 100$$

Table 3.3: Test methods used for physical and chemical parameters

No.	Test	Method used
1-	**pH**	Onsite, Hanna pH meter
2-	**Temperature**	Onsite, Hanna pH meter
3-	**TDS**	Onsite, Hanna pH meter, Gravimetric method
4-	**EC**	Onsite, Hanna pH meter
5-	**Cl^-**	Mohr method, titration with standard $AgNO_3$ and K_2CrO_4 as indicator, using Metrohm 716 Titrino at Chemistry dept. Standard Method No. 4500 –Cl^- B
6-	**NO_3^-**	Screening method, using HP- Diode Array 84153 Spectrophotometer, Chemistry dept./BZU Standard Method No. 4500 – NO_3^- B
7-	**SO_4^{2-}**	Turbidity method, using HP Diode Array 84153 Spectrophotometer, Standard Method No. 4500- SO_4^{-2}- E
8-	**HCO_3^-**	Titration with standard Hydrochloric acid (HCl) at pH 4.78, using Metrohm 716 Titrino.
9-	**Na^+ and K^+**	Flame photometer, Sharewood 4010 at Chemistry dept. BZU
10-	**Fe^{3+}, Cu^{2+}, Cr^{3+}, Zn^{2+}, Pb^{2+}, Cd^{2+}, Co^{2+} Mg^{2+} Ca^{2+},**	Inductively Coupled Plasma (ICP) Perkin-Elmer Optima 3000 at Health Center / BZU
11-	FC & TC	Media culture. Biology dept. BZU

The results show that 35 samples have electrical balance range within ± 10 % which is applicable for data accuracy; these samples will be used for the interpretation of the hydrochemical parameters. The other samples have electrical balance values between >10%, so the will be rejected.

The detection limits of the hydrochemical parameters are listed in table 3.4:

Table 3.4: Detection limits for hydrochemical parameters at BZU and PWA Labs.

Parameter	**Detection limit**	**Parameter**	Detection limit
Ca^{+2}	**10µg/l**	**Co^{+2}**	**7µg/l**
Mg^{+2}	**30µg/l**	**Cr^{+3}**	**7µg/l**
Na^{+}	**30µg/l**	**Cd^{+2}**	**4µg/l**
K^{+}	**100µg/l**	**Pb^{+2}**	**40µg/l**
HCO_3^{-}	**1mg/L**	**Zn^{+2}**	**2µg/l**
Cl^{-}	**4mg/L**	**Fe^{+3}**	**7µg/l**
SO_4^{-2}	**4mg/L**	**Cu^{+2}**	**6µg/l**
NO_3^{-}	**0.1mg/L**		

3.5 Quality Control (QC)

Quality control procedures done during the experimental part were as follows:

1- Standard solutions, for all cations and anions, were prepared and tested before and during the analysis of samples.

2- A standard calibration curve was constructed before the analysis of samples

3- A blank sample of deionized water was tested before and during tests.

4- Spike samples from SGS obtained from PWA laboratory, were introduced between samples and analyzed for major cations and trace elements by ICP and flame photometer, the results of the SGS Samples were within the range of our samples.

5- Samples were tested for Na^{+} and K^{+} by flame photometer and ICP, the results were compared each time.

6-Three samples were sent to Jordan for trace elements analyses in cooperation with the Palestinian Water Authority (PWA), the results were within range of this study.

7- TDS was measured onsite using Hanna multimode meter and was calculated as the sum of the concentrations of cations and anions using Aquachem software. For QC three samples were checked for TDS by gravimetric analysis. The results were convenient.

Chapter Four

Hydrochemistry

4.1 Introduction

The chemical composition of groundwater is highly dependent on the mineralogical composition of the aquifer systems and on the anthropological activities in the study area. When rainfall infiltrates soil and during its journey through flow paths to the groundwater, processes such as cation exchange with clay, dissolution and precipitation of minerals, oxidation reduction reactions and microbial activity will change the chemical composition of old groundwater.

The hydrochemistry of all springs is affected by the dissolution reactions that occur when rain water containing carbon dioxide (CO_2) reacts with carbonaceous rocks which are composed mainly of limestone($CaCO_3$) and dolomite ($CaMg(CO_3)_2$) according to the following equations:

$CO_{2g} + H_2O \longrightarrow H_2CO_{3aq}$ ---------------------- (4.1)

$H_2CO_{3\,aq} + CaCO_{3\,(s)} \longrightarrow Ca^{+2}_{aq} + 2\ HCO_3^{-}{}_{aq}$ ------------- (4.2)

Equation (4.2) shows that massive limestone rocks are dissolved into soluble species, which means chemical weathering of limestone bedrocks and hence the formation of karstic systems, through which pollutants travel rapidly into groundwater

Runoff water carries pollutants from landfill leachate, roads, cesspits and farms, which contribute in the increase of pollutants in spring's water and groundwater reservoirs.

4.2 Interpretation of Hydrochemical Parameters

Hydrochemical and physical parameters measured for samples during study period 2003-2005, are shown in Appendix B. Statistical analysis of all measured and calculated hydrochemical parameters are given in Appendix C.

4.2.1 pH

pH is a term used to express the intensity of the acid or alkaline condition of a solution, it is a way of expressing the hydrogen –ion activity (Sawyer, et.al, 1994). pH is calculated according to the formula (Stumm and Morgan, 1981) :

$$pH = -\log[H^{+}]$$

All water samples from the 12 springs, runoff and Shibteen well show pH values in the narrow pH range 7.1-8.4, with an average value of 7.54, which indicates that all inorganic carbon exists as bicarbonate (HCO_3^-). pH is inversely correlated at 0.01 significance level to EC, TDS, cobalt, $SI_{anhyd.}$, SI_{gyp}.(Fig. 4.1) and positively correlated to SI_{arag}, SI_{calc}. and SI_{dol}. (Appendix C)

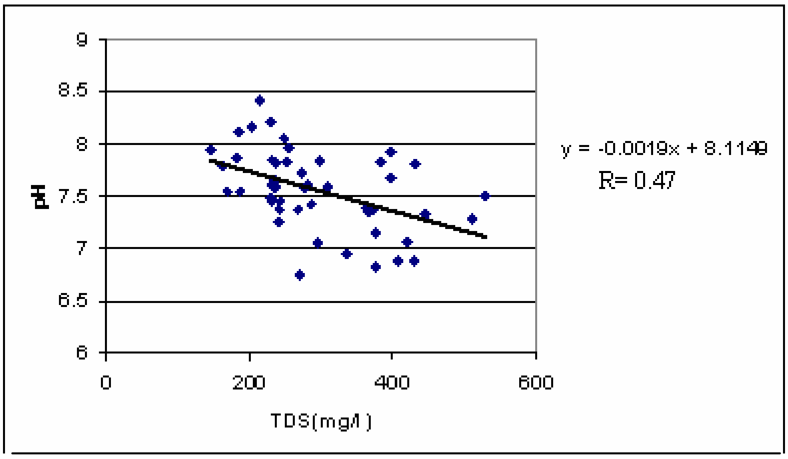

Figure 4.1: Relationship between pH and TDS in the springs of Natuf drainage basin 2003-2005

4.2.2 Temperature

Temperature is an important physical parameter for groundwater monitoring. It has an effect on the dissolution of minerals, microbial activities and the dispersion rates of pollutants in groundwater. it is measured in ^{o}C. The measured temperatures of all springs in the study area were in the range of 19-22 ^{o}C. There was no significant difference between the measured temperatures of the springs and the air temperature in the area at the same time.

4.2.3 Total Dissolved Solids (TDS)

TDS is a measure of all inorganic dissolved species in water. It is used as a hydrochemical parameter for salinity measurements and to determine the suitability of water for domestic and agricultural purposes. Groundwater is classified according to TDS as fresh, brackish, saline and brine (Table 4.1) (Todd, 1980).

Table 4.1: Classification of groundwater according to TDS (Todd, 1980)

Water class	**TDS (mg/L)**
Fresh	<1000
Brackish	1000-10,000
Saline	10,000-100,000
Brine	>100,000

TDS was measured onsite using Hanna multimode meter and calculated using Aquachem software, the difference between the two values was insignificant in most cases. For quality control procedure; TDS was determined gravimetrically for three samples, the results show a decrease of 12% from the recorded and measured values, which is acceptable due to the escape of carbon dioxide (Steel, 1996). The difference between measured and calculated TDS is referred to the un-dissolved zero charged particles of SiO2 (Ghanem, 1999), which can not be determined by calculations of total dissolved ions. The average values of TDS for all springs during the study period

2003-2005 and for the period 1999-2002 samples were <1000mg/L , which means that water from all springs in Natuf drainage basin can be classified according to (Table 4.1) as fresh water. The highest values of TDS were recorded in springs located near populated areas (Fig. 4.2).

The good correlation between TDS and other hydrochemical parameters makes the onsite measurement of TDS useful in rapid prediction of other parameters (Fig. 4.3), which are difficult to measure in the field and require special laboratory procedures and equipment.

Statistical analysis showed that a positive and significant correlation at 0.01 level between TDS and Na^{+}, Mg^{+2}, EC, HCO_3^{-}, NO_3^{-}, Cl^{-}, Cd^{+2}. A negative correlation between TDS and pH was observed, which indicates dissolution of rock minerals at low pH values (Appendix C)

4.2.4 Electrical Conductance (EC)

EC is the parameter that indicates the ability of water to conduct electricity; it is an indication about ion species that are present in water solution. It is the reciprocal of resistance and is measured in units of (S/cm) and its derivatives of mS/cm and µS/cm. The average values of EC during the study period for water samples from springs of Natuf drainage basin range between 403 - 917µS/cm. The highest value (1105 µS/cm) was recorded in Ein Musbah in Ramallah city in the dry season of 2003. In contrast, the average values of EC for five springs, Al-Alaq, Ein Arik Al Fuqa, Ein Arik El Tehta, Beitillu Al Ballad and Harrashah, was calculated as 450-937µS/cm, with the highest value was recorded for Al- Alaq as 1020µS/cm. Variation of EC with time indicates that EC, which is a measure of salt concentrations, is greatly affected by dilution process of rainfall (Fig. 4.4 & Fig. 4.5). Most of the springs

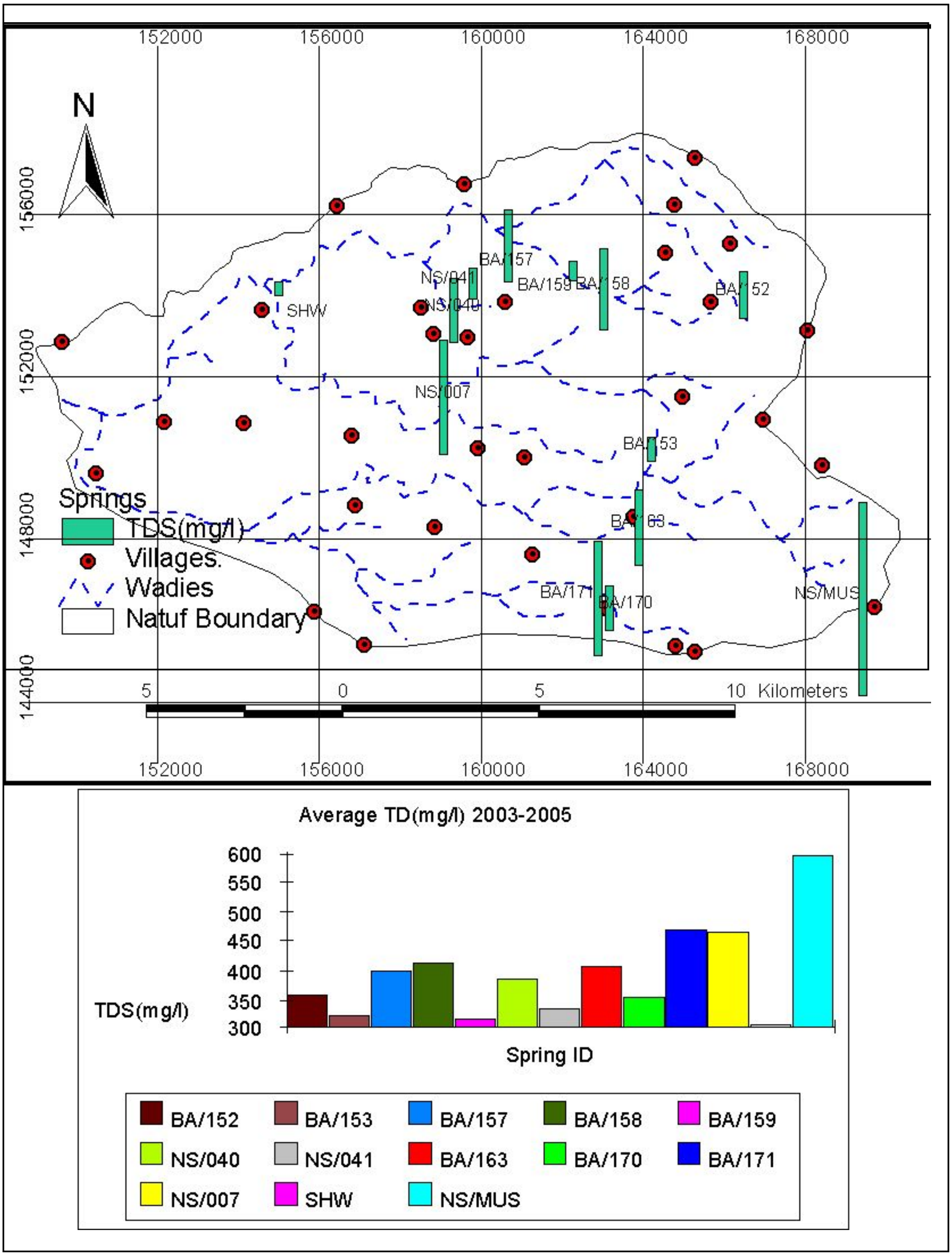

Figure 4.2: Spatial distribution of TDS (mg/L) in springs in the Natuf drainage basin 2003-2005

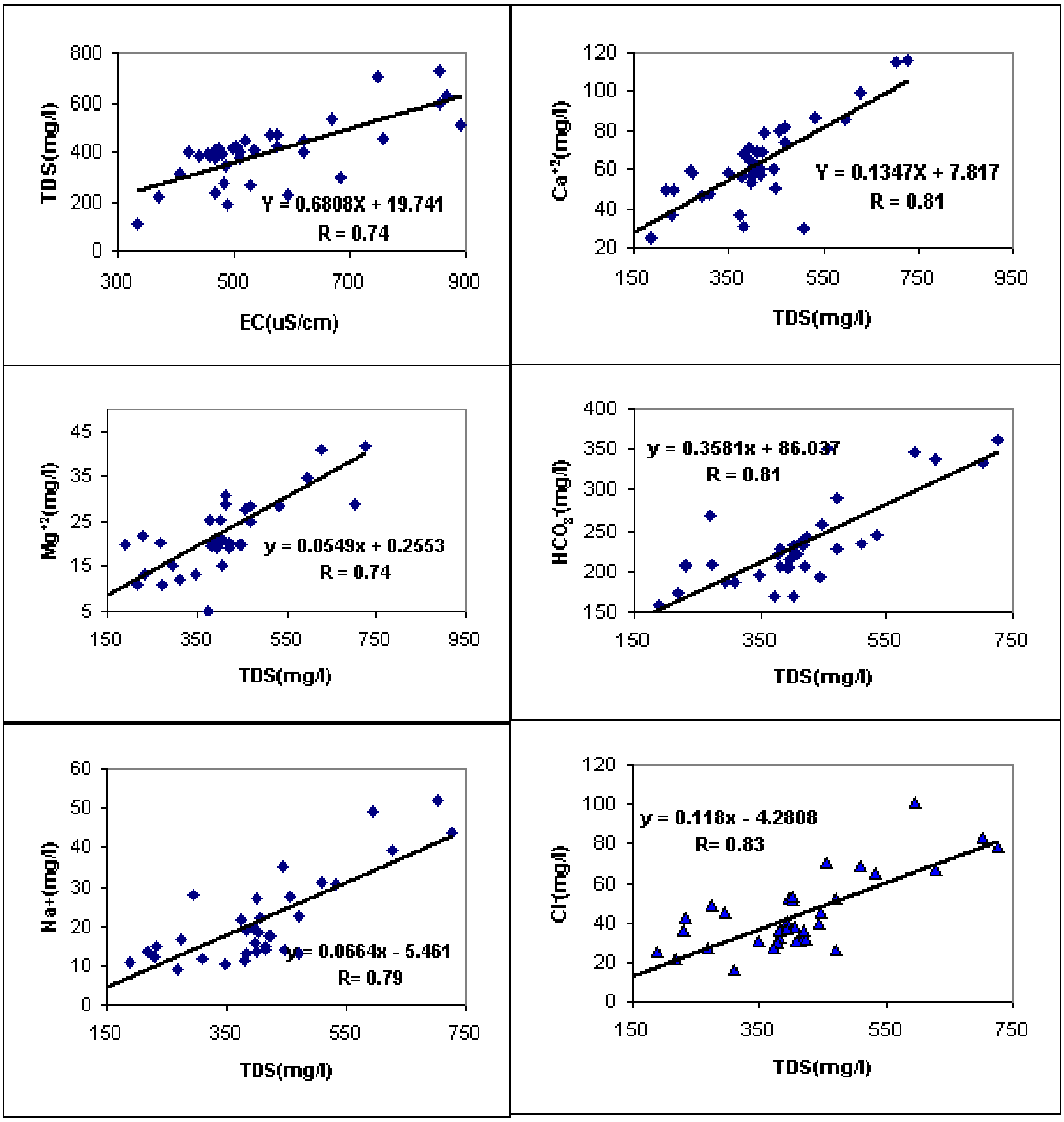

Figure 4.3: Relationship between TDS and some hydrochemical parameters in Natuf Springs 2003-2005

have values range between 300-600 µS/cm, which is considered as good water for agricultural purposes (Bauder, 2005). Only those springs located near highly dense populated areas, shows high values of EC. The spatial distribution of EC for all springs is shown in figure 4.6.

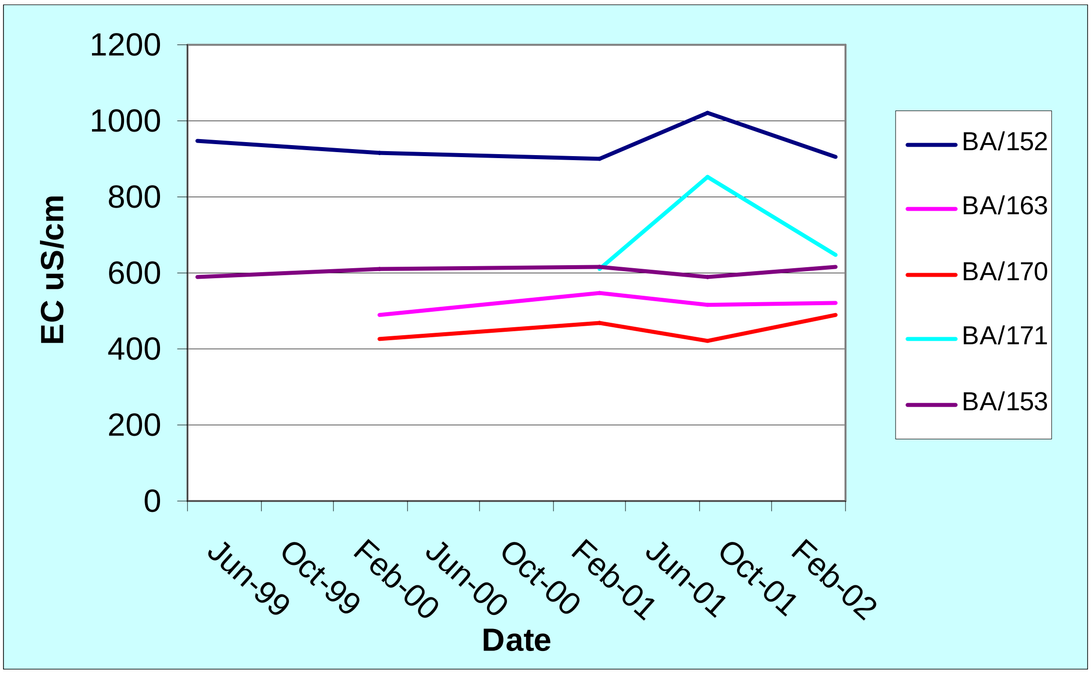

Figure 4.4: Variation of EC with time for Natuf springs 1999-2002

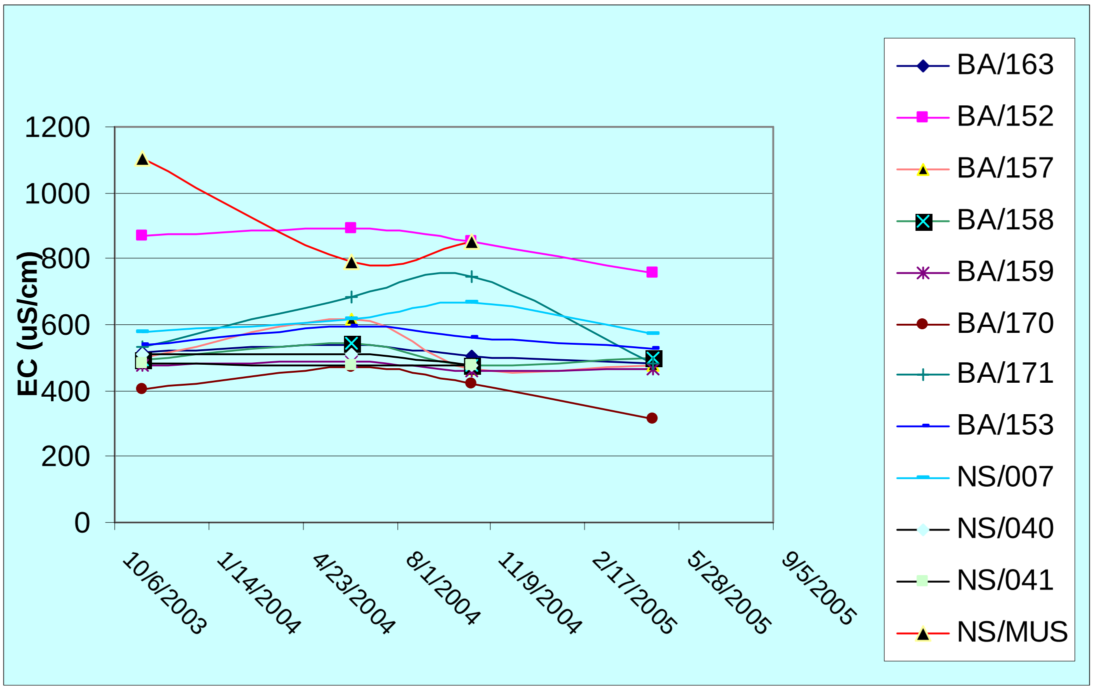

Figure 4.5: Variation of EC with time for Natuf springs 2003-2005

4.2.5 Major Ions

Major ions are the main constituents of the total dissolved solids. They are divided into cations: Ca^{+2}, Mg^{+2}, Na^{+}, K^{+} and anions: NO_3^-, HCO_3^-, SO_4^{-2} and Cl^-. Other ions such as silicates, strontium, bromide, and fluoride are not of concern in this study.

-Nitrate (NO_3^-)

Nitrates are soluble species and can percolate with infiltrate water down to groundwater reservoirs. Nitrate sources in groundwater originate from mineralization of nitrogen from atmosphere, fertilizers and from agricultural activities, where animal manure contributes to the rise of nitrate levels (Widory, 2004). The presence of nitrates in groundwater in concentrations above the WHO guidelines of 43mg/L makes water toxic for humans, poultry and cattle (Manahan, 1994).

In this study, twelve springs were monitored for NO_3^- levels from 2003 to 2005.The concentrations of NO_3^- show moderate values below the WHO limits <45mg/L, and above the guide level of European Community 1980 (Table 4.2).

Nitrate concentrations in two springs, Al Alaq and Ein Musbah, were 56.3 and 51.6mg/L respectively, The possible cause of the increase in levels of NO_3^- in Ein Musbah is that this spring outcrops in a dense populated area from where the possibility of wastewater leakage from sewer network.

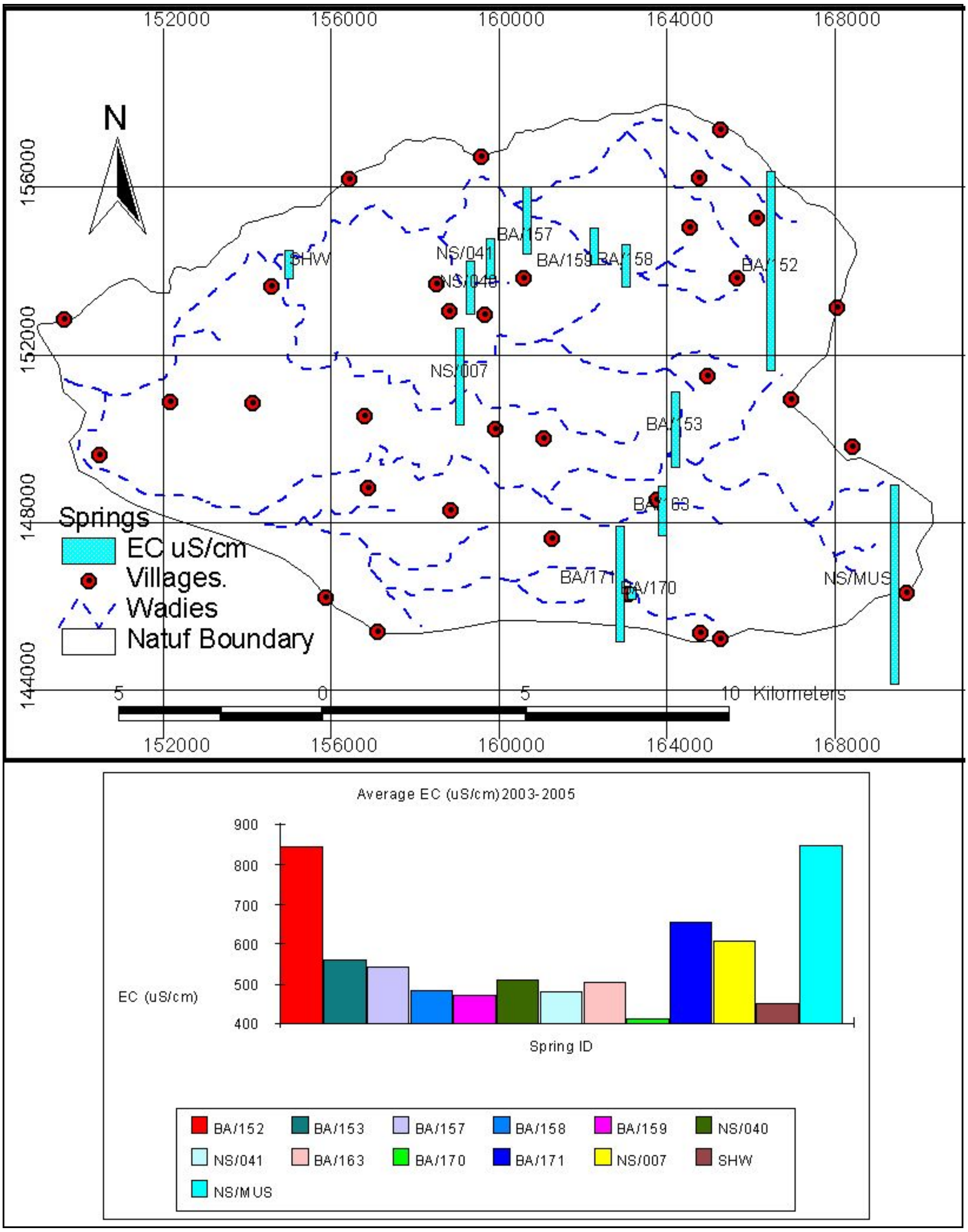

Figure 4.6: Spatial distribution of EC in Natuf springs 2003-2005

Al-Alaq spring outcrops from an agricultural area, where fertilizers and manure collection piles are abundant near the spring outcrop area. The spatial distribution of the average nitrate concentration of Natuf springs (Figure 4.7) illustrates the high levels of nitrate in springs located close to populated areas.

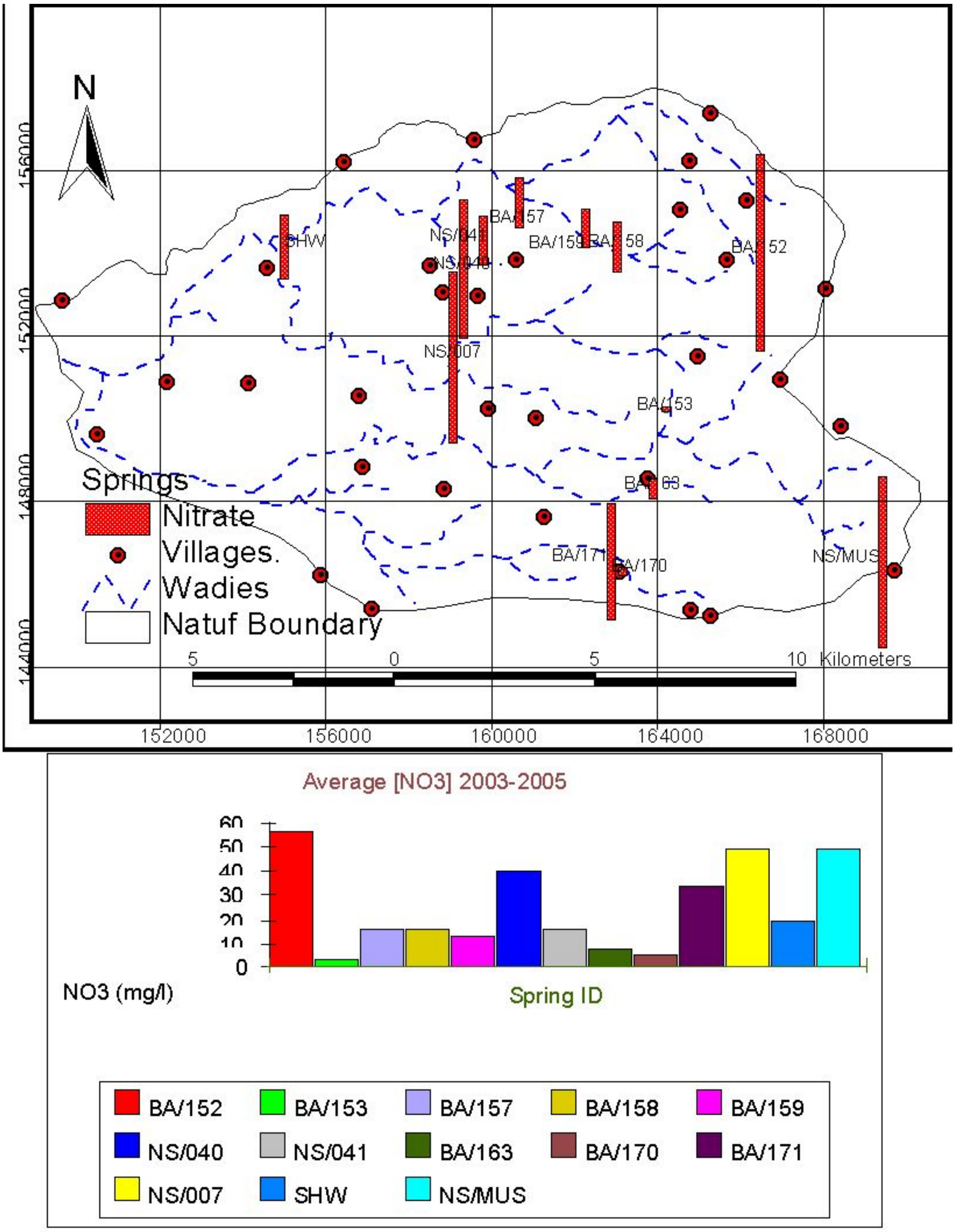

Figure 4.7: Spatial distribution of nitrates in Natuf springs 2003-2005

The statistical analysis of major ions in the Natuf drainage basin show excellent correlation at 0.01 level between NO_3^- and Na^+ (R= 0.92), EC (R=0.89) and Cl^- (R=0.86). Good correlation between NO_3^- and TDS (R= 0.79), Mg^{+2} (R= 0.72), Ca^{+2} (R=0.69) (Appendix C). The mathematical relationship between EC and NO_3^- is considered linear (Fig.4.8). This mathematical relation (Eq. 4.3) can be used for the interpretation of onsite EC measurements to predict nitrate concentrations, which saves time and effort.

$NO3^-$ (mg/L) = 0.12*EC (µS/cm) – 34.9 (R= 0.78) ---------------------------- (4.3)

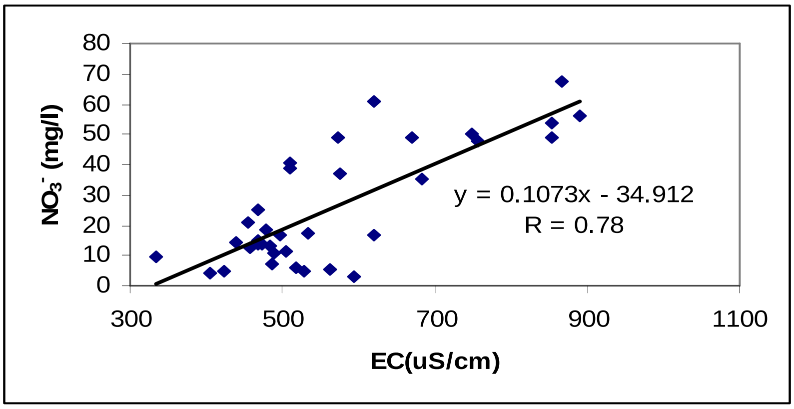

Figure 4.8: Relationship between EC and NO3- in Natuf water 2003-2005

Table 4.2: Water quality for human consumption (Modified after Price, 1996)

Parameter	EUC Guide level (mg/L)	Palestinian Standards (mg/L)	WHO guidelines (mg/L)
Calcium	100	100	100
Magnesium	30	100	100
Sodium	20	200	200
Potassium	10	10	10
Nitrate	25	50	45
Chloride	25	250	250
Sulfate	25	200	250

-Sodium and Potassium (Na^+, K^+)

Sodium and potassium are found in groundwater from mineral sources such as Halite (NaCl) and Sylvite (KCl) minerals. Potassium may originate also from decaying plants. The variation of sodium with time from 1999-2002, which was recorded by PHG teams (Fig. 4.9) (PHG, 2004).

Concentrations of sodium range from 10-45mg/L; higher concentrations were recorded in dry season of 2004 for Ein Musbah, Ein Arik Al Tehta and Ein Al Alaq, which reveals the contamination of these springs from agricultural activities and possible wastewater leakage from Ramallah sewer system into Ein Musbah.

Sodium concentration increases in dry season because of evaporation and lower flow rate (Fig. 4.10). The concentration decreases in wet season due to dilution process by rainfall.

Sodium exhibits excellent correlations at 0.01 significance level, with SAR (R=0.99), TDI (R=0.93), Cl^- (R=0.91), NO_3^- (R=0.90) and good correlated with Mg^{+2} (R= 0.83), TDS (R= 0.79), Ca^{+2} (= 0.78) and HCO_3^- (R=0.74) (Appendix C). The mathematical relations (Eq. 4.4 & Eq.4.5), are linear, with good correlations, between sodium and each of EC and TDS (Fig. 4.11& Fig. 4.12)

Na^+ (mg/L) = 0.06*EC (µS/cm) – 14.04 (R=0.81) ------------------------ (4.4)

Na^+ (mg/L) = 0.07*TDS (mg/L) – 5.46 (R= 0.79) ------------------------- (4.5)

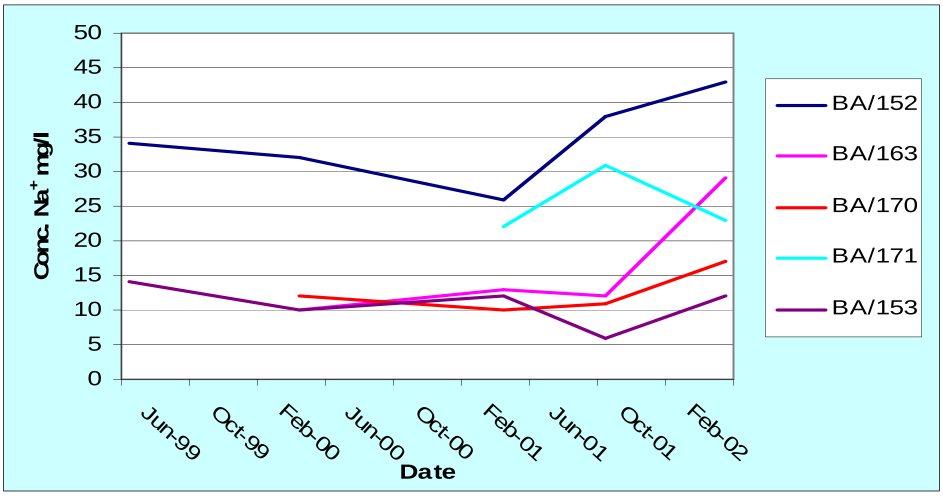

Figure 4.9: Variation of Na^+ levels in some springs of the Natuf drainage basin 1999-2002 (PHG, 2004)

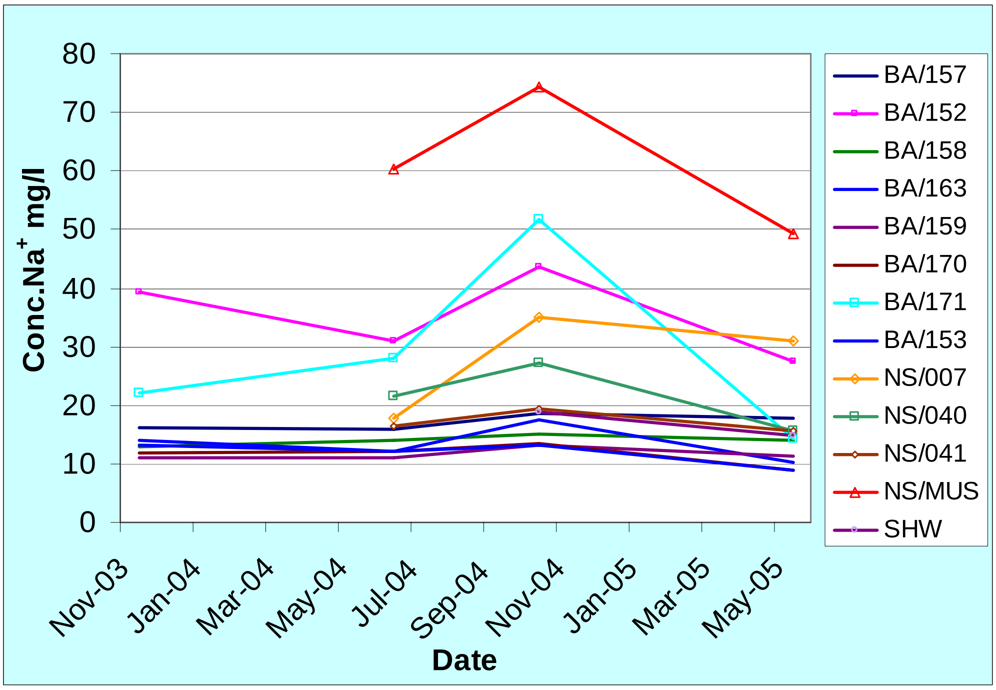

Figure 4.10: Variation of Na^+ levels in springs under study of the Natuf drainage basin 2003-2005

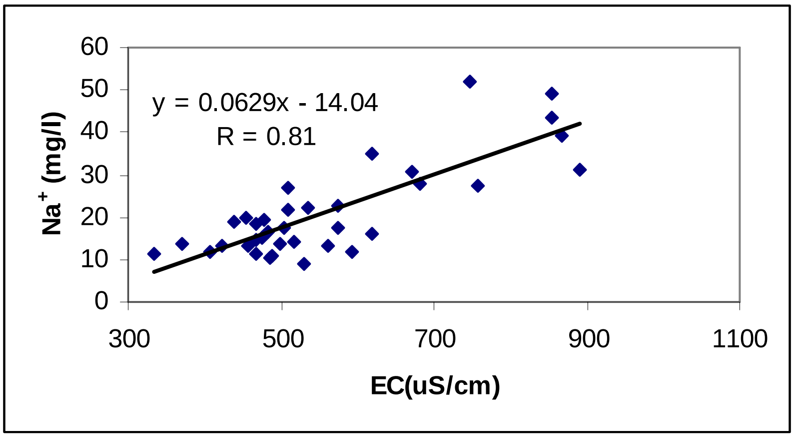

Figure 4.11: Relationship between Na^+ and EC in Natuf water 2003-2005

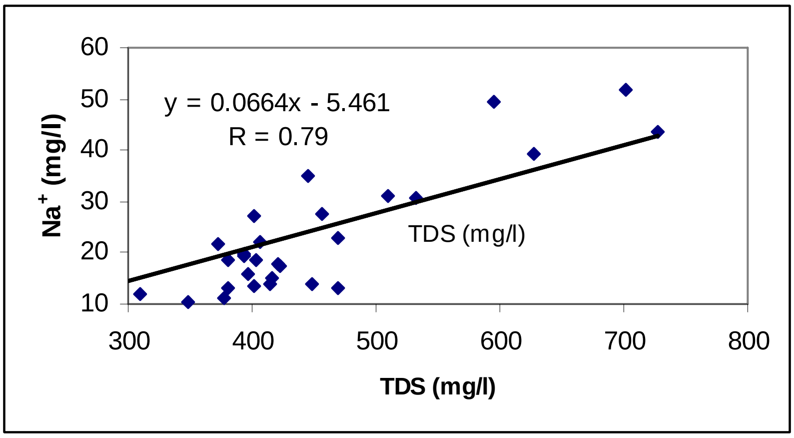

Figure 4.12: Relationship between Na^+ and TDS in Natuf water samples 2003-2005

-Chloride (Cl^-)

Chloride levels are an indication of salinity in groundwater. It is measured in mg/L. Chloride originates from dissolution of Halite (NaCl) and Sylvite (KCl) minerals. Wastewater adds considerable amounts of chloride into groundwater, for example, human excreta, particularly the urine, contain an average amount of 6g/person/day (Sawyer, 1994). Anthropogenic activities such as agricultural and industrial sources contribute in the increase of chloride levels in groundwater. Many pesticides containing chloride, such as poly-chlorinated biphenyls PCB's contribute in pollution of groundwater with chloride through biodegradation processes.

Chloride at concentrations above 250mg/L gives salty taste to water, which is objectionable to many people (Sawyer, 1994). Chloride concentrations in Palestine, including some springs in the Natuf drainage basin, were monitored in groundwater sources during British Mandate and up till now. The values of Cl^- recorded in 1940 by Government of Palestine for Ein Arik and Ein Qinia were 22 and 26mg/L respectively (Government of Palestine, 1948). The recorded values during this study for the same two springs were 38 and 30.6mg/L. The highest chloride concentration was recorded as about 90mg/L in Ein Al-Alaq (BA/152) in October 2001; while in Ein Arik Al

Tehta it was about 80mg/L during the same period (PHG, 2004). Average value of about 100mg/L of chloride was recorded in Ein Musbah during the study period 2003-2005, while it was about 71mg/L and 53mg/L in Ein Arik Al Tehta and Al Alaq springs respectively (Appendix B). Most of the springs have Cl^- values above the EUC guide level of Cl^- (Table 4.2); while springs located in populated areas have higher values, which reveal the possibility of wastewater intrusion from sewer system and cesspits.

Statistical analysis of the recorded data (Appendix B) show that Cl^- is highly correlated to Na^+ (R= 0.92), EC (R= 0.92) and very good correlated with, HCO_3^- (R=0.87), NO_3^- (R= 0.85), Mg^{+2} (R=0.81) and good correlated with Ca^{+2} (R= 0.79), TDS (R= 0.78). The good correlation between chloride and each of EC and TDS makes the use of mathematical relations (Eq. 12) for the interpretation of chloride values through direct measurement of EC or TDS (Fig.4.12).

Cl^- (mg/L) = 0.12* EC (μS/cm) -22.8 (R= 0. 84) ----------------------- (4.6)

Cl^- (mg/L) = 0.12*TDS (mg/L) – 4.3 (R= 0.83) --------------------------- (4.7)

Spatial distribution of chloride during the study period 2003-2005, is illustrated in figure 4.13.

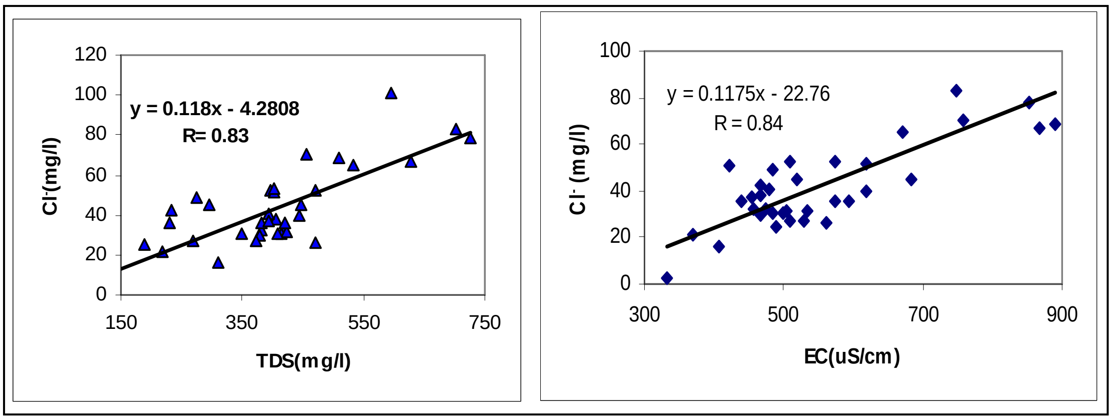

Figure 4.13: Relationship between Chloride and EC, and TDS in Natuf water 2003-2005

-Calcium and Magnesium (Ca^{+2}, Mg^{+2})

Calcium is the major cation found in almost all groundwater, the presence of calcium is mainly due to the dissolution processes of minerals in the top soil and bedrocks during the percolation of rainfall water. High levels of calcium and magnesium cause water to be hard, which is objectionable for domestic and industrial uses.

The acceptable concentrations of calcium and magnesium (Table 4.2) are 100 and 25mg/L respectively (Todd, 1980, Price, 1996), above these concentrations, water becomes hard for some industrial and domestic uses. High concentrations of magnesium are laxative and cause abdomen problems. During the study period 2003-2005, calcium content in most of the measured springs was higher than that recorded in 1999-2002 (PHG, 2004) , the concentration of calcium becomes higher in dry season because of longer residence time, which is the contact time between water and minerals (Fig.4.15).

In wet seasons, the concentration of calcium drops down because of dilution with infiltrated rain water. Average values of magnesium during 1999-2002 were between 20-50mg/L (PHG, 2004). During the study period 2003-2005, the measured concentrations of magnesium were fluctuating between 10-55mg/L (Appendix D).

During wet season, the lowering of magnesium concentration is not sharp as that of calcium because of the low dissolution of dolomite minerals, which is the main source of magnesium. In dry season, the concentration of magnesium becomes higher for the same reasons mentioned in the case of calcium.

The relationship between magnesium and EC is considered as linear with good correlation (R= 0.77), also it is linear between calcium and EC with acceptable correlation (R= 0.53). Useful mathematical relations (Eq. 4.8 and Eq. 4.9) can be used for the interpretation of calcium and magnesium through direct measurement of EC (Fig. 4.16).

Ca^{+2}(mg/L) = 0.08* EC (µS/cm) +16.8(R=0.53) -------------------------- (4.8)

Mg^{+2}(mg/L) = 0.05* EC (µS/cm)-7.1 (R=0.77) --------------------------- (4.9

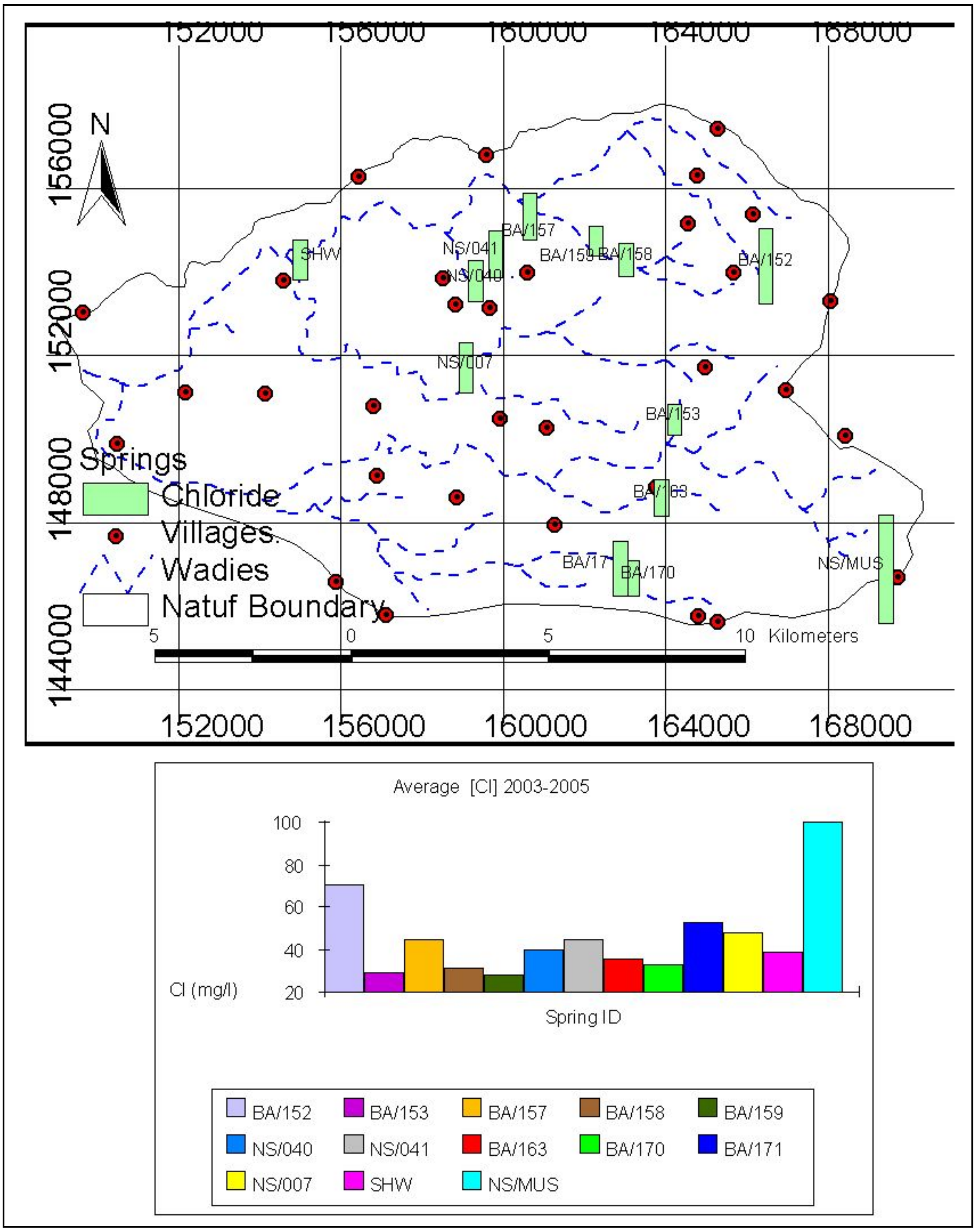

Figure 4.14: Spatial distribution of mean values of chloride in the Natuf drainage basin 2003-2005

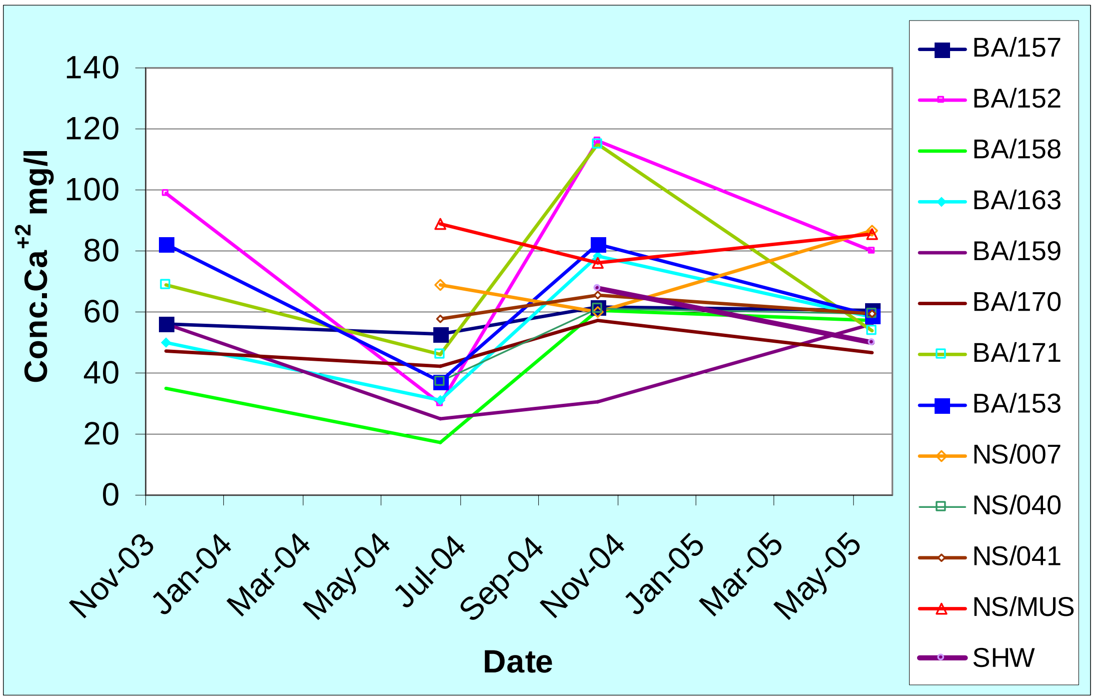

Figure 4.15: Variation of Ca^{+2} in springs in the Natuf drainage basin 2003-2005

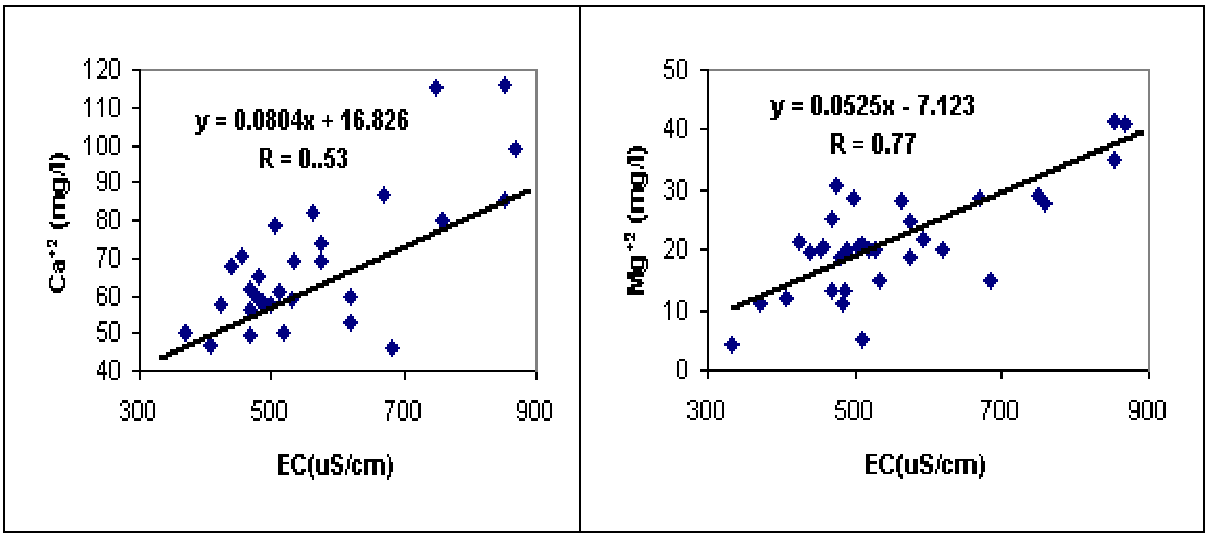

Figure 4.16: Relationship between Calcium, Magnesium and EC in Natuf water 2003-2005

-Bicarbonate (HCO_3^-)

Bicarbonate is associated usually with calcium and magnesium concentrations, it is the common anion in groundwater (Manahan, 1994). Most of bicarbonate in springs water comes from the reaction between carbon dioxide, which is dissolved in rainfall droplets and that accumulated in soil particles as a result of biological activities on organic matter, and rock minerals of limestone (Eq. 4.1 & Eq.4.2)

Concentrations of bicarbonate in groundwater is acceptable in the range of 500mg/L (Todd, 1980), more than this concentration increases alkaline bitter taste. The highest values of bicarbonate in the springs of study area were recorded during the dry seasons, which is referred to the longer residence time of water and hence more dissolution of limestone and dolomite minerals.

From statistical analysis (Appendix C), bicarbonate is highly correlated to TDI (R=0.091), Ca^{+2} (R= 0.86), Mg^{+2} (R= 0.82), Na^{+} (R= 0.74), Cl^{-} (R=0.82), EC (R= 0.81) and with TDS (R= 0.71). The good correlation between bicarbonate and each of EC and TDS (Fig.4.17), makes it easy for the onsite estimation of bicarbonate levels using the mathematical relations with EC and TDS (Eq. 4.10 & 4.11),

HCO_3^- = 0.3*EC (µS/cm) + 62.9 (R= 0.73) ------------------------------ (4.10)

HCO_3^- = 0.68*TDS (mg/L) + 19.7 (R= 0.74) --------------------------- (4.11)

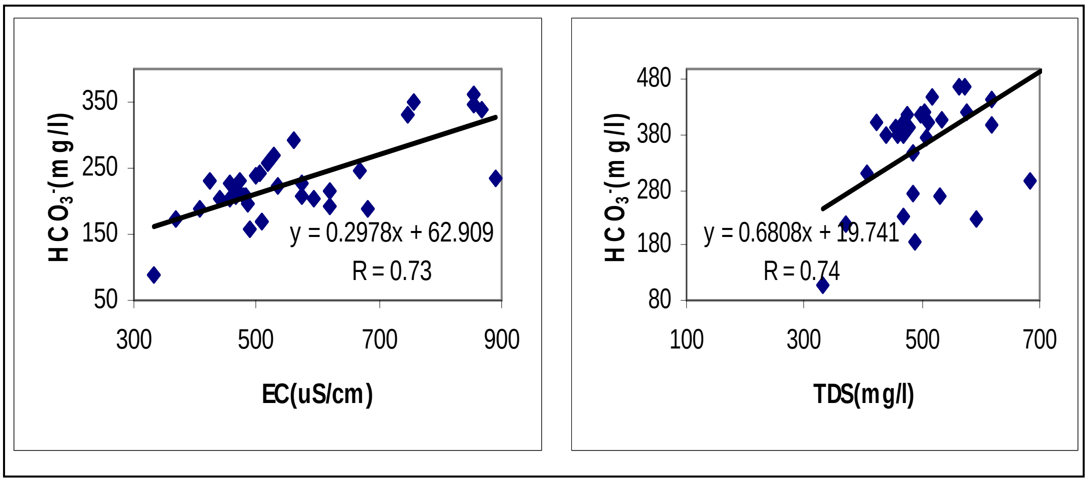

Figure 4.17: Relationship between bicarbonate and EC and TDS in Natuf water 2003-2005

-Sulfate SO_4^{-2}

Sulfate is a common ion in groundwater; it originates from dissolution of minerals of anhydrite and gypsum. Industrial disposals, fertilizers and decomposition of organic material are another source of sulfur enrichment to groundwater reservoirs (Ghanem, 1999).

Acceptable levels of sulfate in groundwater are up to 250mg/L (Todd, 1980), while EUC guide line level is up to 25mg/L (Price, 1996) (Table 4.2). Higher concentrations of sulfate in industrial water is objectionable, it causes with calcium and magnesium hard scales which prevents heat exchange in heaters (Todd, 1980). Sulfate is not recommended in high levels for irrigation water. The measured values of sulfate in water sample of the study area range between 16mg/ l in Ein Arik Al Fuqa and 39 mg/L in Ein Arik Al Tehta. The highest values were recorded during wet seasons, which are referred to washing out of sulfate from topsoil; this is also an indication on karstification system in the study area.

4.2.6 Trace Elements

Trace elements exist naturally in groundwater in concentrations below 0.05mg/L. The presence of trace elements in water limits its use for certain purposes. Heavy metals such as cadmium, lead, copper, zinc, chromium, cobalt and iron are toxic for living organisms as well as humans if they exceed allowable concentration (Table 4.3). Contamination of groundwater by irrigation water and runoff over urban areas may increase the concentrations of trace elements due to the use of galvanized iron, copper and brass in plumbing fixtures and water storage tanks. The acceptable levels for irrigation are 0.2 mg/L for Cu^{+2}, and 2.0 mg/L for Zn^{+2}.

The levels of trace elements found in springs of the study area (Appendix F), are within the Palestinian drinking water standard 41/2005 (Palestinian Standards

Institute, 2005). The highest value (27.5µg/l) of Pb^{+2} was recorded in Ein Ayoub in dry season of 2004, and decreases to 16ug/l in the wet season of 2005 because of dilution process. The recharge area of Ein Ayoub contains old vehicle dumping sites where used galvanic batteries are disposed. Zinc content shows variations between 1 µg/l at Ein Arik El Tehta in wet season of 2005 to 142 µg/l at Al Alaq in dry season of 2004. Other springs contain values of zinc within this range and show dilution effect between dry and wet seasons. The contamination with zinc is referred to vehicles and to runoff from urban areas (Zimmermann, 2005). Iron content varies between 0 to 45µg/l at Al Quos spring. Higher levels of trace elements found in Natuf springs, were recorded in wet seasons, which indicates contamination from runoff through karstified rocks in the study area. Analysis of runoff water from BZU and Natuf Wadi show that it contains considerable amounts of trace elements, which reveals the risk of runoff as a pollution source (Appendix E).

4.2.7 Runoff Analysis

Runoff generated after successive rainfall in the hilly and urban areas of the Natuf drainage basin, may last for two to three days, and may cause floods in wadis after heavy storms. Quantity and quality of runoff water is affected by many factors, including precipitation quality and quantity, duration of storm, slope and land use. Water quality and water type of groundwater recharged by runoff is greatly affected by quantity and quality of runoff

The Chemical analysis of the runoff was interpreted from historical hydrochemistry data that was collected by PHG (2001) and showed that it is rich in major cations, anions and heavy metals from streets, surfaces and industrial zones and there is a possible leakage of cesspits and sewer systems

Table 4.3: Allowable Trace Elements Concentrations in Drinking Water
(Modified after Freeze, 1979)

No.	Constituent	Recommended Concentration limit (mg/L)
1-	Iron (Fe)	0.3
2-	Manganese (Mn)	0.05
3-	Copper (Cu)	1.0
4-	Zinc (Zn)	5.0
5-	Boron (B)	1.0
6-	Arsenic (As)	0.05
7-	Cadmium (Cd)	0.01
8-	Chromium (Cr)	0.05
9-	Selenium	0.01
10-	Antimony (Sb)	0.01
11-	Lead (Pb)	0.05
12-	Mercury (Hg)	0.002

Figures 4.18 and 4.19 show the chemical analysis of runoff water at two points, Ramallah city and Ein Arik Bridge. The analysis shows that the chemical content of major cations and anions in runoff water in Ramallah city (Fig. 4.18) (Appendix E) is moderately low compared to the chemical content in spring's water. This is referred to the short residence time of rainfall water and to the nature of surfaces that runoff passes by inside Ramallah city. The situation is quite different at Ein Arik Bridge, where runoff water originates from hilly areas and has longer residence time. Concentration of nitrate, sulfate and chloride were high at the beginning of runoff and declines with time (Fig. 4.19), which means that contamination from cesspits,

agricultural activities and industrial wastes are the sources of pollution in the area, and contamination with these ions starts at source and diluted with rainfall water. Chemical analysis of runoff water collected near BZU and at the mouth of Wadi Natuf, near Shibteen, show that chemical content of the major cations and anions is higher in near Shibteen than that near BZU which is referred to the residence time of runoff water and the land use in the area as illustrated by Schoeller diagram (Fig.4.20). Water type of runoff from BZU and Natuf Wadi, according to Langguth water type classification; indicate that both waters are of earth alkaline, with prevailing bicarbonate (Fig.4.21).

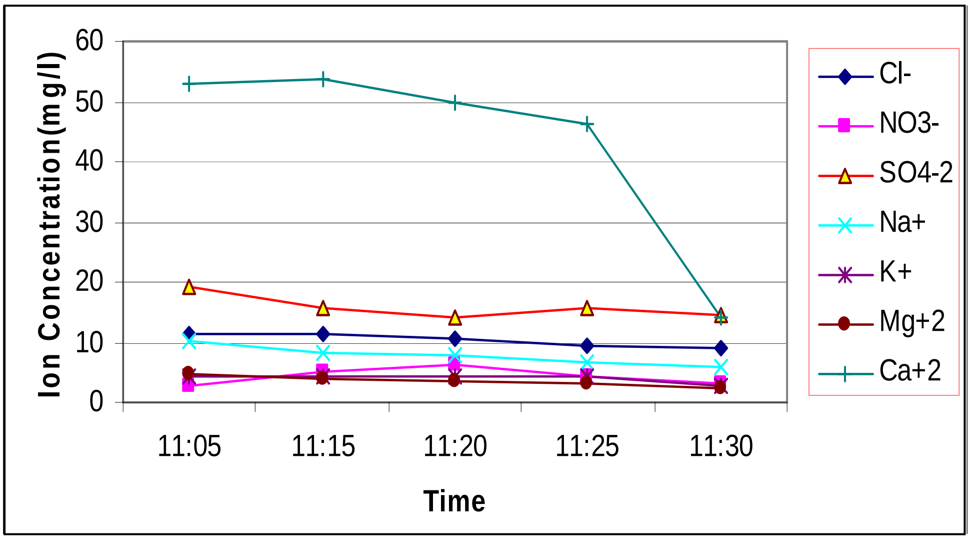

Figure 4.18: Variation of Runoff chemical analysis inside Ramallah city (2001) (PHG, 2004)

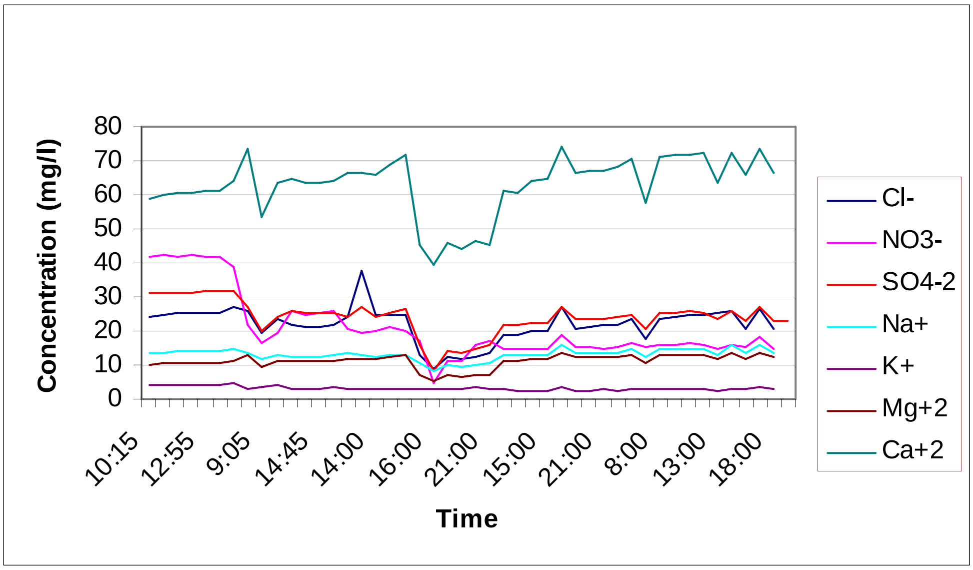

Figure 4.19: Variation of Runoff chemical analysis at Ein Arik Bridge

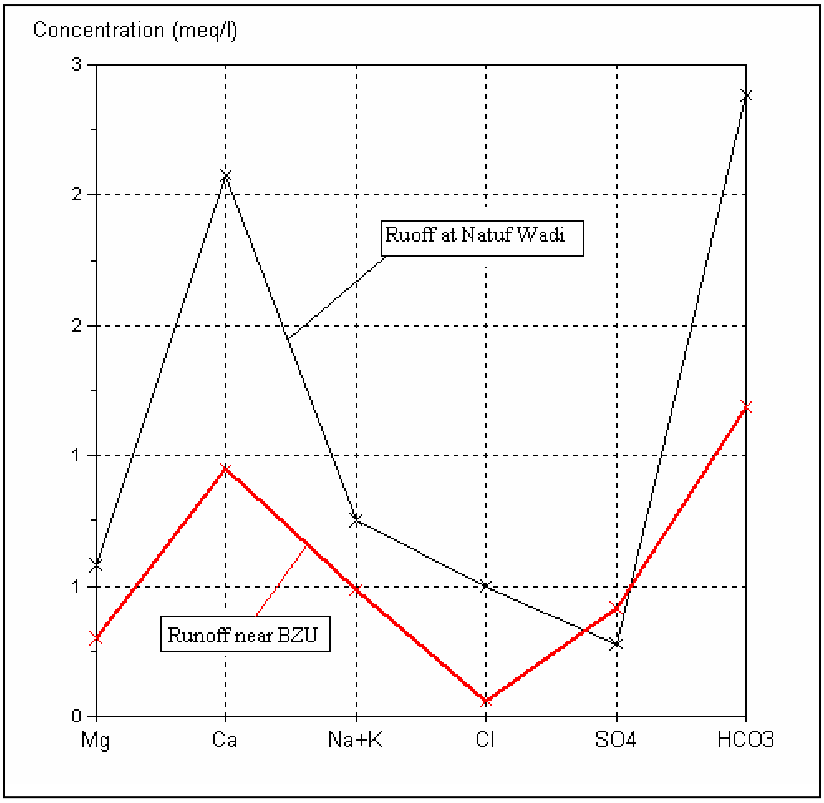

Figure 4.20: Schoeller Diagram for Runoff in Natuf Wadi and near BZU 2005

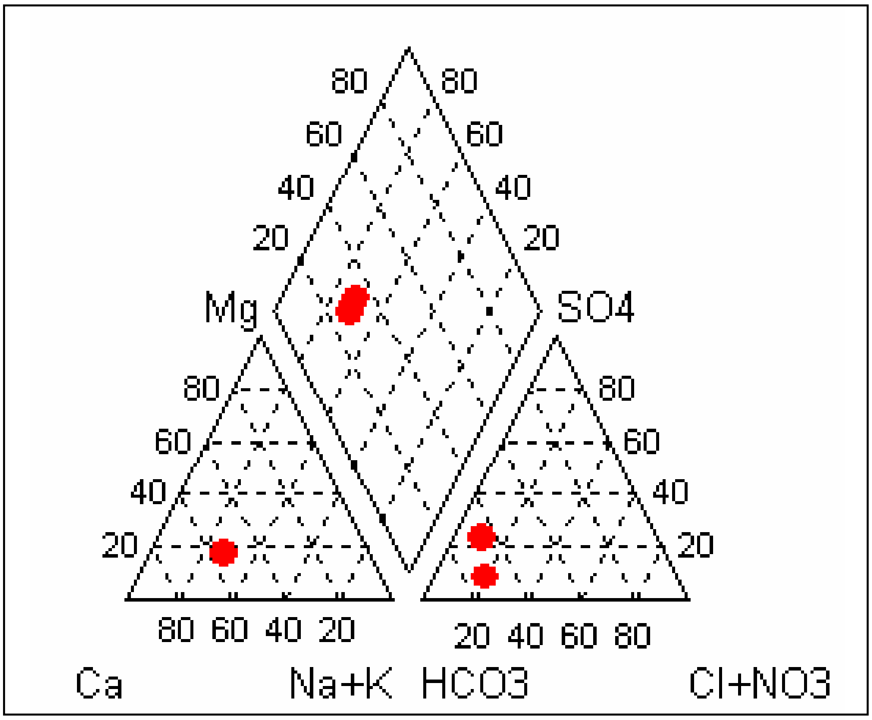

Figure 4.21: Piper diagram of runoff water at BZU and Wadi Natuf/ Shibteen

4.3 Water Genesis

Most of the springs in the Natuf drainage basin have a water type of earth alkaline with prevailing bicarbonate. In the wet seasons, the water types are more likely earth alkaline with prevailing bicarbonate and an increase in alkalis such as sodium and an increase in chloride.

The water genesis of the springs is affected by water- rock interaction, mixing with wastewater and agricultural effluents (Abed Rabbo, et.al, 1999).

4.3.1 Saturation Indices (SI)

Precipitation, dissolution and equilibrium of certain minerals are three processes accompanied with equilibrium between water and minerals.. Precipitation occurs if minerals are saturated in water solution, dissolution occurs if minerals are undersaturation. SI is an indication on the three processes. It is calculated according to Equation 4.12 (Freeze, 1979):

$$SI= Log\ (\frac{K_{IAP}}{K_{sp}}) \text{ --------------------------- } (4.12)$$

Where, IAP is the Ion Activity Product, which is dependent on the ionic strength of the ions encountered in the solution. The ionic strength U is calculated according to equation 4.13:

$$\mu= \frac{1}{2} \sum C_i Z_i^2 \text{ ---------------------- } (4.13)$$

Where C_i is the molar concentration and Zi is the charge of the ion (Sawyer, 1994). The ion activity is calculated from the ionic strength according to Debye- Hückel equation 4.14:

$$Log\ \gamma = -0.5\ Z^2 \frac{\sqrt{\mu}}{1+\sqrt{\mu}} \text{ --------------------- } (4.14)$$

Where γ is the ion activity coefficient, Z is the charge of the ion and μ is the ionic strength calculated in equation 4.13.

K_{sp} is the solubility product of the mineral. The water solution is considered to be in equilibrium when SI = 0. It is considered to be saturated if the SI >0 and hence the mineral tends to precipitate and if SI<0, the water is undersaturation with respect to the mineral which tends to dissolution.

Average values of SI for Anhydrite ($CaSO_4$), Aragonite ($CaCO_3$), Calcite ($CaCO_3$), Dolomite ($CaMg\ (CO_3)_2$) and Gypsum ($CaSO_4.2H_2O$) (Table 4.4), were calculated for 35 samples using PHREEQ C under Aquachem software. Mineral phases encountered in the thermodynamic calculations of saturation indices are listed in table 4.5.

The results show that SI<0 for Anhydrite and Gypsum in all samples, which means that water is under-saturation with respect to Anhydrite and Gypsum. SI for Aragonite ranges between -0.71 to 0.9 with 40.4% of the samples have SI>0 which means over saturation and Aragonite is precipitated, 8.5% of the samples have SI =0 which means that water is in equilibrium in these samples with respect to Aragonite and 51.01% of the samples have SI<0 which means under saturation with respect of Aragonite. SI for Calcite ranges between -0.6 - 1.1 with 57.44% of the sample have SI>0, which means over saturation and precipitation of Calcite, 12.76% of the samples have SI=0 which means equilibrium and 29.79% of the samples have SI<0 which means und saturation with respect to Calcite. For dolomite, SI ranges between -2.2 to 1.9 and 51.1% of the sample have SI>0, which means over saturation and precipitation process for Dolomite, 10.6% of the samples have SI=0 which means equilibrium conditions and 38.3% of the samples have SI<0 which means under saturation with respect to Dolomite.

4.3.2 Water genesis in the springs of the Natuf drainage basin

4.2.2.1 Al Alaq (BA/152) and Harrashah (BA/153)

These two springs are located in the eastern part of the Natuf drainage basin, in Abu Shekhedem and Al Mazr'a Al Quibliya. The geological formation of these two springs is Qatana formation, which is formed mainly from layers of limestone and sandstone.

Waters from those springs exhibits undersaturation with respect to anhydrite, aragonite and gypsum. Water in Al Alaq spring is undersaturated with respect to calcite and dolomite, while Harrashah is saturated with respect to those two minerals.

A plot of Al Alaq spring and Harrashah, in Durov diagram, shows that these springs are along the line of mixing and in the field where calcium and bicarbonate are dominant, which indicates that water type of those two springs recharges in limestone and sandstone. A little shift is observed in wet season in Al Alaq spring which indicates possible mixing with wastewater (Fig. 4.22)

Table 4.4 : Average values of Saturation Indices for Natuf drainage basin 2003-2005

Spring _ ID	Anhydrite	Aragonite	Calcite	Dolomite	Gypsum
BA/152	-2.4	-0.72	-0.05	-0.08	**-2.16**
BA/157	-2.58	0.09	0.24	0.36	**-2.34**
BA/158	-2.44	0.4	0.55	1.1	**-2.20**
BA/159	-2.73	-0.25	-0.11	-0.02	**-2.5**
BA/163	-1.78	-0.14	-0.01	-0.26	**-2.21**
BA/170	-2.63	0.26	0.41	0.67	**-2.39**
BA/171	-2.38	-0.55	-0.4	-1.06	**-2.14**
BA153	-2.5	-0.03	0.12	0.14	**-2.3**
NS/007	-2.42	-0.28	-0.13	-0.41	**-2.22**
NS/040	-2.35	-0.03	0.12	0.06	**-2.12**
NS/041	-2.44	0.03	0.17	0.07	**-2.22**
NS/MUS	-2.28	0.37	0.52	0.92	**-2.04**
SHW	**-2.65**	**0.58**	**73**	**1.24**	**-2.43**

. 4.3.2.2 Ein Arik Al Fuqa (BA/170) and Ein Arik Al Tehta (BA/171)

The two springs are located near Ein Arik village and they emerge from lower lower Beit Kail (LLBK). This formation is characterized by marine limestone, dolomite and with the karstic formations. Waters from these two springs is undersaturation with respect to anhydrite and gypsum. Ein Arik Al Tehta shows undersaturation of the carbonate mineral phases (aragonite, calcite and dolomite); while Ein Arik Al Fuqa shows oversaturations of these carbonate phases.

Table 4.5: Mineral Phases in the thermodynamic calculations of saturation indices (Modified after: Abed Rabbo, et.al. 1999)

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

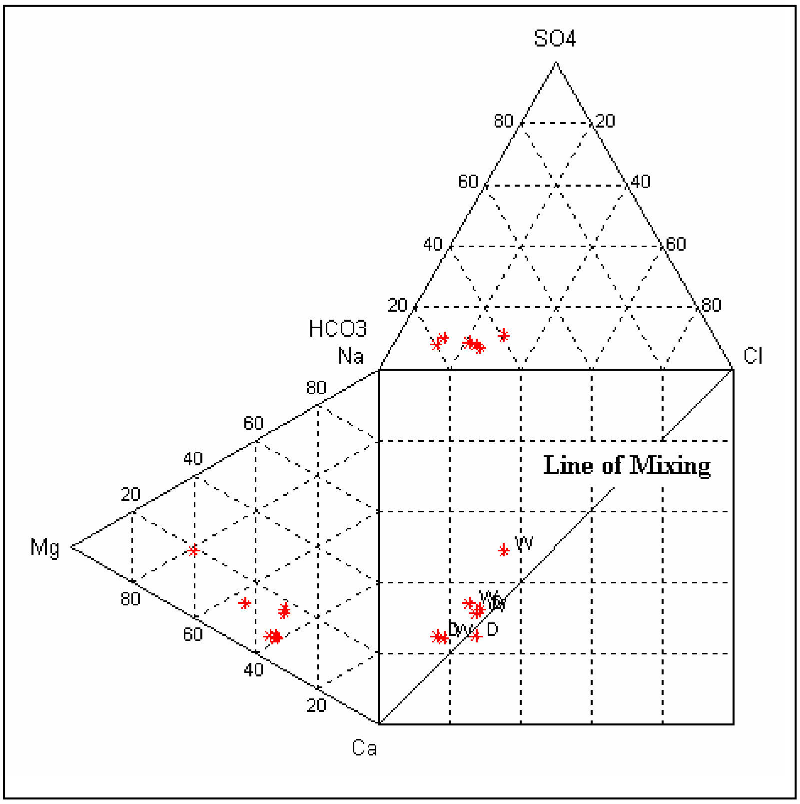

Figure 4. 22: Durov plot of Al Alaq and Harrashah springs 2003-2005

In Durov diagram (Fig. 4.23), the two springs plot along the line of mixing in dry season (D), a little deviation from the line of mixing is observed in the wet season (W) in Ein Arik Al Tehta. Both springs lie in the area where calcium and bicarbonate are dominant, which reveals that they outcrop from the recharge area of limestone and sandstone. In the wet season, the deviation is mainly from mixing with wastewater.

4.3.2.3 Ein Musbah (NS/MUS), Al Quos (BA/159) and Akari (BA/157)

The lithological formation of these springs is from lower Beit Kahil and upper Beit Kahil. This lithological formation is characterized by sugary dolomite and dolomitic limestone, marl and chert, and a karstic nature.

Water from these springs show undersaturation with respect to anhydrite and gypsum. The carbonate mineral phases (aragonite, calcite and dolomite) are oversaturated in these springs.

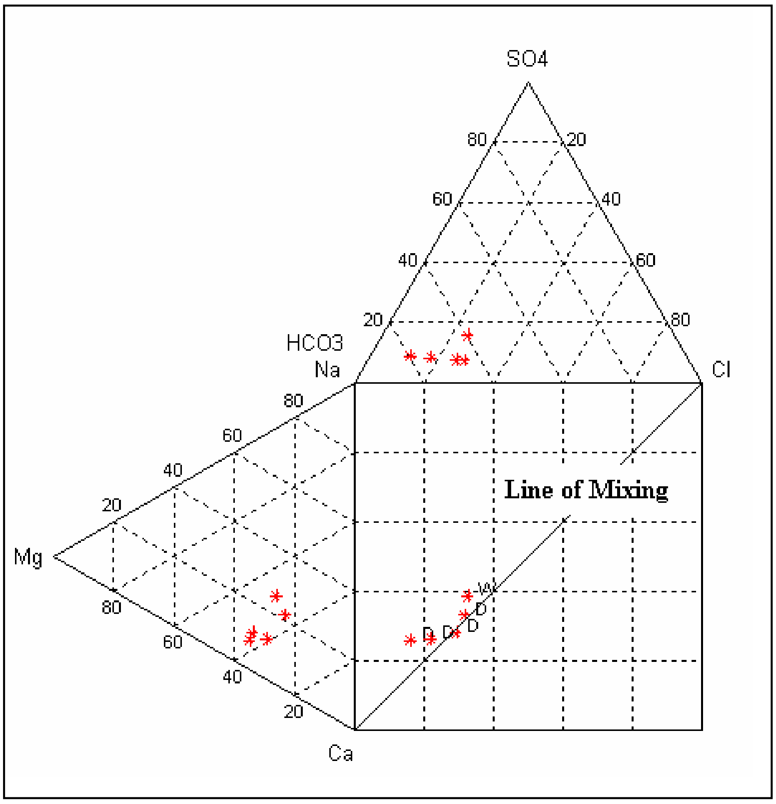

Figure 4. 23: Durov plot of Ein Arik Tehta and Al Fuqa springs 2003-2005

The three springs plot along the line of mixing in Durov diagram (fig.4.24), they lie in the region where calcium and bicarbonate are dominant, with a shift to more magnesium in Ein Musbah and Al Quos, which reveals that the springs outcrop from the recharge area of dolomite and dolomitic limestone.

4.3.2.4 Beitillu Al Balad (BA/158), Al Tina (NS/040) and Al Shakhariq (NS/041)

The lithological formation from which these three springs is lower Yatta is characterized by limestone and clay. Waters from the three springs are undersaturation with respect to anhydrite and gypsum. Waters from Beitillu Al Balad and Al Shakhariq show oversaturation with respect to carbonate mineral phases (aragonite, calcite and dolomite), while Al Tina shows undersaturation with respect to aragonite.

The three springs lie along the line of mixing and are the region where calcium and bicarbonate are dominant with a little shift towards magnesium region which reveals that they outcrop from the recharge area of limestone and dolomitic limestone.

4.3.2.5 Ein Ayoub (NS/007) and Shibteen well

These two sites are located in the western part of the Natuf drainage basin. The lithological formation in Ein Ayoub and Shibteen well is considered as Hebron formation which is characterized by lime stone and karstic nature. Water from these sites shows undersaturation with respect to anhydrite and gypsum.

Oversaturation is observed in these sites with respect to carbonate mineral phases (aragonite, calcite and dolomite). Both sites plot along the line mixing in Durov diagram (Fig. 4.26) and are in the region where calcium and bicarbonate are dominant, Ein Ayoub shifts in the wet season towards magnesium region, which reveals mixing with runoff.

4.4 Statistical Analysis

The mean values and the standard deviation of major ion concentrations, pH, calculated P_{CO2} for the 12 springs and Shibteen dug well, over the study period from Oct. 2003- May 2005, are listed in (Appendix C). The results show that HCO_3^- is the dominant anion in all springs and ranges between 174 to 321 mg/L and Cl^- is the second abundant anion which ranges between 29.5-97.5mg/L. NO_3^- is the third abundant anion while, SO_4^{-2} concentrations are moderate compared to the dominant anions. The sequence of anions concentration is $HCO3^- > Cl^- > NO_3^- > SO_4^{-2}$.

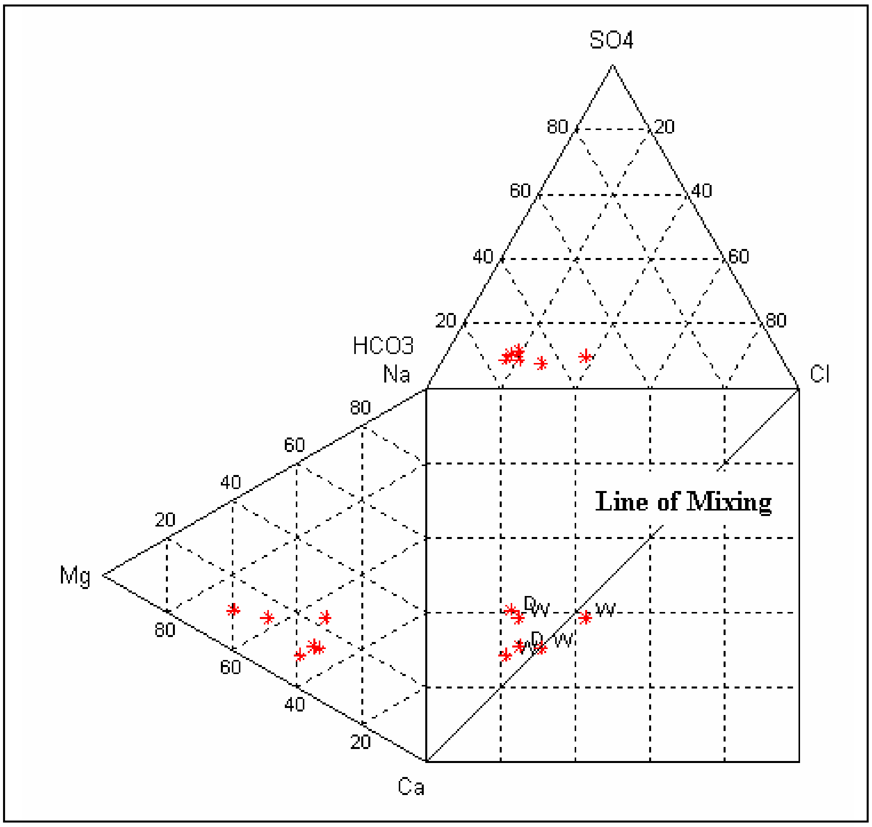

Figure 4. 24: Durov plot of Ein Musbah, Al Quos and Akari springs 2003-2005

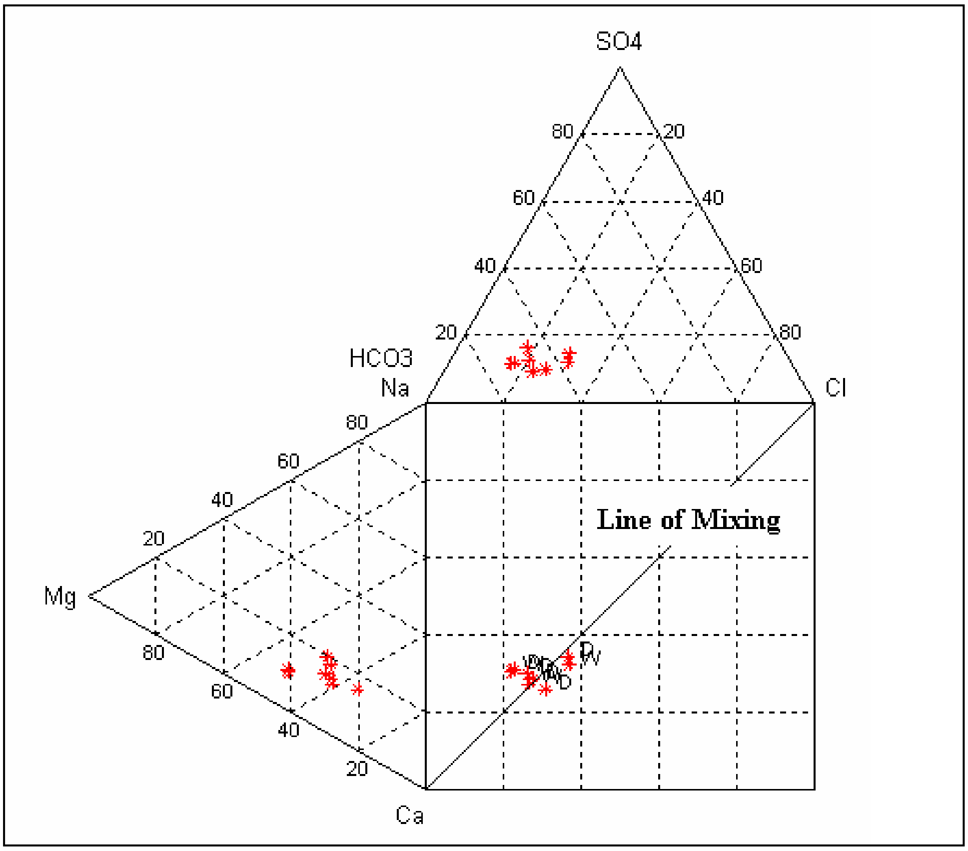

Figure 4. 25: Durov plot of Beitillu Al Balad, Al Tina and Al Shakhariq 2003-2005

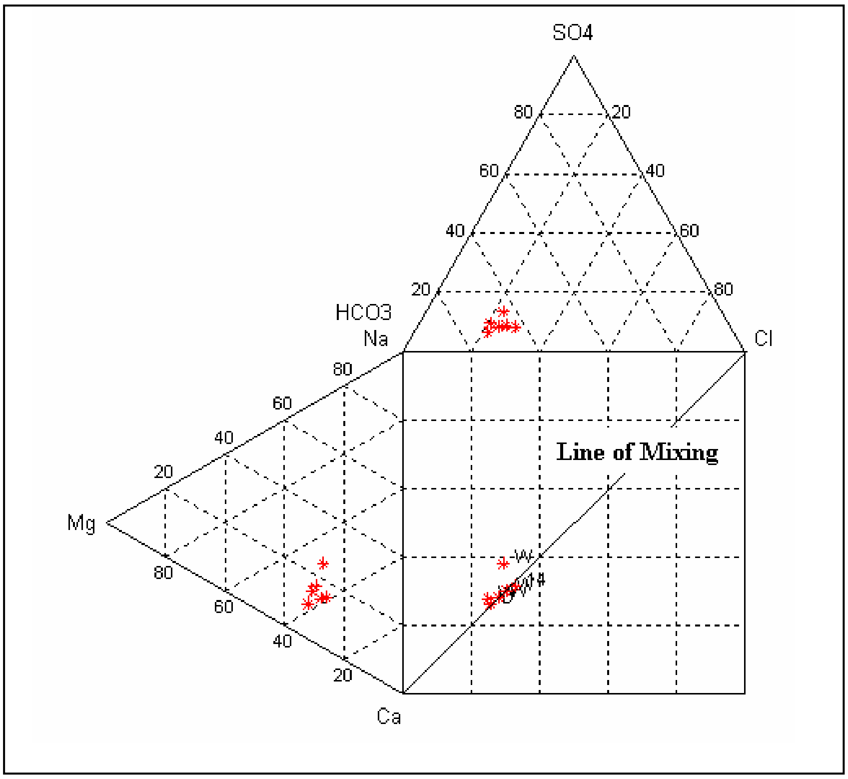

Figure 4. 26: Durov plot of Shibteen well and Ein Ayoub 2003-2005

Calcium is the most abundant cation in springs of the study area. It shows a range between 30-116mg/L. The recorded values of calcium show an increase in dry seasons, which is referred to the longer residence time of water and hence more dissolution of limestone minerals. Magnesium comes in the second place after calcium; also it increases in the dry seasons. Sodium and potassium concentrations show increase in wet seasons, which indicates that these ions are from anthropogenic sources. The sequence of cations in the study area is $Ca^{+2} > Mg^{+2} > Na^{+} > K^{+}$.

Except one measurement in dry season 2003 for Akari spring, this spring had Na^{+}/Cl^{-} ratio of 1.8, which can be explained as shock load. In all other samples, Na^{+}/Cl^{-} ranges between 0.3-0.8, since sodium and chloride are not naturally present in the surrounding areas, the local high levels of sodium and chloride have to be related to contamination processes (Helena, 1998), The high concentrations of sodium and chloride found in Al Alaq, Ein Ayoub and Ein Musbah reveal the hypothesis of wastewater intrusion from sewer systems or cesspits.

The calculated values of P_{CO2} are higher than the atmospheric P_{CO2} ($10^{-3..5}$ bar), which indicates that spring's water is influenced by CO_2 that is accumulated in soil particles as a result of the metabolism of organic matter in the top soil and infiltrated with water to the groundwater.

Pearson's 2-tailed bivariate (ρ =0.01), correlation analysis was performed using SPSS version 11.5, between all parameters (Appendix D). Based on the correlation coefficient value (R), the interrelationships between hydrochemical parameters can be classified from poor ($R < 0.7$) to very high significance ($R > 0.9$) (Abed Rabbo, 1999).

4.5 Graphical Representation of Hydrochemical Data

The chemical composition of the spring's water is affected by rainfall chemistry, climate, rock type, rock division, human activities and residence time of water (Cruze, 2004). The hydrochemical characteristics and water types of spring's water based on the percentages of anions and cations are illustrated by Piper trilinear diagram (Fetter, 1991) (Fig. 4.22). Similar waters are clustered in clearly defined areas, indicating water-mixing phenomena, precipitation and dissolution (Helena, 1998).

Analysis of major cations and anions, for water types, by Aquachem software for all samples during the study period 2003-2005, show that 41% of the samples have a water type of Ca-Mg- HCO3, which means interaction of the spring's water with dolomitic limestone. 4% of the samples show water type of Mg-Ca– HCO3 nature which indicates interaction with dolomite rocks. During the dry season of 2004, 14% of the samples show water type of Ca-Mg- HCO3-Cl, and 14% of Ca- Mg-Na- HCO3 water type, which indicates the effect of chloride and sodium introduced from fertilizers and pesticides in the water type of the springs (Table 4.6).

Based on Langguth classification for water types (Fig. 4.27), there are no obvious changes in the chemical composition of spring's water, during the study period 2003-2005, at Harrashah, Akari, Ein Arik Al Fuqa, Beitillu Al Balad, Al Shakhariq and Al Quos springs, and the water type remains as normal earth alkaline before and after recharge (Fig. 4.28 & Fig. 29). The chemical composition also remains as earth alkaline with prevailing bicarbonate and sulfate or chloride for Al Alaq and Al Tina springs. Other springs shows different variations in chemical composition before and after recharge, Ein Ayoub and Arik El Tehta shows an increase in alkali (Na^+) with prevailing bicarbonate and chloride after recharge, which indicates human activities contribution in pollution. Ein Musbah shows an increase in chloride concentrations which indicates leakage of wastewater from nearby sewerage system (Table 4.7).

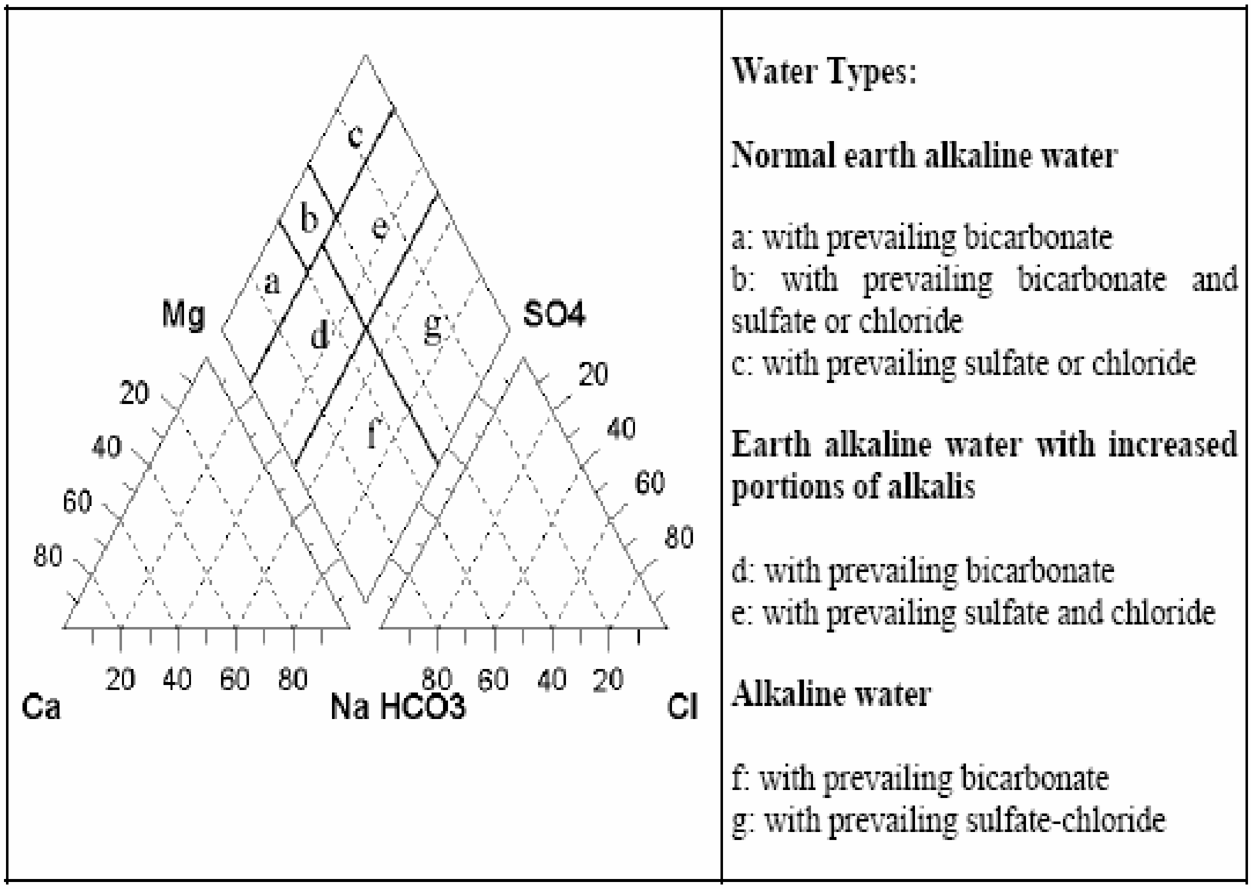

Figure 4.27: Classification of water types (Langguth, 1966)

The water type of Natuf springs from 1999-2002, according to Piper diagrams (Fig. 4.30), are classified as earth alkaline with prevailing bicarbonate, except Ein Arik Al-Tehta which shows an in increase in alkali metals.

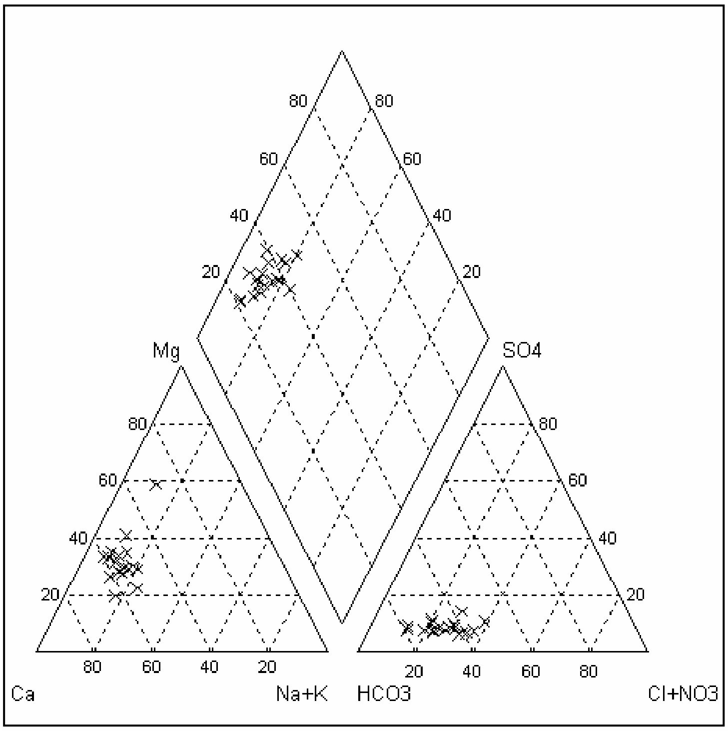

Figure 4.28: Piper diagram of major cations and anions in Natuf springs During dry seasons of 2003-2005

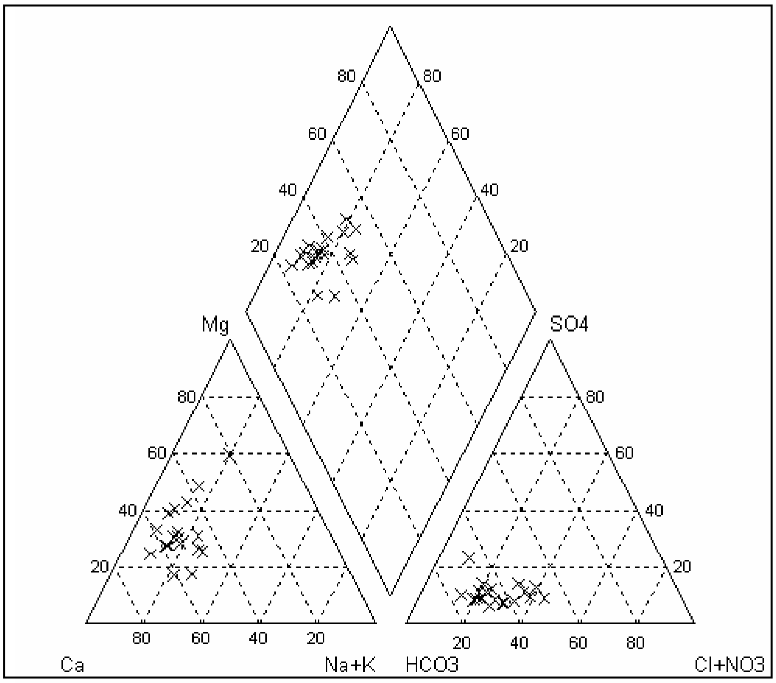

Figure 4.29: Piper diagram of major cations and anions in Natuf springs During wet seasons of 2003-2005

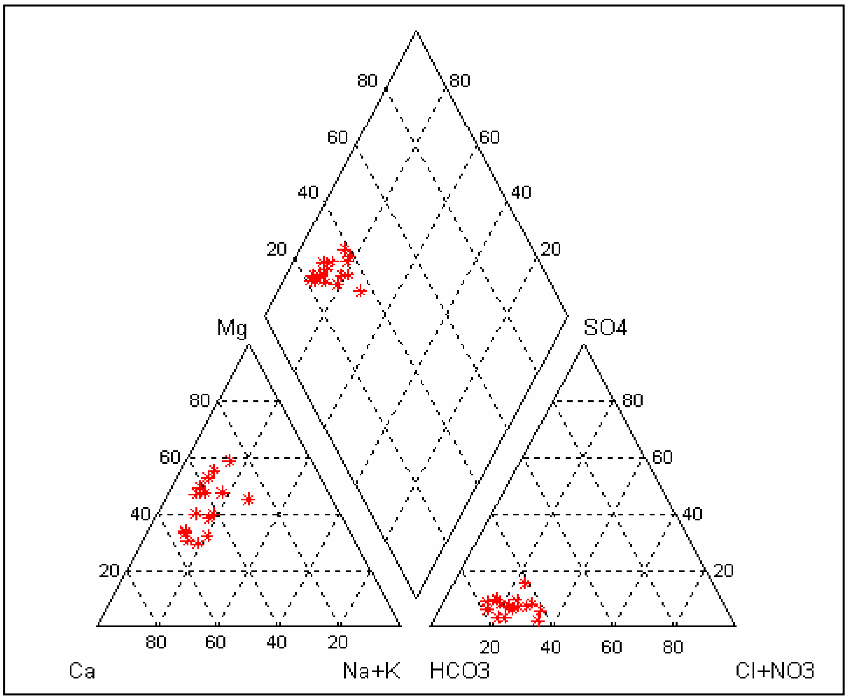

Figure 4.30: Piper diagram for hydrochemical parameters of Natuf springs 1999-200 (PHG, 2004)

4.6 Ion Distribution and Chemical Composition

The total dissolved Ions (TDI) for the major ions in the springs of Natuf drainage basin was calculated to be 211meq/l in the dry season of 2004 and 192meq/l for the wet season of 2005, which reveals the dilution process that occur during recharge time. The higher content of TDI during dry season confirms the effect of contact time of water with minerals and hence more dissolution of the minerals.

Water quality parameters and pollution rates are also affected by dry and wet seasons as well as the effect caused by the human activities and agricultural processes. As indicated by Schoeller diagrams (Fig. 4.31), the concentrations of major cations and anions measured in dry seasons are higher than those in the wet season, which can be explained by the longer residence time of water and lowering the water table in the in the dry season. In the wet seasons, the dilution process due to the infiltrated rainfall is the main cause of lowering the concentrations of major cations and anions.

Table 4.6: Water type in Natuf springs 2003-2005

No.	Spring	Season	Date	Water type
1	AKARI	Wet	6/13/2004	Ca-Mg-HCO3-Cl
2	AKARI	Dry	11/21/2004	Ca-Mg-HCO3-Cl
3	AL BALAD/ BEITILLU	Dry	11/21/2004	Ca-Mg-HCO3
4	AL BALAD/ BEITILLU	Wet	1/5/2005	Ca-Mg-HCO3
5	AL 'ALAQ	Dry	11/5/2003	Ca-Mg-HCO3-Cl
6	AL 'ALAQ	Dry	10/19/2004	Ca-Mg-HCO3-Cl
7	AL 'ALAQ	Wet	6/13/2004	Ca-Mg-HCO3-Cl
8	AL 'ALAQ	Wet	4/24/2005	Ca-Mg-HCO3-Cl
9	ALQUOS(D)	Dry	11/21/2004	Ca-Mg-HCO3
10	ALQUOS	Wet	6/13/2004	Ca-Mg-HCO3
11	ALQUOS	Wet	1/5/2005	Ca-Mg-HCO3
12	ALSHAKHARIQ	Dry	11/2/2003	Ca-Mg-HCO3
13	ALSHAKHARIQ	Dry	11/21/2004	Ca-Mg-Na-HCO3-Cl
14	ALSHAKHARIQ	Wet	1/5/2005	Ca-Mg-HCO3
15	ALTINA	Dry	11/2/2003	Ca-Mg-HCO3
16	ALTINA	Dry	11/21/2004	Ca-Mg-Na-HCO3-Cl
17	ALTINA	Wet	1/5/2005	Ca-Mg-HCO3-Cl
18	ARIK AL FUQA	Dry	11/1/2003	Ca-Mg-HCO3
19	ARIK AL FUQA	Dry	10/19/2004	Ca-Mg-HCO3-Cl
20	ARIK AL TEHTA	Dry	11/2/2003	Ca-Mg-HCO3
21	ARIK AL TEHTA	Wet	6/13/2004	Ca-Mg-Na-HCO3-Cl
22	ARIK AL TEHTA	Dry	10/19/2004	Ca-Mg-Na-HCO3-Cl
23	EIN AYOUB	Dry	11/1/2003	Ca-Mg-HCO3
24	EIN AYOUB	Wet	6/13/2004	Ca-Mg-Na-HCO3
25	EIN AYOUB	Dry	11/21/2004	Ca-Mg-HCO3-Cl
26	EIN AYOUB	Wet	1/5/200 5	Ca-Mg-HCO3-Cl
27	EIN MUSBAH	Wet	4/24/2005	Ca-Mg-Na-HCO3-Cl
28	HARRASHEH)	Dry	10/19/2004	Ca-Mg-HCO3
29	HARRASHEH	Wet	6/13/2004	Ca-Mg- HCO3-Cl
30	HARRASHEH	Wet	4/24/2005	Ca-Mg-HCO3
31	AL BALAD EIN QINIA	Dry	11/1/2003	Ca-Mg-HCO3
32	AL BALAD EIN QINIA	Dry	11/3/2004	Ca-Mg-HCO3
33	AL BALAD EIN QINIA	Wet	4/24/2005	Ca-Mg-HCO3
34	ALFAWARAH SHIBTEEN	Wet	1/20/2005	Ca-Mg-HCO3
35	SHIBTEEN WELL	Wet	1/20/2005	Ca-Mg-HCO3
36	SHIBTEEN WELL	Wet	4/24/2005	Ca-Mg-HCO3-Cl
37	RUNOFF AT BZU	Wet	2/6/2005	Ca-Na-HCO3-SO4
38	RUNOFF WADI NATUF	Wet	6/2/2005	Ca-HCO3

Nitrates and chloride concentrations increase in wet seasons more than dry seasons, which indicates the possibility of pollution by runoff over agricultural and urban areas.

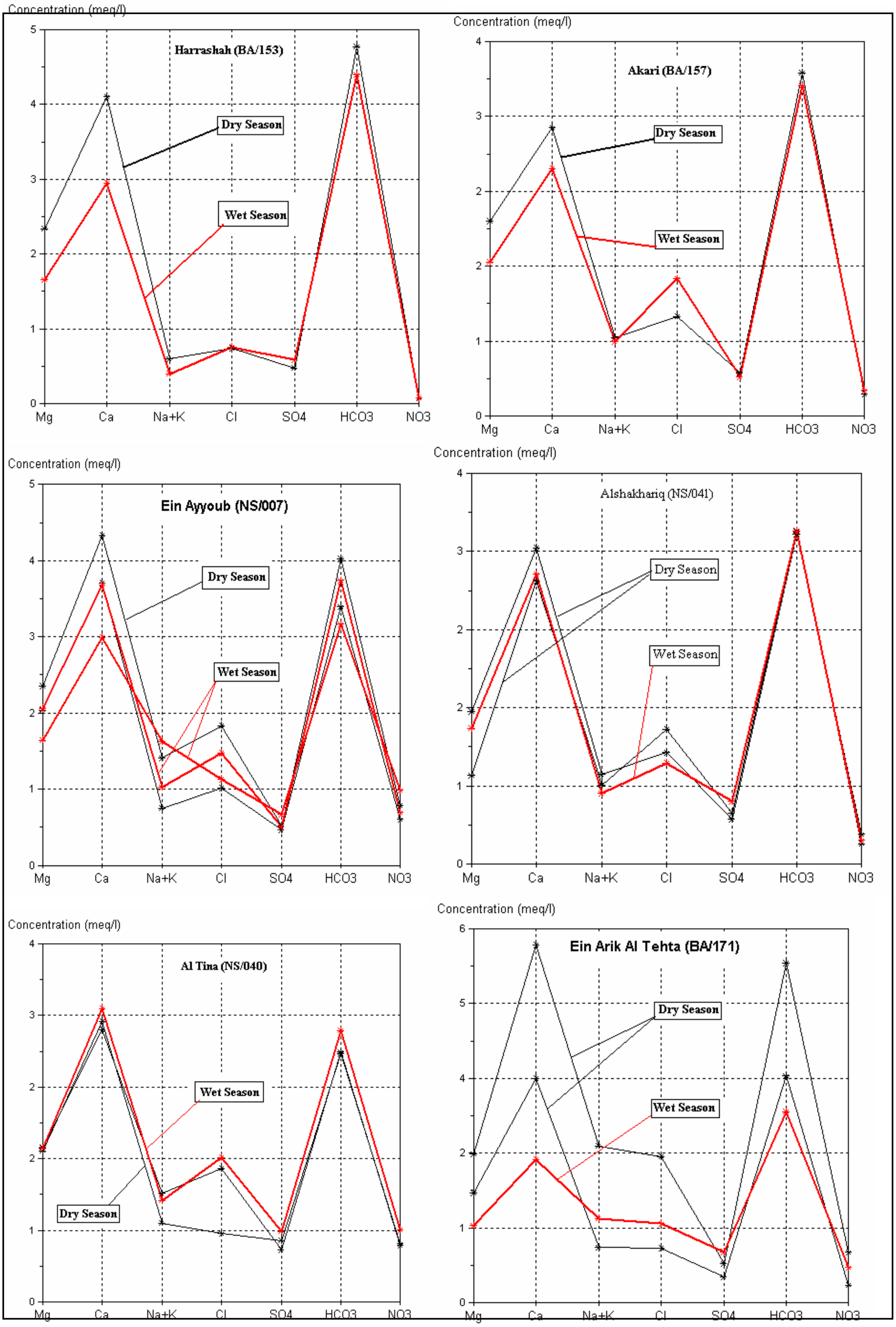

Figure 4.31: Schoeller Diagrams for some springs in Natuf Area 2003-2005

4.7 Water Quality Parameters

4.7.1 Salinity

Springs in Natuf drainage basin are used mainly for irrigation purposes in localities where many market vegetables such as lettuce, cabbages, bell pepper, beans, parsley and zucchini in addition to many other fruits such as citrus. Many of these crops are sensitive to high water salinity (Todd, 1980). According to the classification in table 4.6, only Ein Musbah spring located in Ramallah city is considered as high saline and can not be used for unrestricted irrigation in crops sensitive to this parameter. Other springs in the area are of medium salinity and can be used for irrigation purposes in crops of suitable choice. Classification of Natuf springs according to salinity during the study period 2003-2005 is listed in table 4.8. Graphical representation of EC- SAR is illustrated by Wilcox diagram (Fig.4.32).

Table 4.7: Grouping of irrigation water based on EC and TDS (Richard, 1954)

TDS (mg/L)	EC µS/cm	Water Class	Remarks
<200	<250	C1	Low salinity hazard: can be used for irrigation With most crops on most soils
200-500	250-750	C2	Medium salinity hazard: can be used to irrigate plants with moderate salt tolerance if moderate amounts of leaching occur.
500-1500	750-2250	C3	High salinity hazard: can not be used on soils with restricted drainage. Can be used to irrigate plants with high salt tolerance.
1500-300	2250-5000	C4	Very high salinity hazard: not suitable for irrigation under ordinary conditions. It can be used for irrigation occasionally under very special circumstances.

Table 4.8: Classification of water salinity in Natuf springs 2003-2005, based on EC

Spring Code	Spring Name	Date	EC µS/cm	TDS mg/L	Water Class & Remarks	
BA/157	'Akari	11/21/2004	619	397	C2: Medium salinity water	
BA/157	'Akari	6/13/2004	467	234	C2: Medium salinity water)	
BA/152	**Al 'Alaq**	**11/5/2003**	**867**	**444.3**	**C3: High salinity water**	
BA/152	**Al 'Alaq**	**6/13/2004**	**891**	**509.7**	**C3: High salinity water**	
BA/152	**Al 'Alaq**	**10/19/2004**	**853**	**429**	**C3: High salinity water**	
BA/152	**Al 'Alaq**	**4/3/2005**	**757**	**377**	**C3: High salinity water**	
BA/158	Al Balad	11/21/2004	474	236	C2: Medium salinity water	
BA/158	Al Balad	5/1/2005	498	248	C2: Medium salinity water	
BA/163	Al Balad	11/1/2003	518	269.8	C2: Medium salinity water	
BA/163	Al Balad	11/3/2004	505	254	C2: Medium salinity water	
BA/163	Al Balad	4/24/2005	485	242	C2: Medium salinity water	
BA/159	Al Quos	6/13/2004	488	187.5	C2: Medium salinity water	
BA/159	Al Quos	11/21/2004	458	229	C2: Medium salinity water	
BA/160	Al Quos	4/24/2005	467	233	C2: Medium salinity water	
BA170	'Arik Al Fuqa	11/1/2003	406	310	C2: Medium salinity water	
BA170	'Arik Al Fuqa	10/19/2004	423	204	C2: Medium salinity water	
BA/171	'Arik Al Tehta	11/1/2003	534	407	C2: Medium salinity water	
BA/171	'Arik Al Tehta	6/13/2004	683	294.7	C2: Medium salinity water	
BA/171	'Arik Al Tehta	10/19/2004	748	376	C2: Medium salinity water	
BA/153	Harrashah	6/13/2004	593	229.5	C2: Medium salinity water	
BA/153	Harrashah	10/19/2004	562	281	C2: Medium salinity water	
BA/153	Harrashah	4/24/2005	529	269	C2: Medium salinity water	
NS/007	EIN AYOUB	11/1/2003	575	420.6	C2: Medium salinity water	
NS/007	EIN AYOUB	6/13/2004	619	445	C2: Medium salinity water	
NS/007	EIN AYOUB	11/21/2004	670	335	C2: Medium salinity water	
NS/007	EIN AYOUB	4/24/2005	574	287	C2: Medium salinity water	
NS/040	ALTINA	11/2/2003	509	373.1	C2: Medium salinity water	
NS/040	ALTINA	11/21/2004	510	253	C2: Medium salinity water	
NS/041	ALSHAKHRIQ	11/2/2003	484	274	C2: Medium salinity water	
NS/041	ALSHAKHRIQ	11/21/2004	479	241	C2: Medium salinity water	
NS/MUS	**Ein Musbah**	4/24/2005	**854**	**431**	**C3: High salinity water**	

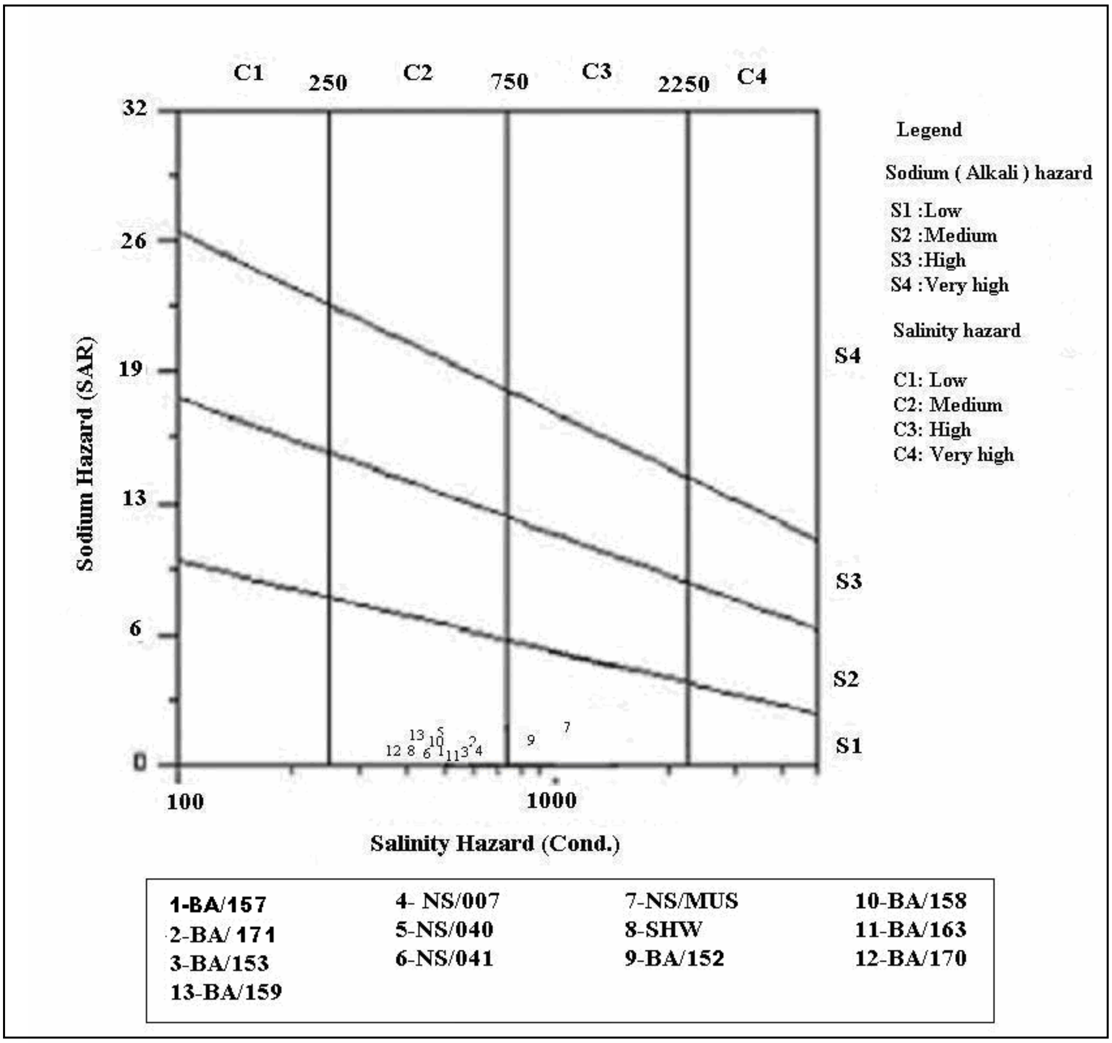

Figure 4.32: Wilcox diagram of EC-SAR of water samples 2003-2005

4.7.2 Total Hardness (TH)

Hardness of water is defined as the inhibition of soap action in water because of the precipitation of magnesium and calcium salts such as carbonates, sulfates and chlorides. It can be temporary or permanent hardness. Temporary harness is mainly due to the presence of calcium carbonate and is removed by boiling water. Permanent hardness is caused by the presence of calcium and magnesium chlorides and sulfates and can be cured only with ion exchange processes.

Hardness of water limits its use for industrial purposes; it causes scaling of pots and boilers, closure to irrigation pipes and may cause health problems to humans, such as kidney failure.

TH is calculated according to equation (4.13) (Todd, 1980):

$$TH\ (CaCO_3)\ mg/L = 2.497\ Ca^{+2} + 4.115Mg^{+2} \quad (4.13)$$

The concentrations of Ca^{+2} and Mg^{+2} are expressed in mg/L.

As a water quality parameter, TH values can be used to classify water for domestic and industrial uses (Table 4.9).

Table 4.9: Sawyer and McCarty (1967) classification of water based on hardness

CLASS OF WATER	HARDNESS AS $CACO_3$ MG/L	WATER TYPE
I	0-75	Soft
II	75-150	Moderately Hard
III	150-300	Hard
IV	>300	Very Hard

In the study area, the lowest value of TH recorded was 74.8mg/L for Wadi Natuf runoff on 6th Feb 2005, and the highest value was 568.8 mg/L for Ein Musbah spring on 19th Oct. 2004. Water types according to the average TH in the study area range from soft to very hard water with prevailing hard water in 80% of the samples. Classifications of the spring's water in the study area based on Sawyer and McCarty classification (Abed Rabbo, et. al. 1999) are listed in table 4.10.

4.7.3 Soluble Sodium Percentage (SSP)

Water quality for agricultural purposes in the Natuf drainage basin shows variation between excellent to good based on Todd classification of Soluble Sodium Percentage (SSP) values. SSP is defined as (Ghanem, 1999):

$$SSP = \left(\frac{(Na^+ + K^+)}{(Na^+ + K^+ + Ca^{+2} + Mg^{+2})}\right)*100$$, where all concentrations in meq/l.

SSP values were recorded to be 16.7 and 13.67 for dry 2004 and wet 2005 seasons respectively.

4.7.4 Sodium Adsorption Ratio (SAR)

Sodium Adsorption Ratio (SAR) is used as an index for sodium hazard in water for irrigation purposes in accordance with EC values. SAR is calculated according to the formula: SAR = $\frac{Na^{+}}{\sqrt{\frac{Ca^{+2}+Mg^{+2}}{2}}}$ where all concentrations are in meq/l.

Sodium hazard starts at values of SAR>1 and EC values > 650uS/cm respectively (Bauder, 2005). The values of SAR are <1 and <650uS/cm for EC in most the springs, Ein Arik Al Tehta, Ein Ayoub and Ein Musbah show values of SAR > 1 and >650uS/cm, which means that water from these springs is not recommended for unrestricted irrigation .

4.7.5 Microbiological Analysis

Water is a good media for microorganism. Groundwater and surface water may contain bacteria, viruses, fungus and algae, which makes water objectionable for domestic purposes and health threatening. Analysis of water samples, from three springs located near dense populated areas, for Faecal (FC) and total Coliform (TC).

The results obtained from microbiological analysis of Harrashah, Ein Musbah and Al-Alaq show that Ein Musbah and Al Alaq contain uncountable colonies of FC and TC, which reveals contamination from wastewater from sewerage system near Ein Musbah and cesspits near Al-Alaq. Harrashah spring show uncountable TC, this is referred to sheep herds and manure piles near the spring outlet.

Table 4.10: Classification Water of Natuf springs according to TH (mg/L)

SPRING NAME	AVERAGE TH (MG/L)	CLASS	WATER TYPE
'Akari	244	III	Hard
Al 'Alaq	359	IV	Very Hard
Al Balad/Beitillu	239	III	Hard
Al Balad /Ein Qinia	229	III	Hard
Al Quos	217	III	Hard
'Arik Al Fuqa	183	III	Hard
'Arik Al Tehta	262	III	Hard
Harrashah	291	III	Hard
EIN AYOUB	285	III	Hard
ALTINA	243	III	Hard
ALSHAKHRIQ	216	III	Hard
Ein Musbah	449	IV	Very Hard
Shibteen Well	214	III	Hard
Shibteen Fawwar	257	III	Hard

Chapter five

Conclusions and Recommendations

The Natuf drainage basin is an important part of the recharge zone in WAB. It is highly vulnerable to pollution risks caused by agricultural and human activities in the area. The damage to the surface of this area by quarries and stone cutting plants in some parts of the area and the uncontrolled damage to the vegetation increases vulnerability to the pollution of groundwater stored in perched and upper aquifers.

5.1 Conclusions

Most of the springs in the Natuf drainage basin emerge from perched aquifers and are distributed over Yatta Aquiclude formation below the upper aquifer. This study shows that water from tested springs is considered, according to TDS, fresh water. Water quality of these springs varies between wet and dry seasons. According to total hardness, water is categorized into hard or very hard water. All springs have hard water, except Ein Musbah and Al- Alaq springs, in which very hard waters are found. These springs are located close to populated areas and have agricultural activities nearby (Appendix G). Recorded values of SAR, SSP, and EC in the springs of Natuf drainage basin indicate that there is a pollution risk. Uncountable FC and TC were found in these springs which make the water of these springs unsuitable for drinking purposes.

The recorded trace elements amounts are not harmful according to WHO guidelines and Palestinian water quality standards. The karstic nature in the recharge area for all springs brings the risk of future pollution from runoff originated over industrial zones, farms and uncontrolled piles of municipal solid wastes may increase the risk of trace elements contamination in Natuf springs. Water genesis in the springs of Natuf drainage basin is mainly originates from the recharge area of limestone and dolomitic limestone and affected by dry and wet seasons as well as leakage from wastewater. Water types that are dominant in springs of Natuf drainage basin are earth alkaline with prevailing bicarbonate, some springs show earth alkaline water type with an increase in alkalis and prevailing bicarbonate and sulfate or chloride. Changing the type of water in some springs is due to the fact that the spring water mixes with wastewater and runoff water.

5.2 Recommendations

After three years of monitoring hydrochemical parameters in the Natuf drainage basin, the following recommendations are offered to minimize pollution risk and to provide heath protection guidelines for inhabitants in the area:

- Uncontrolled wastewater disposed by trucks in the valleys of the study area must be stopped immediately.
- Water for drinking purposes from springs located in populated areas must be boiled before use.
- Ein Musbah in Ramallah city must be closed for domestic uses.
- Local Authorities must clean springs outlets from disposals on a daily basis.
- Establishing sewer systems in the local communities of the area.
- Disposal of industrial wastes from workshops near springs must be under the control of authorities.

- Agricultural disposals and animal manure piles should not be stored near the springs.
- Monitoring waste disposals from Settlements, with the cooperation of PWA.
- Continuous monitoring of hydrochemical and biological parameters should be done by PWA and reported to local authorities and inhabitants.
- Encouraging plantation of mountains and hills in the area
- Further research on other chemicals such as volatile organic compounds (VOC’s), semi-volatile organic compounds (SMVOC), arsenic and mercury is beneficial for the prediction of pollution sources in the area.

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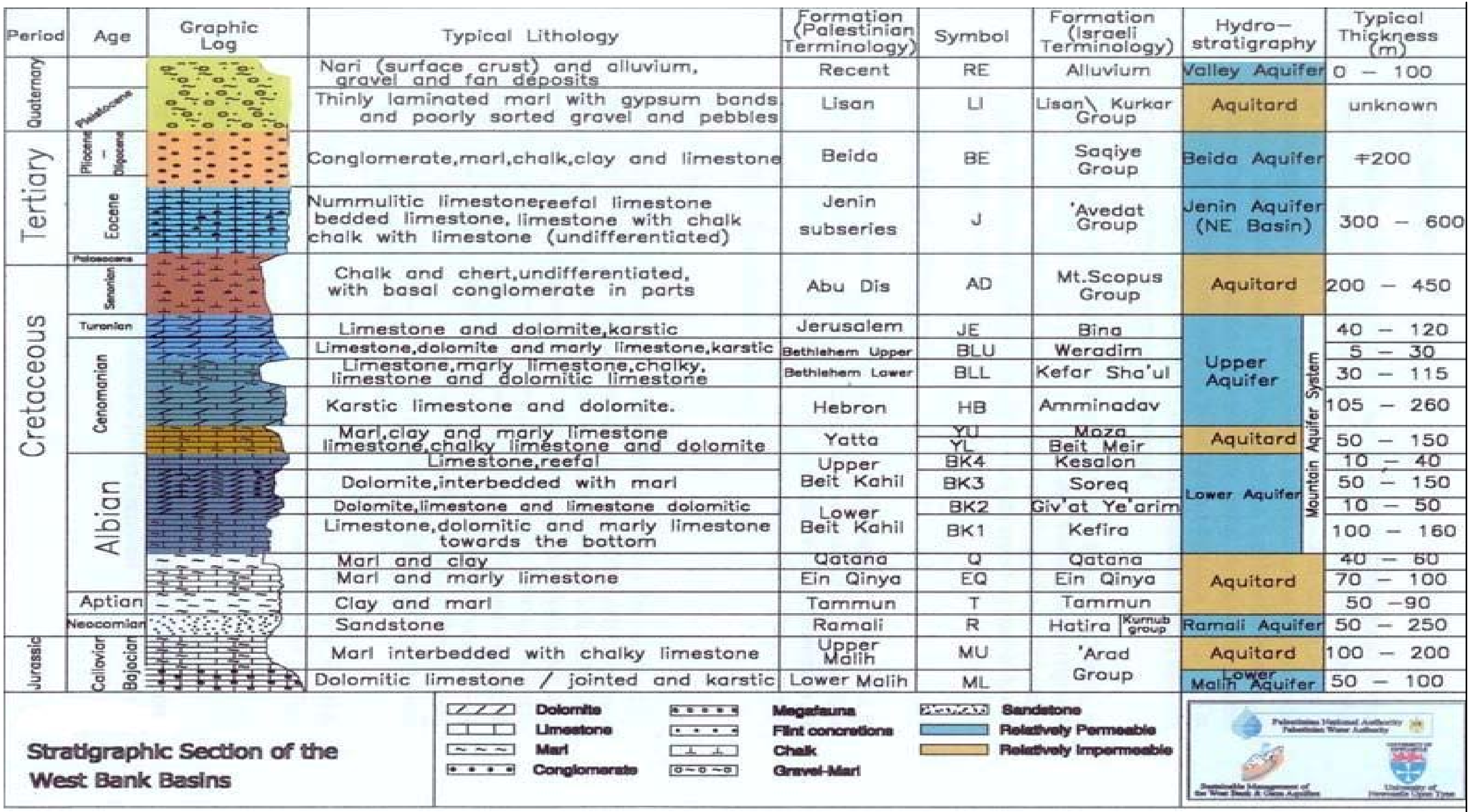
Appendices

Appendix A: Stratigraphy of West Bank (Source: PWA, 2004)



Period	Age	Typical Lithology	Formation (Palestinian Terminology)	Symbol	Formation (Israeli Terminology)	Hydro-stratigraphy	Typical Thickness (m)
Quaternary		Nari (surface crust) and alluvium, gravel and fan deposits	Recent	RE	Alluvium	Valley Aquifer	0 – 100
Quaternary	Pleistocene	Thinly laminated marl with gypsum bands and poorly sorted gravel and pebbles	Lisan	LI	Lisan\ Kurkar Group	Aquitard	unknown
Tertiary	Pliocene - Oligocene	Conglomerate, marl, chalk, clay and limestone	Beida	BE	Saqiye Group	Beida Aquifer	∓200
Tertiary	Eocene	Nummulitic limestone, reefal limestone bedded limestone, limestone with chalk chalk with limestone (undifferentiated)	Jenin subseries	J	'Avedat Group	Jenin Aquifer (NE Basin)	300 – 600
Tertiary / Cretaceous	Palaeocene / Senonian	Chalk and chert, undifferentiated, with basal conglomerate in parts	Abu Dis	AD	Mt.Scopus Group	Aquitard	200 – 450
Cretaceous	Turonian	Limestone and dolomite, karstic	Jerusalem	JE	Bina	Upper Aquifer (Mountain Aquifer System)	40 – 120
Cretaceous	Cenomanian	Limestone, dolomite and marly limestone, karstic	Bethlehem Upper	BLU	Weradim	Upper Aquifer (Mountain Aquifer System)	5 – 30
Cretaceous	Cenomanian	Limestone, marly limestone, chalky, limestone and dolomitic limestone	Bethlehem Lower	BLL	Kefar Sha'ul	Upper Aquifer (Mountain Aquifer System)	30 – 115
Cretaceous	Cenomanian	Karstic limestone and dolomite.	Hebron	HB	Amminadav	Upper Aquifer (Mountain Aquifer System)	105 – 260
Cretaceous	Cenomanian	Marl, clay and marly limestone limestone, chalky limestone and dolomite	Yatta	YU / YL	Moza / Beit Meir	Aquitard (Mountain Aquifer System)	50 – 150
Cretaceous	Albian	Limestone, reefal	Upper Beit Kahil	BK4	Kesalon	Lower Aquifer (Mountain Aquifer System)	10 – 40
Cretaceous	Albian	Dolomite, interbedded with marl	Upper Beit Kahil	BK3	Soreq	Lower Aquifer (Mountain Aquifer System)	50 – 150
Cretaceous	Albian	Dolomite, limestone and limestone dolomitic	Lower Beit Kahil	BK2	Giv'at Ye'arim	Lower Aquifer (Mountain Aquifer System)	10 – 50
Cretaceous	Albian	Limestone, dolomitic and marly limestone towards the bottom	Lower Beit Kahil	BK1	Kefira	Lower Aquifer (Mountain Aquifer System)	100 – 160
Cretaceous	Albian	Marl and clay	Qatana	Q	Qatana	Aquitard	40 – 60
Cretaceous	Albian	Marl and marly limestone	Ein Qinya	EQ	Ein Qinya	Aquitard	70 – 100
Cretaceous	Aptian	Clay and marl	Tammun	T	Tammun	Aquitard	50 –90
Cretaceous	Neocomian	Sandstone	Ramali	R	Hatira (Kurnub group)	Ramali Aquifer	50 – 250
Jurassic	Callovian	Marl interbedded with chalky limestone	Upper Malih	MU	'Arad Group	Aquitard	100 – 200
Jurassic	Bajocian	Dolomitic limestone / jointed and karstic	Lower Malih	ML	'Arad Group	Lower Malih Aquifer	50 – 100

Appendix B: Hydrochemical Parameters in Natuf springs 2003 - 2005

Spring Name	Spring Code	Date	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)
Al 'Alaq	BA/152	11/5/2003	99	41	39	6	337	67	31	67
Al 'Alaq	BA/152	6/13/2004	30	52	31	3	235	69	34	56
Al 'Alaq	BA/152	10/19/2004	116	42	44	4	362	78	29	54
Al 'Alaq	BA/152	4/24/2005	80	28	28	4	351	70	26	48
Harrashah	BA/153	6/13/2004	37	22	12	2	205	36	20	3
Harrashah	BA/153	10/19/2004	82	28	13	1	291	26	23	5
Harrashah	BA/153	4/24/2005	59	20	9	1	268	27	28	5
'Akari	BA/157	6/13/2004	53	20	16	4	215	52	20	17
'Akari	BA/157	11/21/2004	62	25	19	1	224	38	22	15
Al Balad	BA/158	11/21/2004	61	31	15	3	232	32	30	14
Al Balad	BA/158	1/5/2005	58	29	14	0	237	31	30	17
Al Quos	BA/159	6/13/2004	25	20	11	1	158	25	21	11
Al Quos	BA/159	11/21/2004	31	20	13	2	227	32	26	13
Al Quos	BA/159	1/5/2005	56	25	11	0	221	30	21	14
Al Balad	BA/163	11/1/2003	50	20	14	3	257	45	20	6
Al Balad	BA/163	11/3/2004	79	20	18	1	243	31	20	11
Al Balad	**BA/163**	**4/24/2005**	**58**	**13**	**10**	**0**	**196**	**31**	**32**	**7**

Appendix B: Continued….

Spring Name	Spring Code	Date	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)**
'Arik Al Fuqa	**BA170**	**11/1/2003**	**47**	**12**	**12**	**2**	**187**	**16**	**17**	**4**
'Arik Al Fuqa	**BA170**	**10/19/2004**	**58**	**21**	**13**	**1**	**231**	**51**	**21**	**5**
'Arik Al Tehta	**BA/171**	**11/1/2003**	**69**	**15**	**22**	**6**	**222**	**31**	**20**	**18**
'Arik Al Tehta	**BA/171**	**6/13/2004**	**46**	**15**	**28**	**5**	**187**	**45**	**39**	**35**
'Arik Al Tehta	**BA/171**	**10/19/2004**	**115**	**29**	**52**	**10**	**332**	**83**	**30**	**50**
EIN AYOUB	**NS/007**	**11/1/2003**	**69**	**19**	**18**	**3**	**207**	**36**	**22**	**37**
EIN AYOUB	**NS/007**	**6/13/2004**	**60**	**20**	**35**	**4**	**193**	**40**	**32**	**61**
EIN AYOUB	**NS/007**	**11/21/2004**	**87**	**29**	**31**	**2**	**245**	**65**	**25**	**49**
EIN AYOUB	**NS/007**	**1/5/2005**	**74**	**25**	**23**	**1**	**228**	**52**	**24**	**49**
ALTINA	**NS/040**	**11/2/2003**	**37**	**5**	**22**	**2**	**169**	**27**	**33**	**40**
ALTINA	**NS/040**	**11/21/2004**	**61**	**21**	**27**	**1**	**170**	**53**	**28**	**39**
ALSHAKHRIQ	**NS/041**	**11/2/2003**	**58**	**11**	**17**	**4**	**208**	**49**	**25**	**13**
ALSHAKHRIQ	**NS/041**	**11/21/2004**	**65**	**19**	**19**	**3**	**206**	**40**	**22**	**19**
Ein Musbah	**NS/MUS**	**4/24/2005**	**85**	**35**	**49**	**1**	**346**	**101**	**35**	**49**
Shibteen Well	**SHW**	**1/20/2005**	**68**	**20**	**19**	**2**	**206**	**36**	**15**	**15**
Shibteen Well	**SHW**	**1/5/2005**	**50**	**13**	**15**	**2**	**208**	**43**		**25**
Shibteen Fawwar	**SHF**	**1/20/2005**	**71**	**20**	**20**	**2**	**204**	**37**	**21**	**21**
Wadi Natuf runoff	**SHR**	**2/6/2005**	**50**	**11**	**14**	**12**	**174**	**21**	**16**	
Runoff Birzeit		**2/7/2005**	**22.6**	**4.4**	**11.4**	**3.4**	**86.9**	**2.6**	**24**	**9.4**

Spring Name	Spring Code	Date	EC(µS/cm)	pH	TDS(mg/L)	**P_{CO2}(Bar)**	SAR	SSP	TH	Na^+/Cl^-
Al 'Alaq	**BA/152**	**11/5/2003**	**867**	**7.33**	**627**	**5.58E-03**	**0.3**	**0.08**	**374**	**0.59**
Al 'Alaq	**BA/152**	**6/13/2004**	**891**	**7.29**	**510**	**2.21E-02**	**0.79**	**0.23**	**289**	**0.45**
Al 'Alaq	**BA/152**	**10/19/2004**	**853**	**6.88**	**727**	**3.78E-02**	**0.89**	**0.21**	**458**	**0.56**
Al 'Alaq	**BA/152**	**4/24/2005**	**757**	**7.14**	**457**	**1.66E-02**	**0.68**	**0.19**	**314**	**0.39**
Harrashah	**BA/153**	**6/13/2004**	**593**	**7.49**	**230**	**7.14E-03**	**0.39**	**0.14**	**183**	**0.33**
Harrashah	**BA/153**	**10/19/2004**	**562**	**7.61**	**470**	**1.85E-03**	**0.32**	**0.09**	**322**	**0.50**
Harrashah	**BA/153**	**4/24/2005**	**529**	**7.37**	**269**	**7.77E-03**	**0.25**	**0.08**	**230**	**0.33**
'Akari	**BA/157**	**6/13/2004**	**619**	**7.67**	**397**	**2.18E-03**	**0.48**	**0.16**	**215**	**0.31**
'Akari	**BA/157**	**11/21/2004**	**467**	**7.66**	**404**	**1.96E-03**	**0.5**	**0.016**	**258**	**0.49**
Al Balad	**BA/158**	**11/21/2004**	**474**	**7.82**	**416**	**9.54E-04**	**0.39**	**0.12**	**278**	**0.47**
Al Balad	**BA/158**	**1/5/2005**	**498**	**8.06**	**415**	**3.33E-04**	**0.37**	**0.12**	**262**	**0.45**
Al Quos	**BA/159**	**6/13/2004**	**488**	**7.55**	**188**	**8.02E-03**	**0.4**	**0.17**	**145**	**0.44**
Al Quos	**BA/159**	**11/21/2004**	**458**	**7.61**	**381**	**4.96E-03**	**0.38**	**0.12**	**230**	**0.41**
Al Quos	**BA/159**	**1/5/2005**	**467**	**7.45**	**378**	**5.66E-03**	**0.31**	**0.1**	**225**	**0.38**
Al Balad	**BA/163**	**11/1/2003**	**518**	**6.74**	**448**	**1.67E-01**	**0.25**	**0.07**	**317**	**0.31**
Al Balad	**BA/163**	**11/3/2004**	**505**	**7.96**	**423**	**3.86E-04**	**0.46**	**0.14**	**280**	**0.56**
Al Balad	BA/163	4/24/2005	485	7.25	348	1.37E-02	0.32	0.11	201	0.34

Spring Name	Spring Code	Date	EC(µS/cm)	pH	TDS(mg/L)	P_{CO_2}(Bar)	SAR	SSP	TH	Na^+/Cl^-
'Arik Al Fuqa	**BA170**	**11/1/2003**	**406**	**7.59**	**310**	**3.55E-03**	**0.28**	**0.09**	**223**	**0.74**
'Arik Al Fuqa	**BA170**	**10/19/2004**	**423**	**8.16**	**401**	**2.10E-04**	**0.38**	**0.13**	**232**	**0.26**
'Arik Al Tehta	**BA/171**	**11/1/2003**	**534**	**6.88**	**407**	**6.36E-02**	**0.43**	**0.13**	**268**	**0.71**
'Arik Al Tehta	**BA/171**	**6/13/2004**	**683**	**7.05**	**295**	**4.36E-02**	**0.92**	**0.35**	**177**	**0.62**
'Arik Al Tehta	**BA/171**	**10/19/2004**	**748**	**6.82**	**702**	**5.03E-02**	**1.12**	**0.28**	**406**	**0.62**
EIN AYOUB	**NS/007**	**11/1/2003**	**575**	**7.06**	**421**	**2.77E-02**	**0.39**	**0.11**	**287**	**0.49**
EIN AYOUB	**NS/007**	**6/13/2004**	**619**	**7.29**	**445**	**1.11E-02**	**1**	**0.33**	**232**	**0.88**
EIN AYOUB	**NS/007**	**11/21/2004**	**670**	**6.95**	**533**	**3.66E-02**	**0.74**	**0.2**	**334**	**0.47**
EIN AYOUB	**NS/007**	**1/5/2005**	**574**	**7.42**	**470**	**4.95E-03**	**0.58**	**0.17**	**287**	**0.43**
ALTINA	**NS/040**	**11/2/2003**	**509**	**7.37**	**373**	**1.24E-02**	**0.55**	**0.18**	**241**	**0.80**
ALTINA	**NS/040**	**11/21/2004**	**510**	**7.83**	**401**	**9.07E-04**	**0.77**	**0.25**	**238**	**0.51**
ALSHAKHRIQ	**NS/041**	**11/2/2003**	**484**	**7.71**	**274**	**1.65E-03**	**0.52**	**0.19**	**190**	**0.34**
ALSHAKHRIQ	**NS/041**	**11/21/2004**	**479**	**7.37**	**393**	**7.03E-03**	**0.54**	**0.18**	**240**	**0.48**
Ein Musbah	**NS/MUS**	**4/24/2005**	**854**	**7.81**	**595**	**7.10E-04**	**1.14**	**0.3**	**356**	**0.49**
Shibteen Well	**SHW**	**1/20/2005**	**439**	**8.41**	**381**	**5.62E-05**	**0.52**	**0.16**	**250**	**0.52**
Shibteen Well	**SHW**	**1/5/2005**	**467**	**7.84**	**232**	**1.06E-03**	**0.48**	**18**	**179**	**0.35**
Shibteen Fawwar	**SHF**	**1/20/2005**	**455**	**8.21**	**393**	**3.16E-04**	**0.52**	**0.16**	**257**	**0.53**
Wadi Natuf runoff	**SHR**	**2/6/2005**	**370**	**7.87**	**218**	**3.16E-04**	**0.48**	**0.19**	**159**	**0.65**
Runoff Birzeit		2/7/2005	333	8.27	108	3.20E-04	0.57	0,33	75	4.38

Appendix C: General Statistical Analysis for Springs in the Natuf Drainage Basin 2003-2005

Spring Name	Mathematical Relation	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)	EC (µS/cm)	pH	TDS (mg/L)
'Akari	**Average**	**57**	**23**	**17**	**2**	**219**	**45**	**21**	**16**	**543**	**7.7**	**401**
'Akari	**St.Dev**	**6.2**	**3.7**	**1.8**	**2.2**	**6.1**	**10.0**	**1.4**	**1.6**	**107.5**	**0.0**	**4.9**
'Akari	**Median**	**57**	**23**	**17**	**2**	**219**	**45**	**21**	**16**	**543**	**7.7**	**401**
'Akari	**Max**	**62**	**25**	**19**	**4**	**224**	**52**	**22**	**17**	**619**	**7.7**	**404**
	Min	**53**	**20**	**16**	**1**	**215**	**38**	**20**	**15**	**467**	**7.7**	**397**
Al 'Alaq	**Average**	**81**	**41**	**35**	**4**	**321**	**71**	**30**	**56**	**842**	**7.2**	**580**
Al 'Alaq	**St.Dev**	**37.2**	**9.9**	**7.4**	**1.3**	**58.3**	**4.9**	**3.4**	**8.1**	**58.8**	**0.2**	**121.0**
Al 'Alaq	**Median**	**89**	**41**	**35**	**4**	**344**	**70**	**30**	**55**	**860**	**7.2**	**568**
Al 'Alaq	**Max**	**116**	**52**	**44**	**6**	**362**	**78**	**34**	**67**	**891**	**7.3**	**727**
	Min	**30**	**28**	**28**	**3**	**235**	**67**	**26**	**48**	**757**	**6.9**	**457**
Al Balad	**Average**	**59**	**30**	**15**	**2**	**235**	**31**	**30**	**15**	**486**	**7.9**	**416**
Al Balad	**St.Dev**	**2.2**	**1.6**	**0.9**	**1.8**	**3.1**	**0.9**	**0.0**	**2.1**	**17.0**	**0.2**	**0.7**
Al Balad	**Median**	**59**	**30**	**15**	**2**	**235**	**31**	**30**	**15**	**486**	**7.9**	**416**
Al Balad	**Max**	**61**	**31**	**15**	**3**	**237**	**32**	**30**	**17**	**498**	**8.1**	**416**
	Min	**58**	**29**	**14**	**0**	**232**	**31**	**30**	**14**	**474**	**7.8**	**415**
Al Balad	**Average**	**62**	**18**	**14**	**1**	**232**	**36**	**24**	**8**	**503**	**7.3**	**406**
Al Balad	**St.Dev**	**14.7**	**3.9**	**3.7**	**1.4**	**32.0**	**8.1**	**6.9**	**2.8**	**16.6**	**0.6**	**52.0**
Al Balad	**Median**	**58**	**20**	**14**	**1**	**243**	**31**	**20**	**7**	**505**	**7.3**	**423**
Al Balad	**Max**	**79**	**20**	**18**	**3**	**257**	**45**	**32**	**11**	**518**	**8.0**	**448**
	Min	50	13	10	0	196	31	20	6	485	6.7	348

Appendix C:

Spring Name	Mathematical Relation	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)	EC (µS/cm)	pH	TDS (mg/L)
Al Quos	**Average**	**37**	**22**	**12**	**1**	**202**	**29**	**23**	**12**	**471**	**7.5**	**316**
Al Quos	**St.Dev**	**16.6**	**3.0**	**1.2**	**1.0**	**38.2**	**3.6**	**2.9**	**1.4**	**15.4**	**0.1**	**110.9**
Al Quos	**Median**	**31**	**20**	**11**	**1**	**221**	**30**	**21**	**13**	**467**	**7.6**	**378**
Al Quos	**Max**	**56**	**25**	**13**	**2**	**227**	**32**	**26**	**14**	**488**	**7.6**	**381**
	Min	**25**	**20**	**11**	**0**	**158**	**25**	**21**	**11**	**458**	**7.5**	**188**
'Arik Al Fuqa	**Average**	**52**	**17**	**13**	**1**	**209**	**34**	**19**	**5**	**415**	**7.9**	**356**
'Arik Al Fuqa	**St.Dev**	**7**	**7**	**1**	**1**	**31**	**25**	**3**	**0**	**12**	**0.4**	**64**
'Arik Al Fuqa	**Median**	**52**	**17**	**13**	**1**	**209**	**34**	**19**	**5**	**415**	**7.9**	**356**
'Arik Al Fuqa	**Max**	**58**	**21**	**13**	**2**	**231**	**51**	**21**	**5**	**423**	**8.2**	**401**
	Min	**47**	**12**	**12**	**1**	**187**	**16**	**17**	**4**	**406**	**7.6**	**310**
'Arik Al Tehta	**Average**	**77**	**20**	**34**	**7**	**247**	**53**	**30**	**34**	**655**	**6.9**	**468**
'Arik Al Tehta	**St.Dev**	**35.1**	**8.1**	**15.8**	**2.8**	**75.8**	**27.0**	**9.6**	**16.4**	**109.7**	**0.1**	**210.4**
'Arik Al Tehta	**Median**	**69**	**15**	**28**	**6**	**222**	**45**	**30**	**35**	**683**	**6.9**	**407**
'Arik Al Tehta	**Max**	**115**	**29**	**52**	**10**	**332**	**83**	**39**	**50**	**748**	**7.1**	**702**
	Min	**46**	**15**	**22**	**5**	**187**	**31**	**20**	**18**	**534**	**6.8**	**295**
Harrashah	**Average**	**59**	**24**	**11**	**1**	**255**	**30**	**24**	**4**	**561**	**7.5**	**323**
Harrashah	**St.Dev**	**22.6**	**4.3**	**2.2**	**0.9**	**44.6**	**5.4**	**4.0**	**1.2**	**32.0**	**0.1**	**128.8**
Harrashah	**Median**	**59**	**22**	**12**	**1**	**268**	**27**	**23**	**5**	**562**	**7.5**	**269**
Harrashah	**Max**	**82**	**28**	**13**	**2**	**291**	**36**	**28**	**5**	**593**	**7.6**	**470**
	Min	37	20	9	1	205	26	20	3	529	7.4	230

Appendix C:

Spring Name	Mathematical Relation	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)	EC (µS/cm)	pH	TDS (mg/L)
'Akari	**Average**	**57**	**23**	**17**	**2**	**219**	**45**	**21**	**16**	**543**	**7.7**	**401**
'Akari	**St.Dev**	**6.2**	**3.7**	**1.8**	**2.2**	**6.1**	**10.0**	**1.4**	**1.6**	**107.5**	**0.0**	**4.9**
'Akari	**Median**	**57**	**23**	**17**	**2**	**219**	**45**	**21**	**16**	**543**	**7.7**	**401**
'Akari	**Max**	**62**	**25**	**19**	**4**	**224**	**52**	**22**	**17**	**619**	**7.7**	**404**
	Min	**53**	**20**	**16**	**1**	**215**	**38**	**20**	**15**	**467**	**7.7**	**397**
Al 'Alaq	**Average**	**81**	**41**	**35**	**4**	**321**	**71**	**30**	**56**	**842**	**7.2**	**580**
Al 'Alaq	**St.Dev**	**37.2**	**9.9**	**7.4**	**1.3**	**58.3**	**4.9**	**3.4**	**8.1**	**58.8**	**0.2**	**121.0**
Al 'Alaq	**Median**	**89**	**41**	**35**	**4**	**344**	**70**	**30**	**55**	**860**	**7.2**	**568**
Al 'Alaq	**Max**	**116**	**52**	**44**	**6**	**362**	**78**	**34**	**67**	**891**	**7.3**	**727**
	Min	**30**	**28**	**28**	**3**	**235**	**67**	**26**	**48**	**757**	**6.9**	**457**
Al Balad	**Average**	**59**	**30**	**15**	**2**	**235**	**31**	**30**	**15**	**486**	**7.9**	**416**
Al Balad	**St.Dev**	**2.2**	**1.6**	**0.9**	**1.8**	**3.1**	**0.9**	**0.0**	**2.1**	**17.0**	**0.2**	**0.7**
Al Balad	**Median**	**59**	**30**	**15**	**2**	**235**	**31**	**30**	**15**	**486**	**7.9**	**416**
Al Balad	**Max**	**61**	**31**	**15**	**3**	**237**	**32**	**30**	**17**	**498**	**8.1**	**416**
	Min	**58**	**29**	**14**	**0**	**232**	**31**	**30**	**14**	**474**	**7.8**	**415**
Al Balad	**Average**	**62**	**18**	**14**	**1**	**232**	**36**	**24**	**8**	**503**	**7.3**	**406**
Al Balad	**St.Dev**	**14.7**	**3.9**	**3.7**	**1.4**	**32.0**	**8.1**	**6.9**	**2.8**	**16.6**	**0.6**	**52.0**
Al Balad	**Median**	**58**	**20**	**14**	**1**	**243**	**31**	**20**	**7**	**505**	**7.3**	**423**
Al Balad	**Max**	**79**	**20**	**18**	**3**	**257**	**45**	**32**	**11**	**518**	**8.0**	**448**
	Min	**50**	**13**	**10**	**0**	**196**	**31**	**20**	**6**	**485**	**6.7**	**348**
Al Quos	**Average**	**37**	**22**	**12**	**1**	**202**	**29**	**23**	**12**	**471**	**7.5**	**316**
Al Quos	**St.Dev**	**16.6**	**3.0**	**1.2**	**1.0**	**38.2**	**3.6**	**2.9**	**1.4**	**15.4**	**0.1**	**110.9**
Al Quos	**Median**	**31**	**20**	**11**	**1**	**221**	**30**	**21**	**13**	**467**	**7.6**	**378**
Al Quos	**Max**	**56**	**25**	**13**	**2**	**227**	**32**	**26**	**14**	**488**	**7.6**	**381**
	Min	**25**	**20**	**11**	**0**	**158**	**25**	**21**	**11**	**458**	**7.5**	**188**

Spring Name	Mathematical Relation	Ca^{+2} (mg/	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)	EC (µS/cm)	pH	TDS (mg/L)
'Arik Al Fuqa	**Average**	**52**	**17**	**13**	**1**	**209**	**34**	**19**	**5**	**415**	**7.9**	**356**
'Arik Al Fuqa	**St.Dev**	**7**	**7**	**1**	**1**	**31**	**25**	**3**	**0**	**12**	**0.4**	**64**
'Arik Al Fuqa	**Median**	**52**	**17**	**13**	**1**	**209**	**34**	**19**	**5**	**415**	**7.9**	**356**
'Arik Al Fuqa	**Max**	**58**	**21**	**13**	**2**	**231**	**51**	**21**	**5**	**423**	**8.2**	**401**
	Min	**47**	**12**	**12**	**1**	**187**	**16**	**17**	**4**	**406**	**7.6**	**310**
'Arik Al Tehta	**Average**	**77**	**20**	**34**	**7**	**247**	**53**	**30**	**34**	**655**	**6.9**	**468**
'Arik Al Tehta	**St.Dev**	**35.1**	**8.1**	**15.8**	**2.8**	**75.8**	**27.0**	**9.6**	**16.4**	**109.7**	**0.1**	**210.4**
'Arik Al Tehta	**Median**	**69**	**15**	**28**	**6**	**222**	**45**	**30**	**35**	**683**	**6.9**	**407**
'Arik Al Tehta	**Max**	**115**	**29**	**52**	**10**	**332**	**83**	**39**	**50**	**748**	**7.1**	**702**
	Min	**46**	**15**	**22**	**5**	**187**	**31**	**20**	**18**	**534**	**6.8**	**295**
Harrashah	**Average**	**59**	**24**	**11**	**1**	**255**	**30**	**24**	**4**	**561**	**7.5**	**323**
Harrashah	**St.Dev**	**22.6**	**4.3**	**2.2**	**0.9**	**44.6**	**5.4**	**4.0**	**1.2**	**32.0**	**0.1**	**128.8**
Harrashah	**Median**	**59**	**22**	**12**	**1**	**268**	**27**	**23**	**5**	**562**	**7.5**	**269**
Harrashah	**Max**	**82**	**28**	**13**	**2**	**291**	**36**	**28**	**5**	**593**	**7.6**	**470**
	Min	**37**	**20**	**9**	**1**	**205**	**26**	**20**	**3**	**529**	**7.4**	**230**
EIN AYOUB	**Average**	**72**	**23**	**27**	**3**	**218**	**48**	**26**	**49**	**610**	**7.2**	**467**
EIN AYOUB	**St.Dev**	**11.2**	**4.5**	**7.8**	**1.1**	**23.0**	**13.1**	**4.2**	**9.7**	**45.5**	**0.2**	**48.3**
EIN AYOUB	**Median**	**71**	**23**	**27**	**3**	**218**	**46**	**25**	**49**	**597**	**7.2**	**458**
EIN AYOUB	**Max**	**87**	**29**	**35**	**4**	**245**	**65**	**32**	**61**	**670**	**7.4**	**533**
	Min	**60**	**19**	**18**	**1**	**193**	**36**	**22**	**37**	**574**	**7.0**	**421**
ALTINA	**Average**	**49**	**13**	**24**	**2**	**170**	**40**	**31**	**40**	**510**	**7.6**	**387**
ALTINA	**St.Dev**	**16.9**	**11.3**	**3.9**	**0.9**	**1.0**	**18.3**	**3.5**	**0.9**	**0.7**	**0.3**	**19.7**
ALTINA	**Median**	**61**	**21**	**27**	**1**	**170**	**53**	**28**	**39**	**510**	**7.8**	**401**
	Max	**61**	**21**	**27**	**2**	**170**	**53**	**33**	**40**	**510**	**7.8**	**401**
	Min	37	5	22	1	169	27	28	39	509	7.4	373

Spring Name	Mathematical Relation	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)	EC (µS/cm)	pH	TDS (mg/L)
ALSHAKHRIQ	**Average**	**62**	**15**	**18**	**3**	**207**	**45**	**24**	**16**	**482**	**7.5**	**334**
ALSHAKHRIQ	**St.Dev**	**5.2**	**5.7**	**2.0**	**0.5**	**1.6**	**6.1**	**2.1**	**4.1**	**3.5**	**0.2**	**84.1**
ALSHAKHRIQ	**Median**	**62**	**15**	**18**	**3**	**207**	**45**	**24**	**16**	**482**	**7.5**	**334**
	Max	**65**	**19**	**19**	**4**	**208**	**49**	**25**	**19**	**484**	**7.7**	**393**
	Min	**58**	**11**	**17**	**3**	**206**	**40**	**22**	**13**	**479**	**7.4**	**274**
Shibteen Well	**Average**	**509**	**8**	**362**	**0**	**17**	**3**	**238**	**2**	**406**	**8.0**	**238**
Shibteen Well	**St.Dev**	**12.9**	**4.5**	**2.9**	**0.0**	**1.6**	**4.8**		**7.5**	**19.8**	**0.4**	**105.4**
	Median	**59**	**16**	**17**	**2**	**207**	**39**	**15**	**20**	**453**	**8.1**	**307**
	Max	**68**	**20**	**19**	**2**	**208**	**43**	**15**	**25**	**467**	**8.4**	**381**
	Min	50	13	15	2	206	36	15	15	439	7.8	232

Appendix D: Statistical Correlations for Hydrochemical Parameters of Springs in Natuf Drainage Basin 2003-2005

EC	pH	Ca^{+2}	Mg^{+2}	Na^{+}	K^{+}	HCO_3^{-}	Cl^{-}	NO_3^{-}	SO_4^{-2}	TDS	SI_{anhyd}	SI_{arag}	SI_{calc}	SI_{dol}	SI_{gyps}
	-.583(**)	.524(**)	.757(**)	.813(**)	.135	.737(**)	.840(**)	.787(**)	.585(**)	.822(**)	-.037	-.466(**)	-.323	-.282	.065
	.000	.001	.000	.000	.438	.000	.000	.000	.000	.000	.834	.005	.058	.101	.711
5	35	35	34	35	35	35	35	34	34	35	35	35	35	35	35
583(**)	1	-.356(*)	-.241	-.451(**)	-.314	-.389(*)	-.370(*)	-.492(**)	-.380(*)	-.618(**)	-.074	.415(*)	.508(**)	.479(**)	-.149
00	.	.036	.170	.007	.066	.021	.029	.003	.027	.000	.674	.013	.002	.004	.394
5	35	35	34	35	35	35	35	34	34	35	35	35	35	35	35
24(**)	-.356(*)	1	.465(**)	.664(**)	.233	.794(**)	.630(**)	.471(**)	.106	.408(*)	-.022	-.389(*)	-.285	-.285	.043
01	.036	.	.006	.000	.178	.000	.000	.005	.551	.015	.902	.021	.098	.096	.806
5	35	35	34	35	35	35	35	34	34	35	35	35	35	35	35
57(**)	-.241	.465(**)	1	.550(**)	.056	.706(**)	.663(**)	.523(**)	.302	.502(**)	-.045	-.316	-.149	-.081	.013
00	.170	.006	.	.001	.752	.000	.000	.001	.088	.002	.802	.069	.400	.649	.943
4	34	34	34	34	34	34	34	34	33	34	34	34	34	34	34
13(**)	-.451(**)	.664(**)	.550(**)	1	.338(*)	.629(**)	.850(**)	.852(**)	.532(**)	.702(**)	-.192	-.451(**)	-.356(*)	-.380(*)	-.096
00	.007	.000	.001	.	.047	.000	.000	.000	.001	.000	.269	.007	.036	.024	.583
5	35	35	34	35	35	35	35	34	34	35	35	35	35	35	35
35	-.314	.233	.056	.338(*)	1	.078	.153	.339(*)	-.034	.153	-.145	-.255	-.201	-.296	-.129
38	.066	.178	.752	.047	.	.657	.380	.050	.847	.381	.407	.139	.246	.085	.461
5	35	35	34	35	35	35	35	34	34	35	35	35	35	35	35
37(**)	-.389(*)	.794(**)	.706(**)	.629(**)	.078	1	.749(**)	.454(**)	.283	.525(**)	.116	-.364(*)	-.244	-.137	.173
00	.021	.000	.000	.000	.657	.	.000	.007	.105	.001	.506	.032	.157	.431	.321
5	35	35	34	35	35	35	35	34	34	35	35	35	35	35	35
40(**)	-.370(*)	.630(**)	.663(**)	.850(**)	.153	.749(**)	1	.719(**)	.448(**)	.621(**)	-.136	-.305	-.226	-.188	-.054
00	.029	.000	.000	.000	.380	.000	.	.000	.008	.000	.435	.074	.191	.279	.756
5	35	35	34	35	35	35	35	34	34	35	35	35	35	35	35
87(**)	-.492(**)	.471(**)	.523(**)	.852(**)	.339(*)	.454(**)	.719(**)	1	.569(**)	.760(**)	-.193	-.521(**)	-.376(*)	-.378(*)	-.112
00	.003	.005	.001	.000	.050	.007	.000	.	.001	.000	.273	.002	.028	.028	.527
4	34	34	34	34	34	34	34	34	33	34	34	34	34	34	34

85(**)	-.380(*)	.106	.302	.532(**)	-.034	.283	.448(**)	.569(**)	1	.466(**)	.081	-.253	-.216	-.194	.164
00	.027	.551	.088	.001	.847	.105	.008	.001	.	.005	.650	.148	.220	.272	.353
4	34	34	33	34	34	34	34	33	34	34	34	34	34	34	34
22(**)	-.618(**)	.408(*)	.502(**)	.702(**)	.153	.525(**)	.621(**)	.760(**)	.466(**)	1	-.056	-.373(*)	-.269	-.252	.052
00	.000	.015	.002	.000	.381	.001	.000	.000	.005	.	.748	.027	.118	.145	.765
5	35	35	34	35	35	35	35	34	34	35	35	35	35	35	35
037	-.074	-.022	-.045	-.192	-.145	.116	-.136	-.193	.081	-.056	1	.093	-.028	.037	.985(**)
34	.674	.902	.802	.269	.407	.506	.435	.273	.650	.748	.	.595	.873	.835	.000
5	35	35	34	35	35	35	35	34	34	35	35	35	35	35	35
466(**)	.415(*)	-.389(*)	-.316	-.451(**)	-.255	-.364(*)	-.305	-.521(**)	-.253	-.373(*)	.093	1	.775(**)	.763(**)	.052
05	.013	.021	.069	.007	.139	.032	.074	.002	.148	.027	.595	.	.000	.000	.767
5	35	35	34	35	35	35	35	34	34	35	35	35	35	35	35
323	.508(**)	-.285	-.149	-.356(*)	-.201	-.244	-.226	-.376(*)	-.216	-.269	-.028	.775(**)	1	.968(**)	-.045
58	.002	.098	.400	.036	.246	.157	.191	.028	.220	.118	.873	.000	.	.000	.799
5	35	35	34	35	35	35	35	34	34	35	35	35	35	35	35
282	.479(**)	-.285	-.081	-.380(*)	-.296	-.137	-.188	-.378(*)	-.194	-.252	.037	.763(**)	.968(**)	1	.006
01	.004	.096	.649	.024	.085	.431	.279	.028	.272	.145	.835	.000	.000	.	.973
5	35	35	34	35	35	35	35	34	34	35	35	35	35	35	35
65	-.149	.043	.013	-.096	-.129	.173	-.054	-.112	.164	.052	.985(**)	.052	-.045	.006	1
11	.394	.806	.943	.583	.461	.321	.756	.527	.353	.765	.000	.767	.799	.973	.
5	35	35	34	35	35	35	35	34	34	35	35	35	35	35	35

** Correlation is significant at the 0.01 level (2-tailed). * Correlation is significant at the 0.05 level (2-tailed).

Appendix E: Runoff at Ramallah and Ein Arik 2001

Site	Date	Time	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	K (mg/L)	S04(mg/L)	N03(mg/L)	Cl (mg/L)
Ein Arik Bridge	1/21/2000	10:15	58.82	10.19	13.59	4.04	31.37	42.05	24.39
Ein Arik Bridge	1/21/2000	11:45	60.1	10.51	13.68	4.1	31.26	42.25	24.97
Ein Arik Bridge	1/21/2000	12:05	60.84	10.63	13.97	4.06	31.42	41.98	25.19
Ein Arik Bridge	1/21/2000	12:30	60.47	10.52	14.01	4.17	31.45	42.07	25.16
Ein Arik Bridge	1/21/2000	12:55	61.43	10.72	14.34	4.39	31.68	41.85	25.41
Ein Arik Bridge	1/21/2000	13:10	61.47	10.78	13.87	4.05	31.56	41.87	25.54
Ein Arik Bridge	1/21/2000	17:00	64	11.23	14.9	4.5	31.87	39.09	26.85
Ein Arik Bridge	1/23/2000	17:40	73.7	13.03	13.33	3.07	27.23	21.63	25.96
Ein Arik Bridge	1/27/2000	9:05	53.5	9.44	11.62	3.81	19.98	16.31	19.32
Ein Arik Bridge	1/27/2000	10:05	63.45	11.2	13.09	4.03	23.85	19.46	23.29
Ein Arik Bridge	1/28/2000	14:00	64.62	11.3	12.43	2.89	25.91	26.12	21.84
Ein Arik Bridge	1/28/2000	14:35	63.71	11.18	12.36	2.96	25.17	24.98	21.42
Ein Arik Bridge	1/28/2000	14:45	63.63	11.15	12.29	2.99	25.33	25.24	21.4
Ein Arik Bridge	1/28/2000	16:30	64.26	11.01	12.73	3.5	25.46	25.87	21.91
Ein Arik Bridge	1/29/2000	13:00	66.39	11.9	13.26	3.13	24.31	20.61	24.21
Ein Arik Bridge	1/29/2000	13:35	66.31	11.91	12.75	3.08	26.89	19.38	37.85
Ein Arik Bridge	1/29/2000	14:00	65.85	11.92	12.52	3.04	24.32	20	24.92
Ein Arik Bridge	1/29/2000	15:00	68.99	12.44	12.99	3.05	25.34	21.14	24.93
Ein Arik Bridge	1/30/2000	16:00	71.66	12.85	12.7	2.91	26.67	20.29	24.77
Ein Arik Bridge	3/1/2000	8:00	45.33	7.08	10.46	3.22	15.59	17.17	13.03
Ein Arik Bridge	3/1/2000	16:00	39.27	5.51	8.04	2.7	8.49	4.64	9.09
Ein Arik Bridge	3/1/2000	17:00	45.76	7.21	9.76	3.15	14.35	11.06	12.35
Ein Arik Bridge	3/1/2000	18:00	44.16	6.68	9.34	3.05	13.64	11.26	11.57
Ein Arik Bridge	3/1/2000	19:00	46.5	6.83	9.98	3.3	14.96	15.96	12.54
Ein Arik Bridge	3/1/2000	21:00	45.23	7.2	10.57	3.12	16.1	17.14	13.49
Ein Arik Bridge	3/2/2000	11:00	61.28	11.13	12.66	2.68	21.69	14.99	18.98
Ein Arik Bridge	3/2/2000	12:00	60.84	11.33	12.67	2.55	21.51	14.85	18.77

Appendix D: continued ….

Site	Date	Time	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	K (mg/L)	S04(mg/L)	N03(mg/L)	Cl (mg/L)
Ein Arik Bridge	3/2/2000	14:00	63.97	11.72	12.91	2.62	22.61	14.87	19.75
Ein Arik Bridge	3/2/2000	15:00	64.46	11.8	13	2.57	22.62	14.83	20
Ein Arik Bridge	3/2/2000	18:00	74.12	13.54	15.77	3.37	26.89	18.69	26.94
Ein Arik Bridge	3/2/2000	19:00	66.73	12.25	13.33	2.57	23.44	15.13	20.83
Ein Arik Bridge	3/2/2000	20:00	67.04	12.28	13.41	2.6	23.31	15.03	20.99
Ein Arik Bridge	3/2/2000	21:00	67.33	12.34	13.64	2.74	23.55	14.98	21.57
Ein Arik	3/2/2000	22:00	68.48	12.56	13.68	2.61	24.08	15.34	22.01
Ein Arik Bridge	3/3/2000	7:00	70.83	13.03	14.44	2.74	24.67	16.2	23.31
Ein Arik Bridge	3/3/2000	7:00	57.86	10.34	12.07	2.68	20.62	15.56	17.84
Ein Arik Bridge	3/3/2000	8:00	71.38	13.16	14.45	2.75	25.08	16.05	23.77
Ein Arik Bridge	3/3/2000	9:00	71.57	13.18	14.56	2.8	25.18	16	23.86
Ein Arik Bridge	3/3/2000	10:00	71.83	13.22	14.8	2.86	25.65	16.69	24.59
Ein Arik Bridge	3/3/2000	12:00	72.12	13.2	14.89	3.02	25.58	15.95	24.5
Ein Arik Bridge	3/3/2000	13:00	63.71	11.68	12.94	2.55	23.42	14.99	25.27
Ein Arik Bridge	3/3/2000	13:00	72.51	13.28	15.79	3.13	25.98	15.69	26.16
Ein Arik Bridge	3/3/2000	14:30	65.72	12.04	13.64	2.78	23.21	15.38	20.84
Ein Arik Bridge	3/3/2000	17:00	73.74	13.44	16.09	3.54	27	18.03	26.52
Ein Arik Bridge	3/3/2000	18:00	66.27	12.14	13.3	2.68	22.99	14.81	20.54
Ein Arik Bridge	3/3/2000	afternoon	65.26	11.96	13.08	2.6	22.89	14.91	20.33
Ramallah	2/13/2000	11:05	52.97	4.61	10.35	4.31	19.14	2.82	11.48
Ramallah	2/13/2000	11:15	53.57	3.84	8.13	4.19	15.79	5	11.54
Ramallah	2/13/2000	11:20	49.94	3.72	7.75	4.23	14.22	6.28	10.62
Ramallah	2/13/2000	11:25	46.21	3.22	6.67	4.2	15.67	4.36	9.42
Ramallah	2/13/2000	11:30	14.17	2.4	5.89	2.62	14.48	3.08	9.04

Appendix F: Trace Elements (µg/l) in Natuf Springs and Runoff

Spring Code	Spring Name	Date	Location	Fe	Cu	Co	Cr	Cd	Pb	Zn
BA/157	'Akari	8/12/2003	Beitillu	0	0	10	13	2	10	24
BA/157	'Akari	5/3/2005	Beitillu	5	0	0	2	1	10	76
BA/157	'Akari	5/3/2005	Beitillu	2	0	5	0	0	23	78
BA/152	Al 'Alaq	11/5/2003	Abu Shekhedem	0	8	2	15	4.18	10	62
BA/152	Al 'Alaq	6/13/2004	Abu Shekhedem	.	.	.	.	.	.	.
BA/152	Al 'Alaq	10/19/2004	Abu Shekhedem	11	0	14	0	0	1	142
BA/152	Al 'Alaq	5/3/2005	Abu Shekhedem	0	0	10	3	0	0	5
BA/158	Al Balad/Beitillu	11/2/2003	Beitillu	0.0	0	5	11	2	0	36
BA/158	Al Balad/Beitillu	6/13/2004	Beitillu	.	.	.	.	.	.	.
BA/158	Al Balad/Beitillu	11/21/2004	Beitillu	0	0	0	3	0	0	86
BA/158	Al Balad/Beitillu	5/3/2005	Beitillu	0	0	0	0	0	0	84
BA/163	Al Balad/Ein Qinia	11/1/2003	'Ein Qinia	1.0	0	27	7	2	17	48
BA/163	Al Balad/Ein Qinia	11/3/2004	'Ein Qinia	1	0	0	2	0	0	91
BA/163	Al Balad/Ein Qinia	5/3/2005	'Ein Qinia	0	0	1	1	0	0	2
BA/159	Al Quos	11/2/2003	Beitillu	0.0	1	5	8	2	11	21
BA/159	Al Quos	11/21/2004	Beitillu	45	0	0	2	0	0	8
BA/159	Al Quos	5/3/2005	Beitillu	0	0	4	0	0	15	78
BA170	'Arik Al Fuqa	11/1/2003	'Ein 'Arik	0.0	1	30	1	2	4	31
BA170	'Arik Al Fuqa	10/19/2004	'Ein 'Arik	0	0	0	4	0	19	74
BA170	'Arik Al Fuqa	5/3/2005	'Ein 'Arik	0	0	0	0	0	0	2
BA/171	'Arik Al Tehta	11/1/2003	'Ein 'Arik	11.0	3	33	4	2	0	64
BA/171	'Arik Al Tehta	10/19/2004	'Ein 'Arik	14	0	6	0	0	0	134
BA/171	'Arik Al Tehta	5/3/2005	'Ein 'Arik	0	0	0	0	0	0	1
BA/153	Harrashah	11/5/2003	Al Mazr’a al Quibliya	0.0	0	5	3	2	14	53
BA/153	Harrashah	10/19/2004	Al Mazr’a al Quibliya	24	1	11	0	0	0	106
BA/153	Harrashah	5/3/2005	Al Mazr’a al Quibliya	0	0	0	0	0	0	5

Appendix F: Continued

Spring Code	Spring Name	Date	Location	Fe	Cu	Co	Cr	Cd	Pb	Zn
NS/007	EIN AYOUB	11/1/2003	RAS KARKAR	0.0	2	27	5	2	0	38
NS/007	EIN AYOUB	11/21/2004	RAS KARKAR	30	0	0	0	2	27.7	1.5
NS/008	EIN AYOUB	5/3/2005	RAS KARKAR	11	0	0	0	0	16	113
NS/040	ALTINA	11/2/2003	DIER AMAR	0.0	4	10	0	2	20	33
NS/040	ALTINA	11/21/2004	DIER AMAR	7	0	0	3	0	6	75
NS/041	ALTINA	5/3/2005	DIER AMAR	0	0	0	0	0	6	87
NS/041	ALSHAKHRIQ	11/2/2003	DIER AMAR	0.0	0	0	4	2	7	44
NS/041	ALSHAKHRIQ	11/21/2004	DIER AMAR	0	0	0	0	0	0	79
NS/042	ALSHAKHRIQ	5/3/2005	DIER AMAR	2	0	0	0	2	9	78
NS/MUS	Ein Musbah	11/20/2003	Ramallah	0	0	2	12	1	10	30
NS/MUS	Ein Musbah	10/19/2004	Ramallah	0	0	0	0	0	0	93
NS/MUS	Ein Musbah	5/3/2005	Ramallah	0	0	2	0	0	0	4
SHW	Shibteen Well	1/20/2005	Shibteen	0	0	15	0	0	0	89
SHW	Shibteen Well	5/3/2005	Shibteen	4	0	0	0	0	3	9
SHF	Shibteen Fawarah	1/20/2005	Shibteen	1	0	7	0	0	8	90
Runoff	BZU	1/20/2006	BZU	85	13	17	9	0	0	75

Appendix G: Photos from Natuf drainage basin

Photo 1: Akari Spring - Dir Ammar/ 2004

Photo 2: Al Shakhariq Spring - Dir Ammar / 2004


Photo 3: Beitillu Al ballad / 2004

Photo 4: Agriculture around d Al Tina Spring – Dir Ammar / 2004