Deanship of Graduate Studies
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Nidal Mohammad Abdul-Hamid Nassar

M.Sc. Thesis

Jerusalem- Palestine

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Prepare by:
(**Nidal Mohammad Abdul-Hamid Nassar**)

B.Sc.:……… (Al-Quds University) ……………(Palestine)

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

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Department of Applied Earth and Environmental Studies
Faculty of Science and Technology Al-Quds University.

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

Thesis Approval

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Prepared By: Nidal Mohammad Abdul-Hamid Nassar
Registration No: 20111846

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

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The names and signatures of the examining members are as follows:

1-Head of Committee:……………………………………Signature…………………
2-Internal Examiner: ……………………………………Signature…………………
3-External Examiner: ……………………………………Signature…………………
4-Committee Member:……………………………………Signature…………………

Jerusalem- Palestine

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Dedication

To the dear candle that light my route since my
eyes saw the light till now to my darling mother

To my father's soul and odorous memory that
remain with me all the time, and encourage me
on to perseverance and success

To my friend's soul, who left me in the beginning
of my path my deceased brother Ayser masaeed.

To my beloved wife, who gave me without stint
who support me and stay with me all the time
during the preparation of this thesis

To the near and distant I present hear my work
and a flower
To my brothers, sisters and my children
To all my friends
To all these people I dedicate my modest work

Nidal Mohammad Abdul-Hamid Nassar

Declaration

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

Signed :…………………………………………………………………….

(Nidal Mohammad Abdul-Hamid Nassar)

date:………………………………………………………………..…………..

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Abstract

The study area for this research is the Hebron district lies between 83-120 N and 138-183 E referenced on the Palestinian Grid.

Hydrological, hydrogeological, isotopical and hydrochemical studies conducted along the year. This work aims to find a data base about the springs of the study area, and to identify the amount of major and minor ions and to know the sources of the excess of some ions in many springs. Ready maps were used with other graphs determine the coordinates of the springs and their elevations above the Sea level.

The geology of the area is composed of sedimentary carbonate rocks of Albian to Holocene age. Some of the springs tap the Albian and Turonian–Cenomanian regional aquifers, while the others discharge from the aquifers of the Quaternary age.

The hydrological study aimed mainly to estimate runoff, recharge and the average depth of the annual rainfall in the district using suitable empirical formulas, the calculations gave results for them over the study area during the period 1970-2004, and these results are 55.7 mm (16.4 Mi.m^3) which corresponds to about 11.4%, and 141.03 mm/yr which represents 25.05% of the annual rainfall, and 487.2 mm respectively, the annual precipitation in the study area is 166.1 Mill.m^3.

The hydrochemical study show that rain water is the only source of ground water recharge. Mixing with waste water leaking from the ancient cesspits and the waste water conduit or the infiltration of the leachates from washing the piles of animals dung by the rainfall in winter are factors responsible for pollutants in water.

Samples analyzed for ^2H and ^{18}O, and others analyzed for ^3H. The results show that the isotopic composition during the rainy season ranges for $\delta^{18}O$ between -5.9%o and -5.27%o, and from -25.9%o to -21.1%o for $\delta\ ^2H$, and from 20.3 %o to 22.94%o for d-excess. The results plot in the Mediterranean Meteoric Water Line proving their rainwater origin. The present ^3H content in precipitation is 5-6TU suggests recent recharge and tritium of Meteoric origin.

In the EC-SAR classification the majority of the springs are suitable for irrigation with no limitations and they range from good to excellent for the same purpose based on SSP calculations. Piper diagram shows that 51.2% of the samples plot in the area of earth alkaline water with increased portions of alkalis with prevailing bicarbonate. Durov diagram appear the simple dissolution, the mixing process and the ion exchange of Na^{+1} with Ca^{+2} and Mg^{+2}. Durov diagram shows that 48.8% of the springs indicates water exhibiting dissolution-or mixing.

The water parameters interrelationships between the different analyzed parameters show correlations from very high significant relationship for the variables that have correlation coefficient ≥ 0.9 to poor relationship for the variables that have correlation coefficients < 0.5.

Five clusters appear depending on the common characteristics between the variables of the same cluster, HCO_3^{-1} dominate the majority of the samples of this study (76.9% of the

samples) which show that the water in the study area infiltrate in a carbonate rocks of limestone, sandstone, and marly limestone.

Scatterplot show an excellent relationship between some of the variables in clusters, which support the strong relationship between these variables.

Three seasonal variation of water types appear in this study, springs show a lower winter ion concentration than summer, and also the EC and this is the first type of seasonal variation, the second type is of a higher winter concentrations of some ions as well as higher EC. Some samples show a less concentration of SO_4^{-2}, Na^{+1}, and NO_3^{-1} in summer than in winter.

الملخص

تعتبر منطقة الدراسة لهذا البحث محافظة الخليل والواقعة بين 83–120 شمالا و 138–183 شرقا حسب المقاييس الفلسطينية.

تحتوي هذه الدراسة على نتائج الدراسات الهيدرولوجية، والهيدروجيولوجية، والنظائر المشعة، والهيدروكيميائية والتي أخذت خلال العام. حيث هدفت هذه الدراسة إلى توفير قاعدة بيانات عن هذه الينابيع، والتعرف على تركيز الايونات الموجبة والسالبة، والتعرف على مصادر الزيادة في بعض الايونات إن وجدت. ولبلوغ هذه الغاية، تم استخدام خرائط جاهزة ورسومات أخرى من خلالها تم تحديد إحداثيات الينابيع وارتفاع بعضها عن سطح البحر.

جيولوجية المنطقة تتكون من الصخور الرسوبية الجيرية، والتي تعود إلى العصر الالبي وحتى الهيلوسين. تصل بعض الينابيع إلى صخور العصرالالبي والتوروني والسينوماني لتضخ من خزانها الجوفي، وتستمد باقي ينابيع المنطقة مياهها من الخزانات الجوفية التي تعود إلى العصر الرباعي.

لقد هدفت الدراسة الهيدرولوجية لينابيع المنطقة إلى توفير معلومات عن معدلات الجريان السطحي والتغذية والرشح، حيث دلت القراءات والعمليات الحسابية التي أخذت للمنطقة من العام 1970 إلى العام 2004م بان معدل الجريان السطحي يساوي 55.7ملم (16.4 مليون متر مكعب). وهذا يعادل 11.4% من الأمطار التي تهطل على المنطقة، وتغذية بمقدار 141.03ملم/سنة، وهذا يعادل 25.05% من المعدل السنوي للأمطار. ودلت الدراسة بان 487.2 ملم من المياه ترشح عبر التربة، ومعدل سقوط الأمطار حيث يساوي 563ملم/سنة، والتي تساوي 166.1 مليون متر مكعب/سنة.

لقد دلت نتائج التحاليل الكسميائية بان مياه الأمطار هي المصدر الوحيد لمياه الينابيع، غير أن عمليات الخلط مع المياه العادمة التي تسربت من الحفر الامتصاصية ومن شبكات المجاري ونواتج غسل فضلات الحيوانات هي السبب في وجود بعض الملوثات في مياه الينابيع.
لقد أظهرت نتائج التحاليل لكل من $\delta\ ^{2}H$ و $\delta\ ^{18}O$، وكمية ^{3}H، إلى أن كمية ^{18}O خلال فصل المطر تمتد من – 5.9 o% إلى – 5.27o%، وان كمية $\delta\ ^{2}H$ تتراوح بين – 25.9o% إلى – 21.1o% حيث وجد بالرسم بان المحتوى النظائري لمياه الينابيع يقع على خط مساه البحر المتوسط، وهذا يؤكد مصدر المياه، ودلت كمية ^{3}H المتوفرة في مياه الينابيع والتي تتراوح بين 5–6 TU بان مياه الينابيع جميعها مياه حديثة.

لقد دلت نتائج التصنيف بالاعتماد على العلاقة بين موصلية المياه ومعدلات الصوديوم بان غالبية مياه الينابيع صالحة لأغراض الزراعة بدون محددات، وأنها تتراوح من جيدة إلى ممتازة لنفس الغرض، وبالاعتماد على نموذج (Piper) فان معظم الينابيع ظهرت في منطقة المياه القلوية الأرضية مع زيادة في كمية البايكربونات. اظهر نظام (Durov) للتصنيف فان 48.8% من الينابيع ظهرت على خط التحلل أو الخلط.

تراوحت نتائج ربط المتغيرات المدروسة بين علاقة كبيرة بين المتغيرات التي أعطت معامل ارتباط أعلى أو يساوي 0.9، الى ضعيفة للتي أعطت معامل ارتباط اقل من 0.5. ظهرت خمس مجموعات بالاعتماد على الخصائص المشتركة للعينات، وتبين بان HCO_3^{-1} كان الأعلى تركيز في 67.9% من العينات، وهذا يؤكد بان المياه في منطقة الدراسة تتحرك في الصخور الجيرية. لقد أظهرت الرسومات بوساطة (Scatterplot) ارتباطات ممتازة بين بعض المتغيرات في مياه الينابيع في المجموعة الواحدة.

تخضع مياه الينابيع للتغيرات الفصلية، حيث تكون مكونات المياه التي تجمع في فصل الشتاء اقل تركيزا مقارنة مع المياه التي تجمع في فصل أخر غير فصل المطر، وهذا بسبب التخفيف (Dilution) الناتج عن استمرار تدفق المياه إلى الخزان من الأمطار، ولكن في هذه الدراسة ظهر العكس في بعض الينابيع وهذا ناتج ربما عن الاختلاط بالمياه العادمة، أو بشكل عام يكون ناتج عن سبب أخر من أسباب التلوث كغسيل التربة وسطح الأرض وفضلات الحيوانات. كذلك أظهرت بعض الينابيع تراكيز لايونات مثل NO_3^{-1} في الصيف اقل وهذا بسبب التبخر على شكل NH_4^{+1} أو بسبب امتصاص النباتات كما هو الحال في K^{+1}.

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List of Symbols

^{o}	Degree
%	Percent.
%o	Per mil
$\sum$	Summation.
µS	Micro siemens
^{18}O	Oxygen – 18
^{2}H	Deuterium
^{3}H	Tritium
A	Area
AgNO3	Silver nitrate.
A_i	sub area between two contour lines
Apr	April
Arij	Applied Research Institude-Jerusalem
Aug	August.
Aver	Average.
avP	average annual precipitation.
B	Subarea B
C	Subarea C
Ca^{+2}	Calcium (ion).
Cgw	Chloride concentration of the ground water.
Cl^{-}	Chloride (ion).
cm^{2}	Square centimeter.
Cp	Weighted average chloride concentration in precipitation.
D	Subarea D
Dec	December.
d-excess	Measure of deuterium enrichment that exceeds the $\delta^{18}O$ value by more than 8 times.
E	East.
e	basis of natural logarithm
E	Subarea E
Ec	Electrical conductivity.
EDTA	Ethylenediaminetetraacetic acid
Et al.	And others.
Evap	Evaporation.
F	Subarea F
F^{-}	Fluoride (ion).
FC	Fecal coliform bacteria.
FC	Fecal coliform bacteria.
Feb	February
Fig.	Figure.
G	Subarea G
HCl	Hydrchloric acid.
HCO_3^{-1}	Bicarbonate (ion).
Jan	January.
Jul	July.
Jun	June.
K^{+1}	Potassium (ion).
K_{iap}	Ion activty product.

K_{IAP}	ion activity product
kj	Killo joule.
Km	Kilometer.
Km^{-1}	Per kilometer.
Km^2	Square kilometer.
K_{SP}	solubility product
L	Liter (volume).
m	Meter.
M^3	Cubic meter.
Mar	March.
masl	Meter above sea level.
Max.	Maximum.
MCM	Million cubic meter.
meq	Milliequivalent.
mg	Milligram
Mg^{+2}	Magnesium (ion).
Mid	Middle.
ml	Millilitre (volume).
Mon	Month.
N	North.
Na^{+1}	Sodium (ion).
Nov	November.
^oC	Degree centigrade (Celsius scale)
Oct	October.
P	the average annual rainfall (mm/yr).
P_e	Effective rainfall.
pH	Acidity value.
pH_C	Acidity values at equilibrium with calcite.
P_i	Average precipitation between two successive contour lines.
P_m	main rainfall in (mm).
Pm	Average depth of the rainfall (mm)
ppt	Precipitation.
Press.	Pressure.
Pv	annual volume of the rainfall over the area
Q	the average annual run off (mm/yr).
Q_o	the discharge in M/day at the beginning at time t.
Q_s	amount of stored groundwater at any chosen time.
Q_t	the discharge at time t.
R	Infiltration.
R.H%	Relative Humidity.
RR	recharge and runoff.
SAR	sodium adsorption ratio
SCS	Soil Conservation Service method.
sec	Second.
Sep	September.
SI	saturation index
SO_4^{-2}	Sulfate (ion).
SSP	Soluble Sodium Percentage.
Sun.dur	Sunshine Duration.
T	Tritium.

TC	Total coliform bacteria.
Tem	Temperature.
UN	United nations.
Vol	Volume.
W	Wind.
WHO	World Health Organization.
yr	Year.
Z	Elevation.
α	discharge depletion coefficient
λ	Wave length.
S	Second.
SMOW	standard mean Ocean water
TU	tritium unit
MMWL	Middle East Meteoric Line
MWL	Meteoric World Line

Glossary

Effective rainfall:	The result that would occur if the actual rainfall over a drainage basin, which is variable from place to place, were spread out over the entire basin to an average depth.
Orographic precipitation:	Precipitation which falls as a result of elevating the saturated air to a certain level by mountains effect.
Canyon:	A narrow and deep valley were water move.
Perched aquifer:	A region in the unsaturated zone where the soil may be locally saturated because it is overlies a low-permeability unit.
Drainage basin:	The land area from which surface runoff drains into a stream system.
Aquifer:	Rock or sediment in a formation, group of formations, or part of a formation that is saturated and sufficiently permeable to transmit economic quantities of water to wells and springs.
Aquiclude:	A low-permeable unit that forms either the upper or lower boundary of a ground water flow system.
Aquitard:	A low permeable unit that can store water and also transmit it slowly from one aquifer to another.

Chapter one

Introduction

1.1. Location

The Hebron district is located 36km south of Jerusalem city, in the southern part of West Bank. It is bounded by Bethlehem district from the north and by the 1948 cease fire line from the other directions. The total area of the district is 1036 km^2 with six major land use classes distinguished. There are Palestinian built-up areas, Israeli settlements, closed military areas and bases, nature reserves, forests, and cultivated areas. There are 153 Palestinian built-up areas in the district, these build-up areas comprise 3.6% of the total area. The selected catchment area lies between 83-120 N and 138-183 E referenced on the Palestinian Grid Fig. (1.1).

1.2. Previous studies

Little was done about the water quality in the Best Bank in general and Hebron district in particular. Published scientific papers, reports, maps, and many documents including relevant official Palestinian documentation as unpublished academic studies were reviewed.

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

Abdul-Jaber *et. al.* (1997) studied the effect of contamination from wastewater on the shallow perched aquifer systems in the northern West-Bank. They concluded that most of the springs and wells within the heavily populated areas were probably contaminated with wastewater through infiltration from septic tanks and the open conduit of raw sewage.

Abed-Rabbo *et. al.* (1995) presented the results of a study of the biological characteristics of the networks, cisterns, and springs in the nablus, Jenin, Qalqilia, and Tulkarm areas, based on coliform testing. The study showed that about one third of these water resources is free of coliform contamination and thus satisfactory for drinking, according to the world health organization guidelines (Abed Rabbo, et. al, 1997).

Abed-Rabbo *et. al*. (1997) in the unpublished final report for the Ford foundation presented the results of an extensive study of springs and wells through out the West Bank. The study aimed to determine the levels of biological and chemical pollution and recommended means of improving the situation.

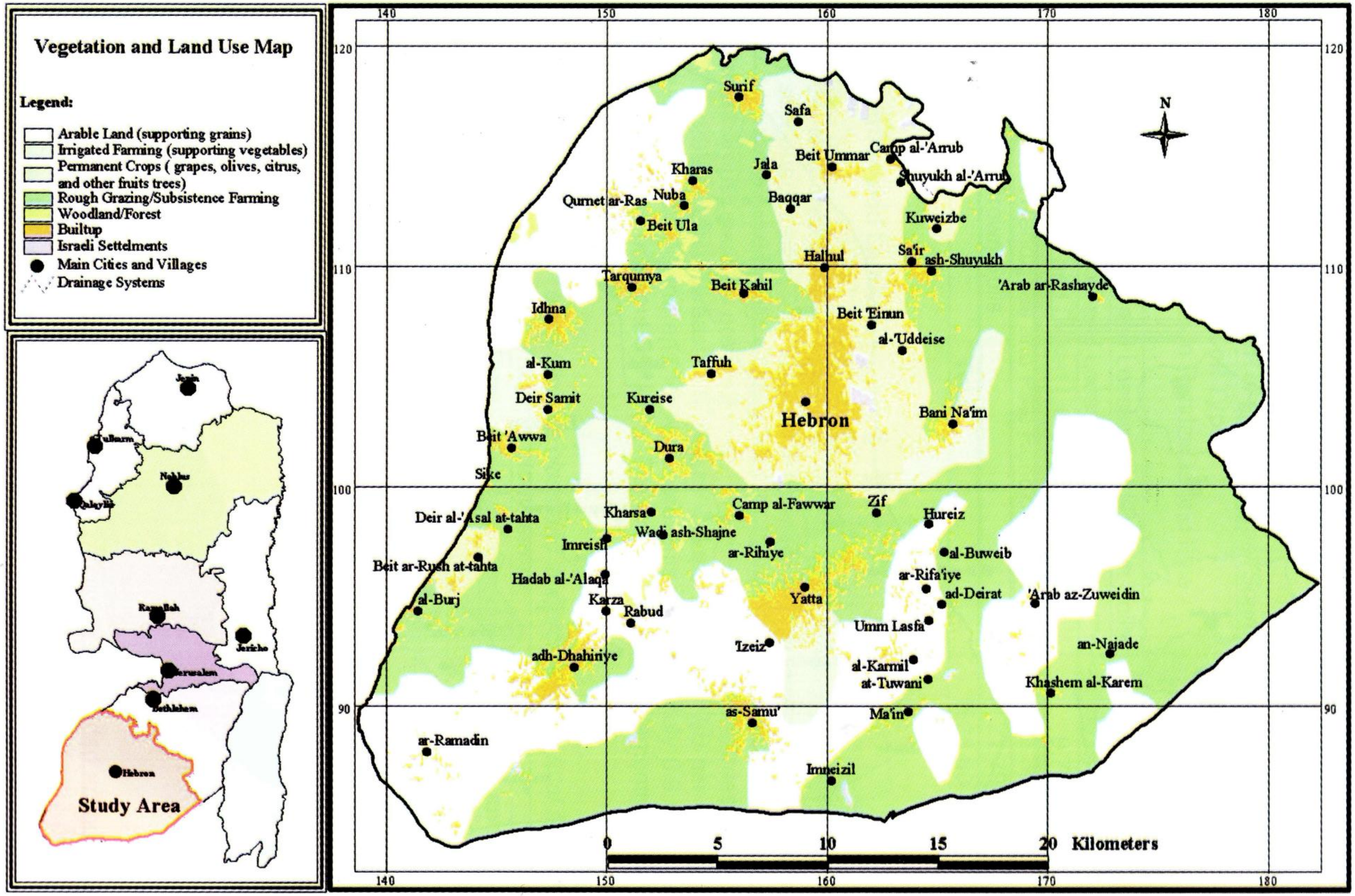


Fig. (1.1): Land use map of the Hebron district (modified after Palestinian Hydrology Group, 2005; EarthSat, 2000; The Gaza Strip and West Bank-A map Folio, 1994).

Qannam (1997) in his M.sc thesis studied, classified and evaluated the water of the major springs and wells in the southern part of the West Bank, south of Jerusallem, for both drinking and irrigation purposes and highlighted the main environmental water-hyphen related issues. The study showed that the area is dominated by earth alkaline water with prevailing bicarbonate, followed by earth alkaline water with increased portions of alkalis and prevailing bicarbonate, then earth alkaline water with increased portions of alkalis and prevailing chloride and alkaline water with lastly prevailing chloride. Most of the water samples were found to be oversaturated with respect to calcite, aragonite, dolomite, and chalecdony, while understurated with respect to gypsum and magensite mineral phases. Only the deep wells were found to be free of coliform bacteria. The water of a few springs exceeds the WHO guidelines for NO_3^-, the water of all the springs and wells is good for irrigation.

Qannam (2003) in his Ph.D thesis studied, He calculated the annual precipitation over the study area to be equal to 38.14 Mill.m^3. Also he found the values of the average pan coefficient, potential evapotranspiration, runoff and actual evapotranspiration to be 0.72, 1108mm/yr, 6.44Mill.m^3/yr and 8.87Mill.m^3 respectively. In his study he found that rain water is the only source of ground water recharge. The modifications in the water types and quality recorded in his thesis are as a result of mixing with waste water leaking from cesspits, and the waste water conduit and /or the infiltration of the leachates from washing the piles of animals dung by the rainfall in winter.

He found that springs and dug wells located between the houses and conduit showing slight contamination, all the samples tested for the $\delta^{18}O$ and $\delta^{2}H$ plot on the Mediterranean Meteoric Line showing rainfall origin, and the ^{3}H analysis show a recent water for the majority of the samples.

Suction cup method used to study the effects of waste water conduit on the chemistry of the rainwater during infiltration, at the depth of 30 cm the bicarbonate dominates the anions, but with depth the chloride increases to dominate the anions at depth of 90cm, also the EC of the recharge water increase significantly in the first 30cm of infiltration.

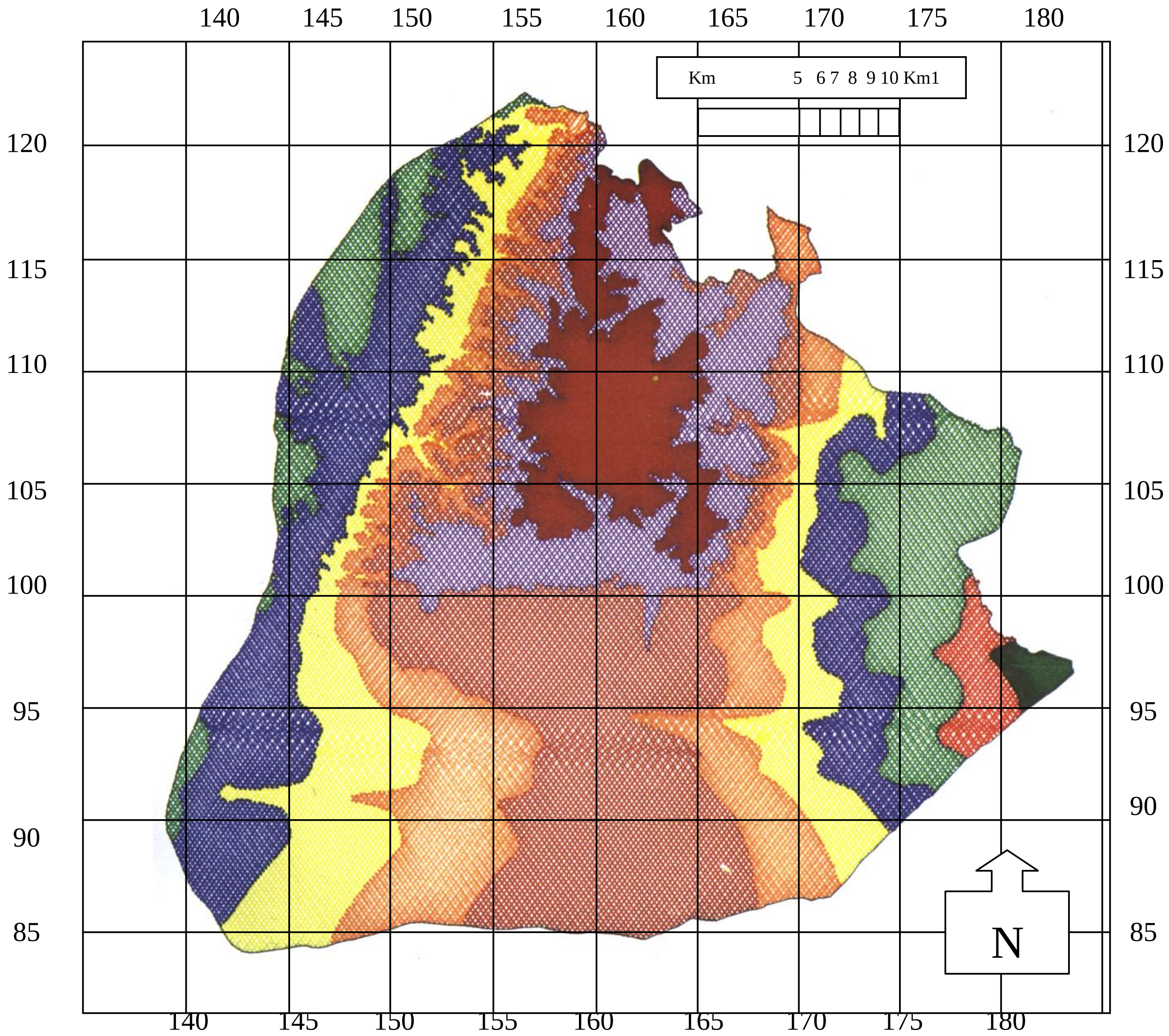
PHG-Palestinian Hydrology Group (2005), In their study they estimated the mean annual precipitation, infiltration and the runoff in the Hebron district to be 390Mill.m^3, 105Mill.m^3 and 15.8 Mill.m^3 respectively. While 2.1Mill.m^3 calculated to be discharged from the springs and dug wells in the study area. They found that the nitrate in 44% of the springs and dug wells tested were exceeded the acceptable standard levels. The shallow aquifer were the higher the polluted. They found that the high pollution of nitrate and chloride was as a result of sewage, fertilizers and manure contamination.

The springs and dug wells water was dominated with the normal earth alkaline water with prevailing bicarbonate/ chloride or sulfate. Durov diagram shows that the water of 34 springs and dug wells is of recharge water type. The study shows that nitrate is increasing during the last 6 years, also the majority of the springs and dug wells water is oversaturated with respect to aragonite, calcite and dolomite.

1.3. Topography

The Hebron district is characterized by great variation in its topography and altitude. The highest elevation of approximately 1011m above mean sea level (amsl) is represented by Halhul area. The eastern slopes, show elevations, which drops to 100m above the sea level. The majority of the Palestinian built-up areas are located at elevations between 600m and 1000m above sea level (Fig. 1.2), (Arij, 1995).

There are two main drainage systems in the Hebron district. The first system runs to the west or south-west (wadi Al-Aroub, wadi Hasaka, wadi Qura, wadi Nar….), the second system runs to the east or south-east. (Wadi Umm El'adees, wadi Abu El-Haiat, wadi Ghar…).



🟩	100-200	🟦	400-500	🟥	700-800	HEBRON DISTRICT DIGITAL ELEVATION MODEL LAP
🟥	200-300	🟨	500-600	🟪	800-900	
🟩	300-400	🟧	600-700	🟫	>900	

Fig 1.2: Topographic map for Hebron district (Arij, 1995).

1.4. Objectives:

The main aim of this study is to provide a hydrological, hydrochemical and water quality data-base for the surface and subsurface water (springs) in the Hebron district drainage basin, and to determine the pollutants, their possible sources and their impact on the springs.

A successful tracing of ground water recharge/ discharge mechanisms requires geochemical and isotopic techniques.

The core of the investigations is a broad spectrum of chemical and isotopic analysis. Groundwater recharge, groundwater flow and discharge mechanisms as well as degradation of ground water quality, a successful implementation of the results of this research will be improve the decision-making processes with respect to the sustainability of water resources in the region. The use of isotope techniques in identifying recharge areas and discharge zones as well as stalinization sources is new in the West Bank. Piper, Durov and Wilcox diagrams were used to determine the water types and the suitability of water for drinking, irrigation, and domestic purposes, statistical analysis using the SPSS 10.0 and excel programs were used to classify the springs depending on the common characteristics between the variables calculated and measured.

Finally there will be a microbiological assessment for the major springs used for drinking in the study area to decide if they are suitable for drinking purposes.

The studding of the aquifer characteristics is one of the targets of this study. Finally there will be recommendations to avoid the springs any pollution from the surrounding areas, especially these used for domestic and agricultural purposes.

Springs are an important but secondary source of water for domestic purposes for irrigation and other agricultural uses through out the Hebron district.

Rural areas in Hebron district depend on spring water through their daily activities, so the proposed study is intended to study the evolution and behavior of the ground water in shallow portion, of the mountain aquifer in Hebron district.

1.4.1. The study has the following objectives:

1. Sampling and testing the water of the springs with respect main parameters (chemical, physical, biological and isotopical).
2. Evaluating the water of the springs pollution using nitrate, chloride and other parameters.
3. Evaluating the water of the springs for irrigation using SSP and SAR.
4. Evaluation of the different sources (natural as well as anthropogenic) of the dissolved substances.
5. Estimating and measuring the discharge of the target springs.
6. Estimating and measuring the recharge area.
7. Estimating and measuring the storage capacity of the target springs.
8. Identifying the aquifers where the springs discharge from.

1.5. Methodology:

Published and unpublished scientific papers, reports, maps, and many documents including relevant official Palestinian documentation were reviewed. Interest was given to contamination, discharge, and water quality information about the springs in the Hebron district.

1.5.1. Field work

A comprehensive sampling program and discharge measuring concerning 43 springs Appendix. (1.1) in Hebron district was carried out from October, 2003 to July, 2004. Two bottles for each sampling site were collected in polyethylene (1000mL) bottles for chemical analysis. Each bottle was rinsed with the water intended for sampling. Each bottle was filled completely and placed in a cold box until arrival at the laboratory. The temperature, pH, and EC were measured in field using a Mettler – Toledo set of pH meter and EC - meter.

For discharge measurments, two containers 18L and, 9L were used. The discharge of selected springs was measured weekly a long one year Appendix. (1.2).

1.5.2. Laboratory work

The analysis of the water samples was conducted in the laboratories of Biological and Chemical analysis center and the laboratories of the Department of Earth and Environmental Sciences of Al-Quds University.

In these Laboratories, the samples were analyzed for the major cations (Ca^{+2}, Mg^{+2}, Na^{+1}, K^{+1}) and major anions (Cl^{-1}, SO_4^{-2}, NO_3^{-1}, HCO_3^{-1}) Table (1.1). Isotope analysis were done in Germany, in the laboratories of the UFZ.

Table 1.1: The analysis methods used in determining the various parameters.

Parameter	Method of analysis
Temperature, EC, and pH – values.	Field Multi – electrode meter (Mettler Toledo).
Ca^{+2}, Mg^{+2}	Titration with Na_2 – EDTA using Murexide and Eriochrome black T indicators.
Na^{+1}, K^{+1}	flame photometer.
SO_4^{-2}	Turbidimetric method, spectrophotometer (λ = 220 nm).
NO_3^{-1}	UV-spectrophotometer method (λ = 220 nm).
Cl^{-1}	Titration with $AgNO_3$ using potassium chromate as indicator
HCO_3^{-1}	Titration with HCl using bromocresol green and phenolphthalein indicators.

1.5.3. Mean Annual rainfall

The total volume of the rainfall over the study area, the recharge, and actual evapotranspiration were calculated. Isohyetal method was used to determine the average (mean) annual depth of rainfall over the study area, here contour line map of raining used.
The areas between each two lines was measured, then was multiplied by the average precipitation between them. Then we divide the summation of the results calculated by the total area of the catchment areas, as in the formula (Chow *et al.* 1990).

$$P_m = \sum (A_i * P_i)/A$$

Where :
P_m : mean rainfall (precipitation) in (mm).
A_i : sub area between two contour lines.
P_i : average precipitation between two successive contour lines. (P1, P2), equals (P1 + P2)/2.
A : Total area; which equals to $\sum A_i$.

1.5.4. Estimation of the surface runoff:

Goldschmidt formula was used to estimate the surface runoff.

Soil surfaces of low hydraulic conductivity could lead to average annual runoff which may reach 20% of the annual precipitation. This done according to Goldschmidt formula (Arad and Michaeli 1967).

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

Where
Q: the average annual run off (mm/yr).
P: the average annual rainfall (mm/yr).

This equation could be used for soils of low hydraulic conductivity like sandy clay soils.

1.5.5. Estimation of infiltration and recharge:

Two methods were used to estimate the recharge in the study area;

a. The chloride mass – balance method.
b. The Goldschmidt and Jacobs formula.

The following equation could be used to estimate the infiltration.

$$R=P_e – Q$$

where

R: Infiltration.
P_e: Effective rainfall.
Q: Runoff.
All parameters in (mm/yr).

1.5.5.1. Chloride mass balance

Chloride mass-balance method assumes that chloride enters the ground water through precipitation only. And its concentration should increase as a result of evaporation because it is non-volatile (Eriksson and Khunakasem 1969 and Bazuhair and Wood 1996). The chloride is conserved in the system as this method assumes, and it will not react or disappear when mixed with other components of ground water. It is assumed that steady-state conditions are maintained in the system, so that long term average concentrations and rainfall amounts are used in the calculations. Finally, it is assumed that surface runoff is known, and that evaporation from the ground water doesn’t occur.

According to this, only the chloride analysis of the springs that are uphill and far away from contamination sources, were used to represent the concentration of chloride in the groundwater. This is to ensure that the chloride is only of airborne origin and to ensure no up-gradient evaporation from the sampling points. Because the runoff in this area can not be neglected and it supposed to remove some chloride that will not be reach the groundwater. The concentration of the mass lead to the following relation between the precipitation and recharge. (Eriksson and Khunakasem 1969):

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

Where :

R: The annual recharge. (mm)
P: The annual precipitation (mm).
Q: The average annual runoff (mm).
C_{gw}: The concentration of chloride of groundwater mg/L.
C_p : The weighted average chloride concentration in precipitation.
(wet and dry deposition) and both in (mg/L).

1.5.5.2. Goldschmidt and Jacobs formula:

According to Goldschmidt in (Lerner et al.1990), the recharge in catchments in Turonian and Cenomanian limestone's aquifers in Palestine, can be calculated from the following equation:

$$R= 0.86 * (P - 360)$$

Where

R: The annual recharge (mm).
P: The annual precipitation (mm).

Result of the above equation is that there will be no calculated recharge in arid regions that have precipitation less than 360 mm/yr. However, that doesn't confirm with empirical data. One reason for this is that in arid regions the extent of vegetation cover on the rocks is negligible and the transpiration is marginal. In other words the relation between precipitation and recharge above and below the threshold amount, which enables vegetation, is not linear. Another reason is that recharge is dependent on singular rain events and their intensity and not so much on the yearly average of rainfall.

1.5.6. Discharge

discharge could be calculated using the formula prepared by Maillet (1995). The equation is used in this study to calculate the discharge depletion coefficient (α) for each spring with discharge measurements during the period from October, 2003 and October, 2004.

$$Q_t = Q_o e^{-\alpha t}$$

Where:

Q_o = the discharge in M/day at the beginning at time t_o .
Q_t = the discharge in M/day at time t.
e = basis of natural logarithm
α = discharge depletion coefficient.

The available data deals only with Q and t since they are the parameters which can be directly measured.
Again we want to use another formula to calculate the amount of water stored in the aquifer at the beginning or at any other time during the discharge period, the formula used is.

$$Q_s = (Q_o / \alpha) * 86400$$

Where:
Q_s = amount of stored groundwater at any chosen time.
86400 = the number of seconds a day.

1.5.7. Quantitative recharge estimates:

Most of the previous recharge estimations are simplifications of the real situation and are missing factors that control the actual amount of recharge. An empirical formula was developed that relates runoff and recharge directly to the long term precipitation over the catchments area (Goldschmid, 1955).

$$RR = 0.9 * (avP – 360)$$

Where:

RR = recharge and runoff (mm).
avP = average annual precipitation (mm).

The factor 0.9 is related to the evapotranspiration loss. The value 360 represents the minimal rainfall needed to give an active contribution to the groundwater table. After measurements of the recharge which where conducted by Goldschmid and Jacob (1958) the formula of 1955 was modified to the following formula:

$$R = 0.86 * (avP – 360)$$

Where:
R = recharge (mm).
avP = average annual rainfall (mm).

The authors assumed that 4% of the recharge and runoff factor of Goldschmid formula is surface runoff. However, other authors give conflicting figures: Schneider (1966) who analyzed a 20-year record of runoff and rainfall for a drainage area of 75km^2 near Jerusalem. Runoff ranged from 0-17% of the annual rainfall and the long term average was 6%.
Rofe and Raffety (1963) estimated that the potential runoff element varies from 7-14% of the total precipitation in the Jerusalem area, whereas in the other parts of the West Bank, surface runoff is less than 5% of the annual rainfall (Rofe & Raffety, 1965).
Taking into account that recharge occurs also in areas were the average annual rainfall is less than 360mm/yr, Guttman and Zuckerman (1998) developed a modification of the Goldschmid and Jacob formula for their model of the lower aquifer in the eastern basin

$R = 0.8 * (avP – 360)$	Rainfall > 650 mm
$R = 0.534 * (avP – 216)$	Rainfall 300 – 650 mm
$R = 0.15 * avP$	Rainfall < 300mm

Where:
R = recharge (mm).
avP = average annual rainfall (mm).

Chapter two

Hydrology

2.1 Climate

Hebron District enjoys a Mediterranean climate, with hot dry summers and mild wet winters. The climate of Hebron district ranges from arid to semi-arid with an increase in aridity towards the Negev desert in the south and the Jordan valley in the east. The central highlands, trending roughly north-south, with elevations up to 1000m above sea level, which acts as a climatic barrier, responsible for the rain-shadow desert to the east, down to the dead sea. At an elevation of 400m below sea level. Rain fall on the central highlands averages 680mm/yr and becomes less than 100mm/yr at the Dead Sea. However, great variations in rain fall and distribution exist (Arij, 1995).

2.2. Wind

Usually Hebron District experiences western winds. During autumn and spring seasons, and these winds are usually humid, during summer and are north-west (Kessler, 1994). From late April to mid-June, the Hebron District is often hit by storms known as the Khamaseen, which originates from the Arabian desert and these winds blow at the beginning and end of summer period. The maximum wind speed averaged at January 312 km/day, and the minimum of 232km/day at October (Fig. 2.1), Table (2.1).

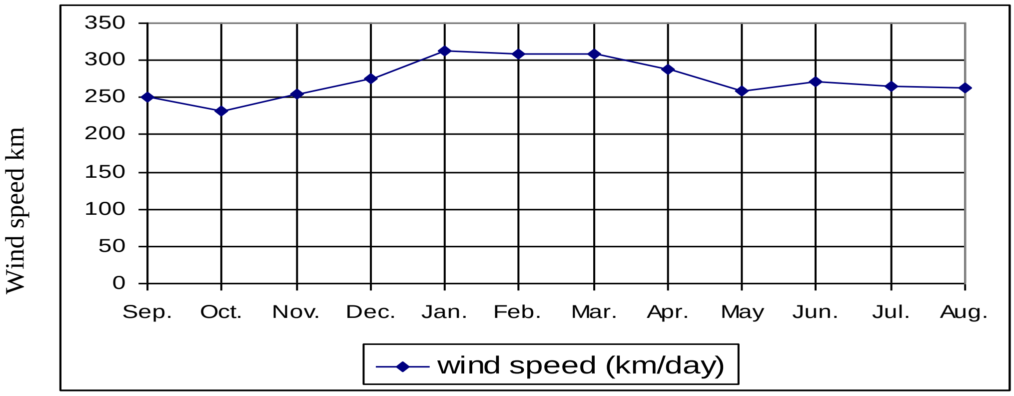


Fig 2.1: Average monthly Wind speed (km/day) in the Hebron district from 1970-2004.

2.3. Temperature

No big deviation between summer and winter in the average temperature which ranges from 7.0-11°C in winter and from15-23 °C in summer. The minimum temperature is –3 °

C in winter (January) and the maximum is 40 °C in August. The ground temperature ranges from a minimum of -5 °C in January, to a maximum of 42 °C in the summer season, (Fig. 2.2), Table (2.1).. (Kessler, 1994).

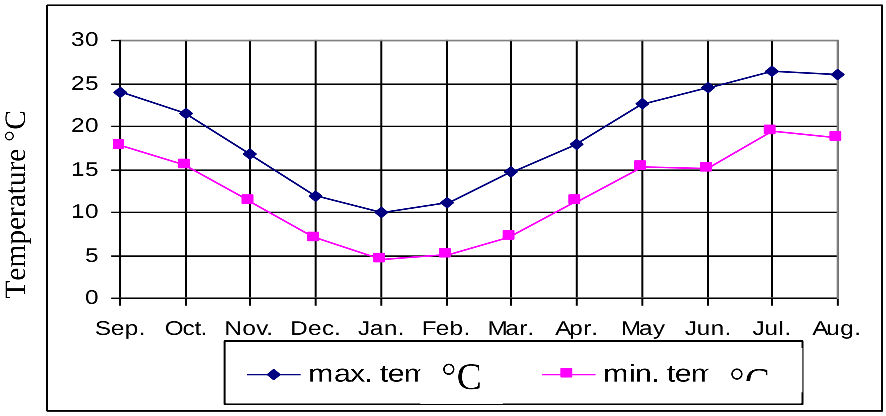


Fig 2.2: Monthly Minimum &Maximum Temperature (°C) in the Hebron district from (1970-2004).

2.4. Relative humidity

The mean range of annual relative humidity is 60-75%. The relative humidity reaches 40% in mid-day and increases gradually to reach 80-100% as an average at night. The minimum mean relative humidity from (1970-2004) is 47% and the maximum mean is 74.5% (Fig. 2.3), Table (2.1) (Hebron Climatic Station (2004, Kessler, 1994).

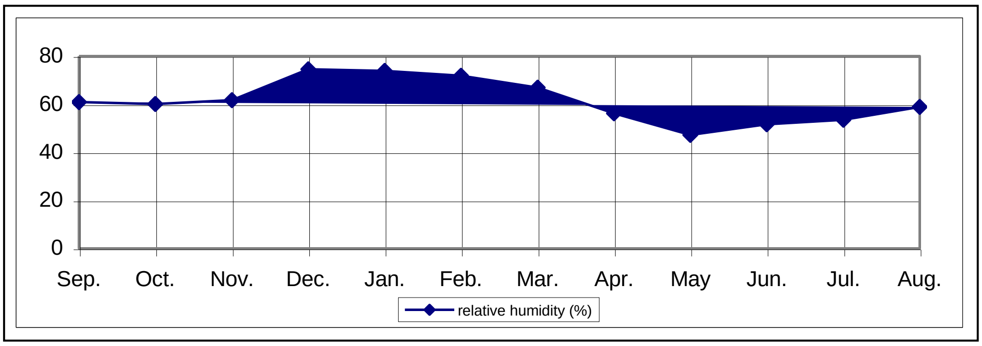


Fig 2.3: Average monthly mean relative humidity(%) in the Hebron district from (1970-2004).

2.5. Rain fall

The mean annual rain fall for the period of 1970-2004 of the Hebron meteorological station was 563 mm/yr (Hebron Climatic Station (2004). The mean annual rain fall in Hebron city disvaries from year to year, while the rain fall reaches 1062 mm in the wet years, it drops to 200mm/yr during the dry years (Hebron Climatic Station (2004). The rain fall decreases from 619.4mm at Al-Aroub in the north to 320mm/yr at Al-Dahriya in the south of the district and 200mm at the eastern boundaries (Fig. 2.4). During the wet year 1979-1980, rainfall reached up to 876mm and in 1991-1992 reached 1062.5mm Table (2.1) (Hebron Climatic Station (2004).

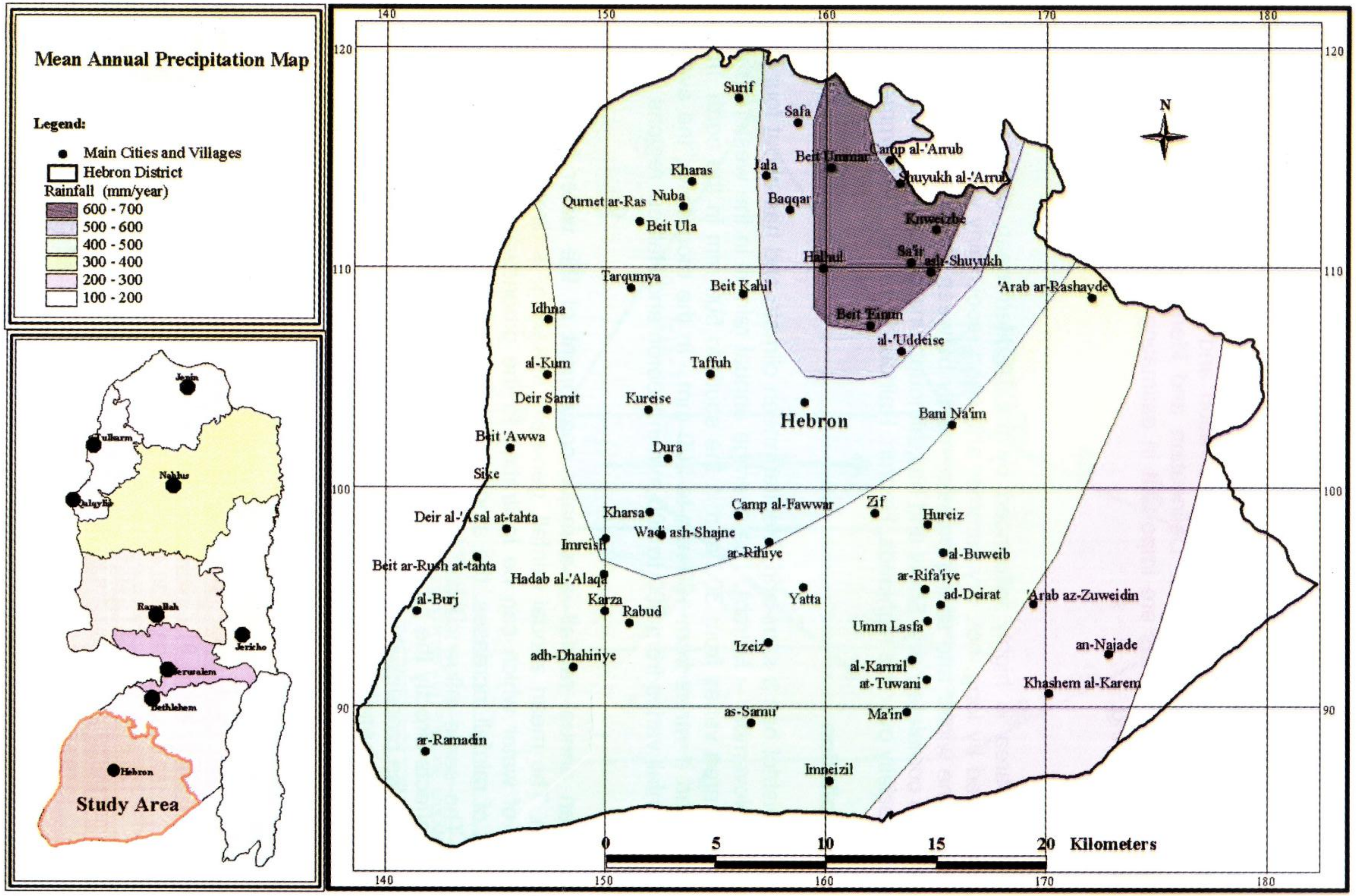


Fig 2.4: Mean annual precipitation map of Hebron district. (modified after Palestinian Hydrology Group, 2005 and atlas of Israel, (1995)

Most of the rain falls during December through February also March has a significant amount of rainfall (Fig. 2.5), although there is rain from mid- October to the end of April.

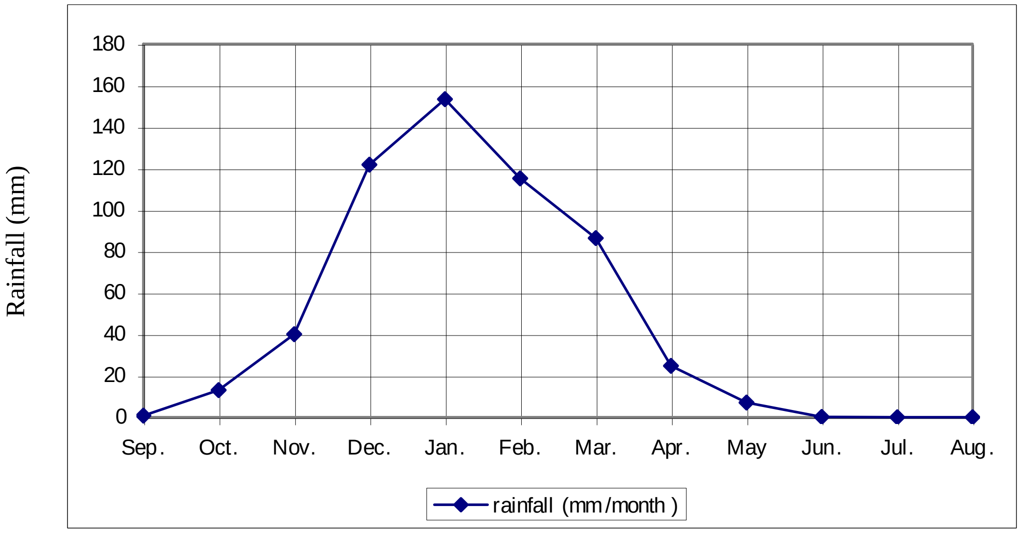


Fig 2.5: Monthly mean rainfall (mm/month) in the Hebron district from (1970-2004)

Rainfall on the mountains is higher than the rainfall on the valleys. Also it decreases eastwards, westwards and to the south (Fig. 2.6).

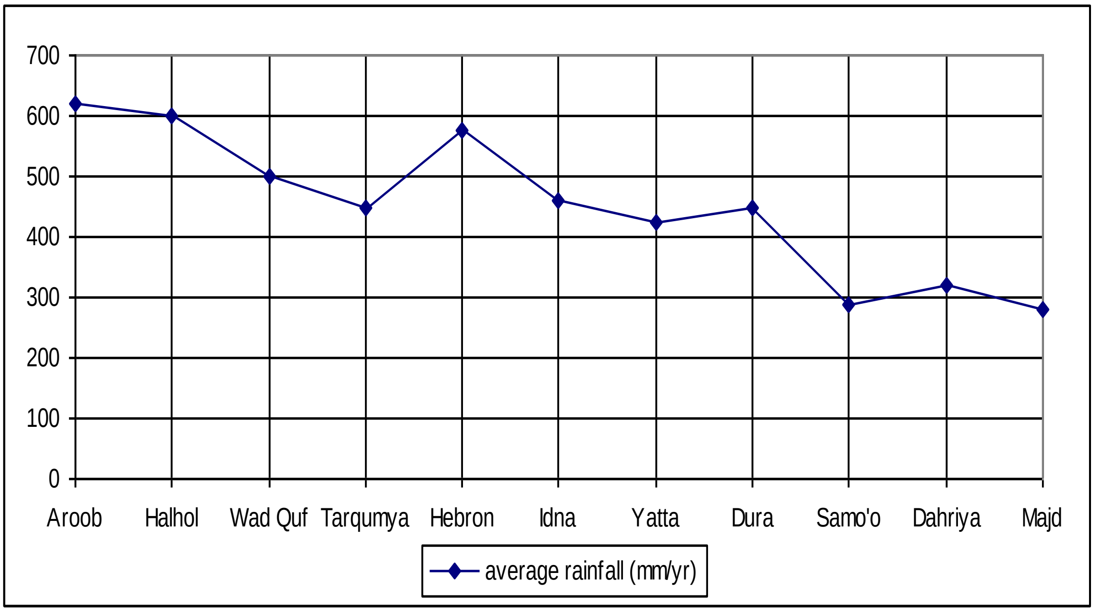


Fig 2.6: Mean annual rainfall (mm) in the Hebron district from 1990-2004. (Hebron Climatic Station, 2004).

2.6. Evaporation

Potential evaporation varies from 2mm/day in December to 8.5mm/day in August. There are only four months (October to March) of the year where rainfall exceeds potential evaporation, the other months (April to November) deficiency in the water level occurs as a result of evaporation rate, which becomes more than the rainfall average (Fig. 2.7), Table (2.1) (Hebron Climatic Station, 2004).

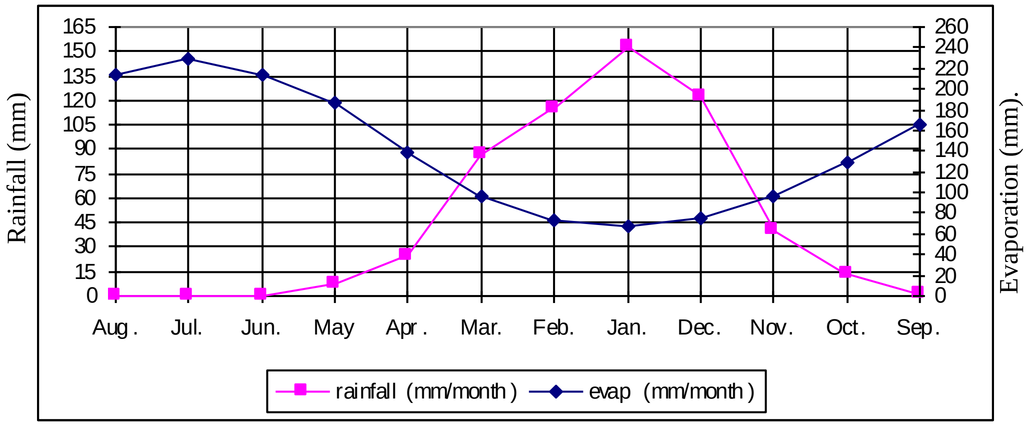


Fig 2.7: Monthly rainfall and evaporation relationship in Hebron district, from (1970-2004).

2.7. Solar radiation:

There are 5-6 hours/day of sunshine in winter, and from 10-11 hours/day during summer (Fig. 2.8), The annual mean solar radiation incident on horizontal surface for Hebron is approximately 2.1kj/cm^2/day Table (2.1). (Atlas of Israel, 1995).

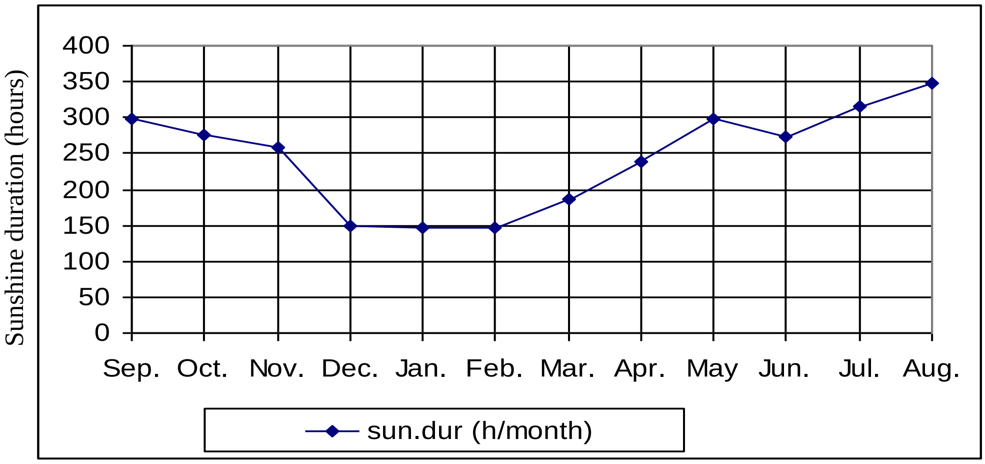


Fig 2.8: Monthly mean radiation (h/month) in the Hebron district from (1970-2004).

Table 2.1: Meteorological conditions at the Hebron Weather Station.

Month	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.
Rainfall (mm/month)	0.76	13.03	40.11	121.85	153.36	115.23	86.32	24.81	7.09	0.23	0.00	0.00
Evaporation (mm/mon)	166.17	128.65	97.03	74.57	67.91	72.47	96.60	139.38	186.30	214.39	230.09	214.46
Sun.Dur h/mon)	298.95	276.72	258.62	149.83	147.20	145.63	186.26	239.62	297.55	274.22	316.63	347.07
R.H(%)	60.83	60.07	61.66	74.47	73.79	71.86	66.86	56.13	47.25	51.71	53.51	58.82
Average Temperature (°C)	20.85	18.53	14.13	9.48	7.25	8.08	10.91	14.63	18.97	19.82	22.93	22.37
Average Maximum temperature (°C)	23.99	21.59	16.85	11.95	9.98	11.05	14.74	17.85	22.62	24.45	26.33	26.02
Average Minimum temperature (°C)	17.72	15.46	11.40	7.01	4.53	5.10	7.08	11.42	15.32	15.19	19.52	18.73
Pressure. (96-2003)	899.97	901.63	902.31	902.01	900.97	901.16	899.11	899.26	899.34	898.14	896.76	897.74
W.speed (km/day)	249.62	232.15	254.05	275.45	311.95	309.35	309.45	288.70	259.15	270.35	264.40	262.10

Source : Israel meteorological service
Table Notes:
R.H: Relative Humidity.
Sun. Dur: Sunshine Duration.
W.speed: Wind speed.

Max.: Maximum., Min.: Minimum

2.8. Discharge of springs:

2.8.1. Springs classification

Springs emerge when the local ground water level of the unconfined aquifers rises above ground level. The springs can be divided into five groups depending on the mechanism of their discharge (Fig. 2.9).

- Depression springs: this type appear when the water table reaches the surface in morphological depressions (Bryan, 1919).
- Fault springs: the ground water force to drain to the surface when the rocks of low permeability are shifted adjacent to the aquifer.
- Contact springs: when a rock unit of low permeability underlain a permeable rock and the water drains freely under gravity to the ground surface (Bryan, 1919).
- Sinkhole springs: they are found in carbonate environments. In these areas runoff carried as subterranean flow through joints and fissures but mostly in karst conduits. Springs may be found when karst conduits are tapped by a karstic shaft (String field, 1966).

- Fracture and Joint springs: springs of this type may emerge where the water table reaches the surface at low elevations, and this done only when the flow within a rock type is restricted to joints and fractures (Bryan, 1919).

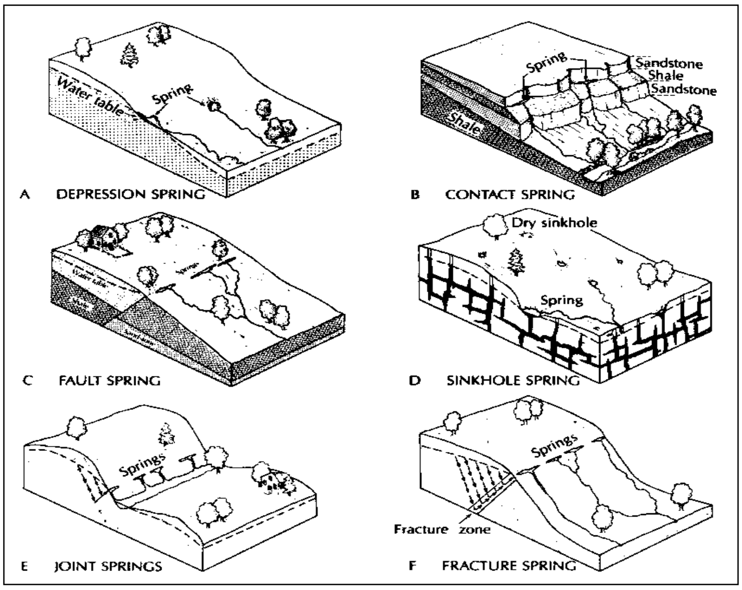


Fig 2.9: Types of springs (Fetter, 1994).

So springs in the study area are either perennial (Dilba, Ma’moudi, Fira’a) or intermittent (Misleh, Khalt Diab, Kurza). In general springs of the study area have a flow of less than 100 L/s.

Continuous discharge measurements are essential for 11 springs from October, 2003 to October,2004 in the Hebron district. Some of them are discharging fresh water others are polluted and unsuitable for human consumption.

Discharge could be calculated using the formula prepared by Maillet (1905). The equation
To calculate the (α) value, a one month period of time was taken for all springs using the discharge measured in March as Q_o, and the discharge measured in April as Q_t, (Table 2.2).

Table 2.2: The calculated values of both the Q_s and α for the springs in the Hebron district during the year 2003/2004.

spring	Time days	Q_o (m^3)	Q_t (m^3)	α/sec	Q_s measured		Discharging Years
					(m^3)	Million.m^3	
Ma'moudi	31	0.0006	0.0006	0.0011	50535.9	0.051	2.732
Elsa'abiya	31	0.0013	0.0012	0.0004	276152.3	0.276	7.725
Knar El-Sharqiya	31	0.0002	0.0001	0.0106	1480.1	0.001	0.384
Fira'a	31	0.0010	0.0010	0.0017	49980.8	0.050	1.865
Dilba	31	0.0010	0.0009	0.0046	18849.4	0.019	0.686
Hasaka	31	0.0009	0.0008	0.0051	15217.5	0.015	0.693
Knar El-Wista	31	0.0002	0.0002	0.0015	12659.4	0.013	2.345
Longor	31	0.0022	0.0020	0.0038	50434.7	0.050	0.793
Eth - Tharwa	31	0.0004	0.0003	0.0119	2748.6	0.003	0.308
Misleh	31	0.00005	0.00005	0.0026	1645.4	0.002	1.636
Deir Bahha	31	0.0001	0.0001	0.0005	22410.0	0.022	0.004

2.8.2. Longor spring

It is located at the coordinates 156,900 east and 101,900 north at an elevation of 870 masl. The spring discharging into Wadi Longor.

The water of this spring was used for domestic purposes until the report of the environmental Authority found that this spring is unsuitable for the purpose. The spring is used now for irrigation and livestock.

The Longor spring discharging from Aminadav Formation which is known as a good aquifer underlain with Moza Formation which acts as Aquiclude. As a result of this consequence of rocks, the spring can be classified as contact spring, because the Aminadav Formation consists of karistic limestone and dolomite, but the Moza Formation consists of marl, clay, and marly limestone.

The discharge of Longor spring depends on the amount of precipitation in the recharge area, which means that its discharge increase in the wet and rainy years, and decrease in the dry years (Rofe & Raffety, 1963). During the period from October, 2003 to October, 2004 the average discharge from Longor spring was 63617.9 m^3/yr. The average discharge of Longor spring during the period from 1982/1983 to 1993/1994 is 53666.7 m^3/yr with maximum discharge of 110,000 m^3/yr in the rainy year 1991/1992, and with minimum discharge of 26,000 m^3/yr in the dry year of 1984/1985 (Fig. 2.10), (Arij, 1995).

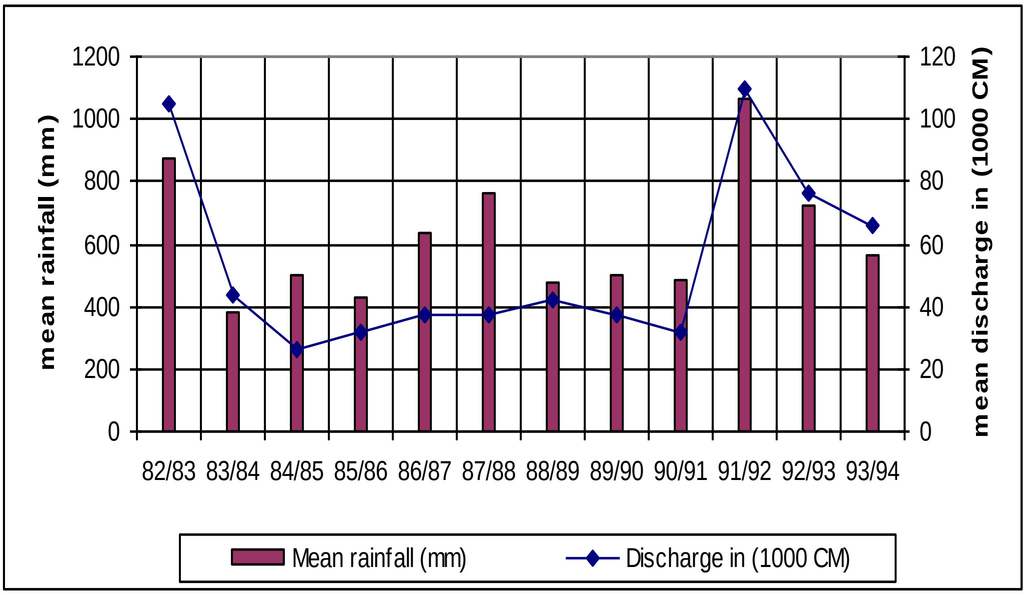


Fig 2.10: The discharge of Longor spring and the main annual rainfall in the period 1982-1994(Arij, 1995, and Hebron Climatic Station, 2004).

The measurements of the discharge for Longor spring from the year 1982 to 1994 shows that this spring depends on the precipitation in its discharge. The measurements of the discharge during the year 2003/2004 show that the delay between the beginning of the rainy season and the spring outflow is about two months (Fig. 2.11). The highest rainfall month was January, but the maximum discharge value appeared in March with a delay of two months of response (Fig. 2.11). This is as a result of the long distance between the recharge area and the discharge area. The spring never dried because of its large storage which was calculated to be 50434.7m^3.

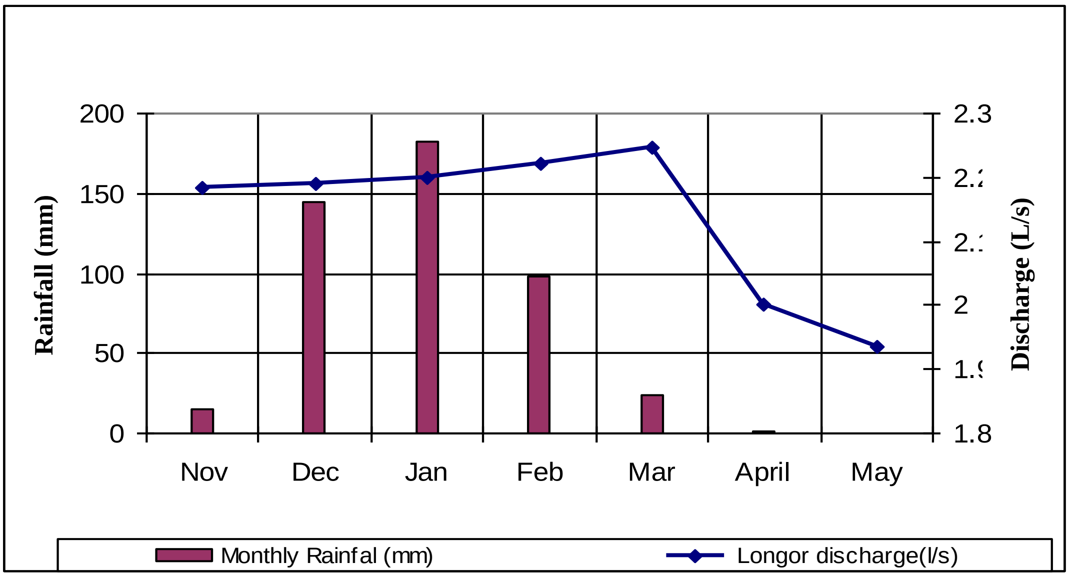


Fig 2.11: The discharge of Longor spring and its response to the rainfall from month to month during the year 2003/2004.

2.8.3. Misleh and Deir Bahha springs

Misleh spring is located at 161,200 east and 111,400 north, and Deir Bahha is located at 157,300 east and 105,600 north, they are used for irrigation and for domestic uses, but Misleh spring is very weak spring which dry at the end of dry years.

Misleh spring classified as sinkhole spring because of the karst conduits, joints and fissures in the area of the spring, and the area is of carbonate rocks type. Deir Bahha spring discharges from the upper Beit Kahil Formation and this may be restricted to joints and fractures. The water table reaches the surface because of the low elevation of the spring to be of fracture or joint classification.

There are no available measurements for the discharge of these two springs Misleh and Deir Bahha. Only the measurements of the discharge during the period from October, 2003 to October, 2004 give a discharge of 1006.1 m^3/yr for Misleh spring and 3637.8 m^3/yr for Deir Bahha spring (Fig. 2.12).

In Fig. (2.12) the maximum response of discharge to the maximum rainfall in January takes place in March. This means that the springs response to the recharge occurs two months later and this was as a result of a non proximate recharge area to the discharge place, and no fast travel times can be assumed.

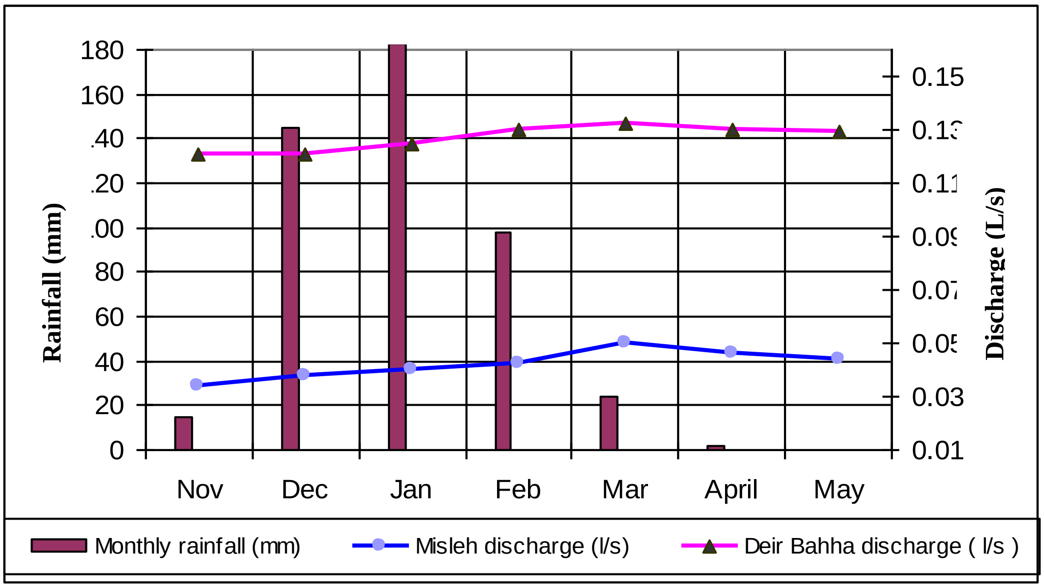


Fig 2.12: The discharge of Deir Bahha and Misleh springs and their response to the rainfall from month to month during the year 2003/2004.

2.8.4. Hasaka and Ma'moudi springs:

Hasaka spring is located at 158,500 east and 108,200 north and Ma'moudi spring located at 153,900 east and 104,500 north. Both of them are used for irrigation and domestic purposes. They are in the Alabian geological time, Hasaka spring issues from the lower Beit Kahil Formation, which consists of two aquifers, Giva'at Yearim and Kefira with thickness of 20-70m and 120-180m respectively (Qannam, 2003), and this spring can be classified as depression spring. Ma'moudi spring issues from the upper Beit Kahil

Formation and consists of two aquifers, Kesalon with thickness of 30-50m and Soreq with thickness of about 110-170m, and this spring can be classified as contact spring as a result of Moza aquifer underlain by Beit Meir aquiclude in Yatta formation which overlain the upper Beit Kahil formation.

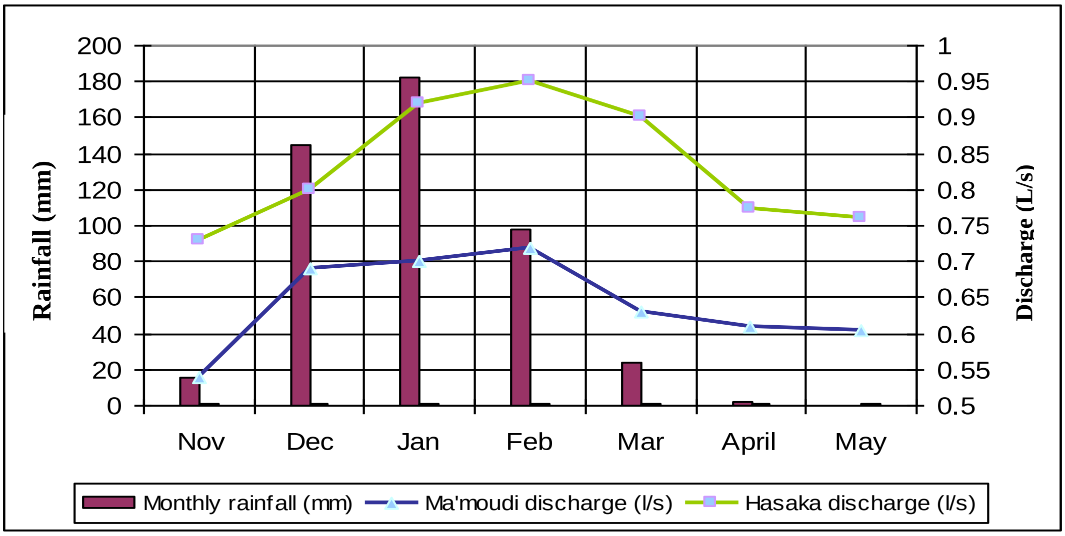


Fig 2.13: The discharge of Ma'moudi and Hasaka springs and their response to the rainfall from month to month during the year 2003/2004.

Fig.(2.13) shows that the response to the rainfall is quick for Hasaka and Ma'moudi springs during less than one month which means proximate recharge area and fast travel for the recharged water. Hasaka spring discharged 21961.5 m^3/yr during the year 2003/2004, but Ma'moudi spring discharged 18495.7 m^3/yr in the same year. Ma'moudi spring continue discharging during the years of low rainfall because of its high storage of 50535.9 m^3, and this is as a result of its low discharging rate, but Hasaka spring will stop discharging in the dry years after 0.693 year because of its high rate of discharging.

2.8.5. Knar El-Sharqiya and Knar El-Wista:

They lie at the coordinates of 154,900 east and 101,500 north and 155,200 east and 101,600 north respectively. They are 850 masl and used for both domestic and irrigation purposes. Knar El-Sharqiya discharged 3855.7 m^3/yr with storage value of 1480 m^3 Table (2.2). Knar El-Wista spring discharged an average of 5398.5 m3/yr, and its storage value is 12659,4 m^3, so and as a result of its high storage value and low discharge rate it can be continue discharging during at least two years of dryness. Fig.(2.14) shows that the response of Kanar El-Wista spring to rainfall is lower than the response of Kanar El-Sharqiya spring which reflect the storage value of Kanar El-Wista spring and its importance.

2.8.6. Elsa'abiya Fira'a and Dilba springs

The three springs are located at the coordinates of 153,300 east and 104,200 north, 151,500 east and 105,900 north, and 154,860 east and 099,140 north respectively. All of them were measured for discharge through the rainy year from October, 2003 to October, 2004 with discharge of 35746.2 m^3/yr for Elsa'abiya, 26802.5 m^3/yr for Fira'a, and 27469.5 m^3/yr for Dilba spring with storage values of 276152.3 m^3, 49980.8 m^3, and 18849.4 m^3

respectively. Only Elsa'abiya spring can continue discharging for at least 7.7 years during dry conditions as a result of its big storage.

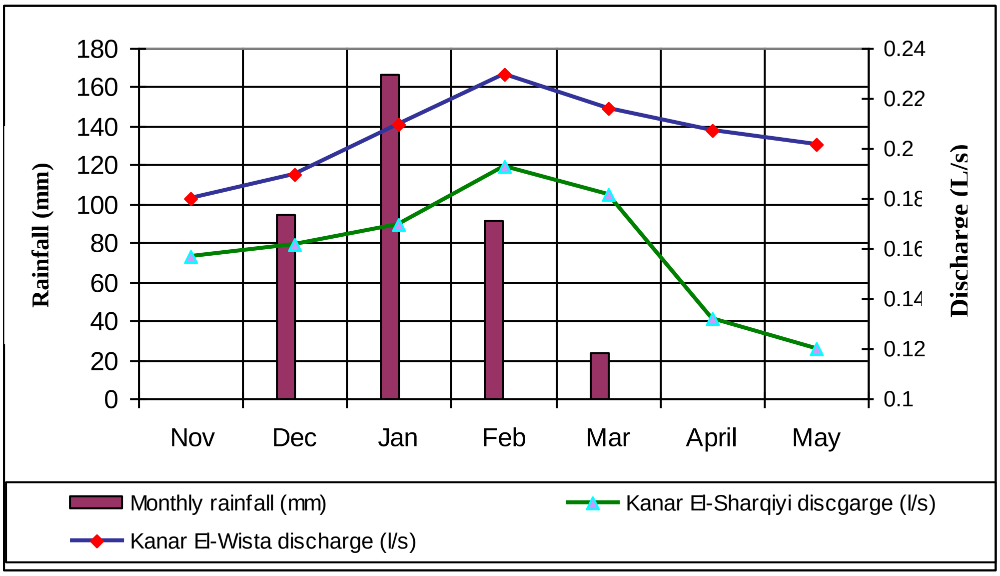


Fig 2.14: The discharge of Knar El-Sharqiya and Knar El-Wista springs and their response to the rainfall from month to month during the year 2003/2004.

All springs of this group have a clear response to the rainfall, and appear the low difference between the discharge of Elsa'abia spring during the dry and rainy months which proves its big storage. Dilba spring has delay for the rainfall three months later which means that the recharge area is of a big distance from the place of discharge or means that the conduits are narrow Fig.(2.15).

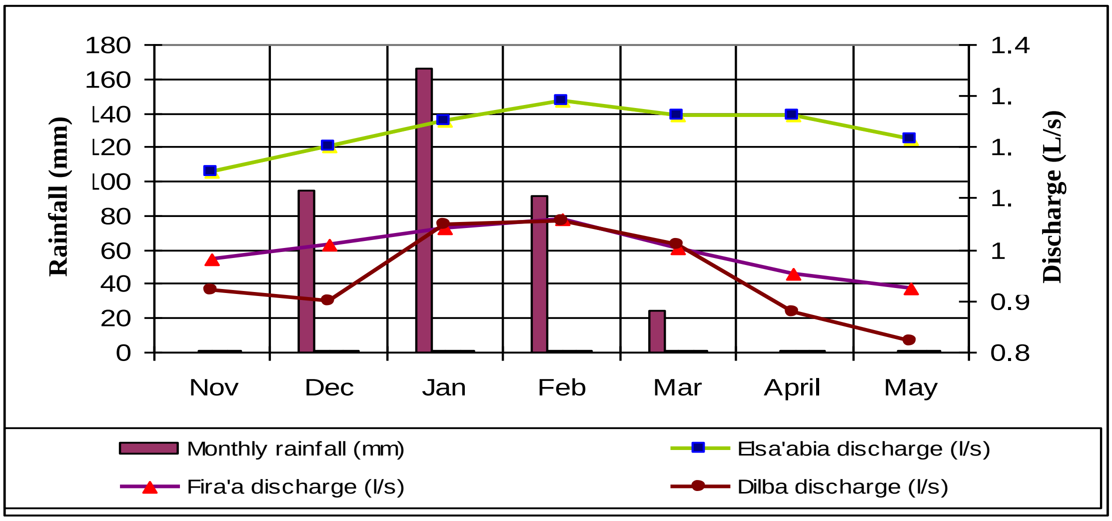


Fig 2.15: The discharge of Elsa'abiya Fira'a and Dilba springs and their response to the rainfall from month to month during the year 2003/2004.

Fig.(2.16) shows the response of Dilba discharge to the precipitation during the period of 1982 – 1994. The discharge gives a peak in the rainy year of 1991/1992, which is the year of the highest rainfall average during the period from 1982-1994. Another peak appear in the year of 1982/1983 because of its high precipitation average.

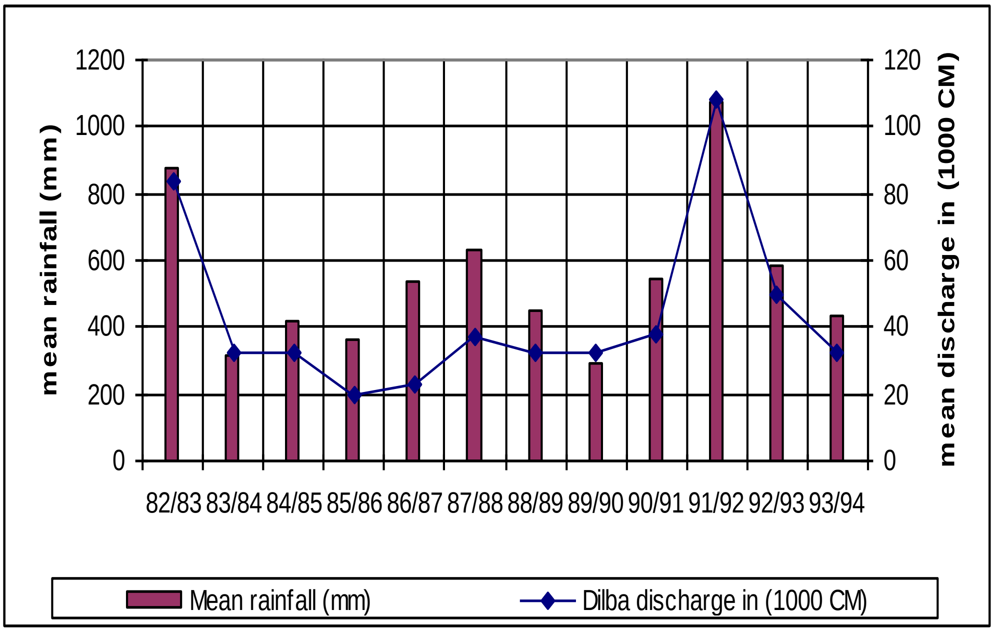


Fig 2.16: The discharge of Dilba spring and the main annual rainfall in the period 1982-1994 (Arij, 1995, and Hebron Climatic Station, 2004).

2.8.7. Eth-Tharwa spring

This spring is located at the coordinates of 159,600 east and 110,500 north, with discharge of 8919.4 m^3/yr and storage value of 2748.6 m^3. The delay of this spring to rainfall began three months after the rainfall, with quick response to rainfall which began in January Fig.(2.17). It can be concluded from the figure that the storage of this spring is small which means that it will dry immediately during the dry years.

Table (2.3): Location and discharge of the springs in the study area.

Spring name	Coordinates E ……….…..N		Elevation [masl]	Q m^3/yr	Min Q [MCM/yr]	Max Q [MCM/yr]	Aver Q [MCM/yr]
Ma'moudi	153,900	104,500	630	18495.65	0.0149	0.0223	0.0182
Elsa’abiya	153,300	104,200	600	35746.19	0.0295	0.0400	0.0353
Knar El-Sharqiya	154,900	101,500	850	3855.66	0.0016	0.0060	0.0038
Fira'a	151,500	105,900	580	26802.45	0.0161	0.0329	0.0264
Dilba	154,860	099,140	840	27469.45	0.0236	0.0327	0.0271
Hasaka	158,500	108,200	940	21961.54	0.0146	0.0295	0.0217
Knar El-Wista	155,200	101,600	850	5398.50	0.0028	0.0071	0.0053
Longor	156,900	101,900	870	63617.88	0.0552	0.0696	0.0627
Eth - Tharwa	159,600	110,500	975	8919.39	0.0065	0.0124	0.0088
Misleh	161,200	111,400	940	1006.12	0.0004	0.0015	0.0010
Deir Bahha	157,300	105,600	880	3637.80	0.0029	0.0041	0.0036

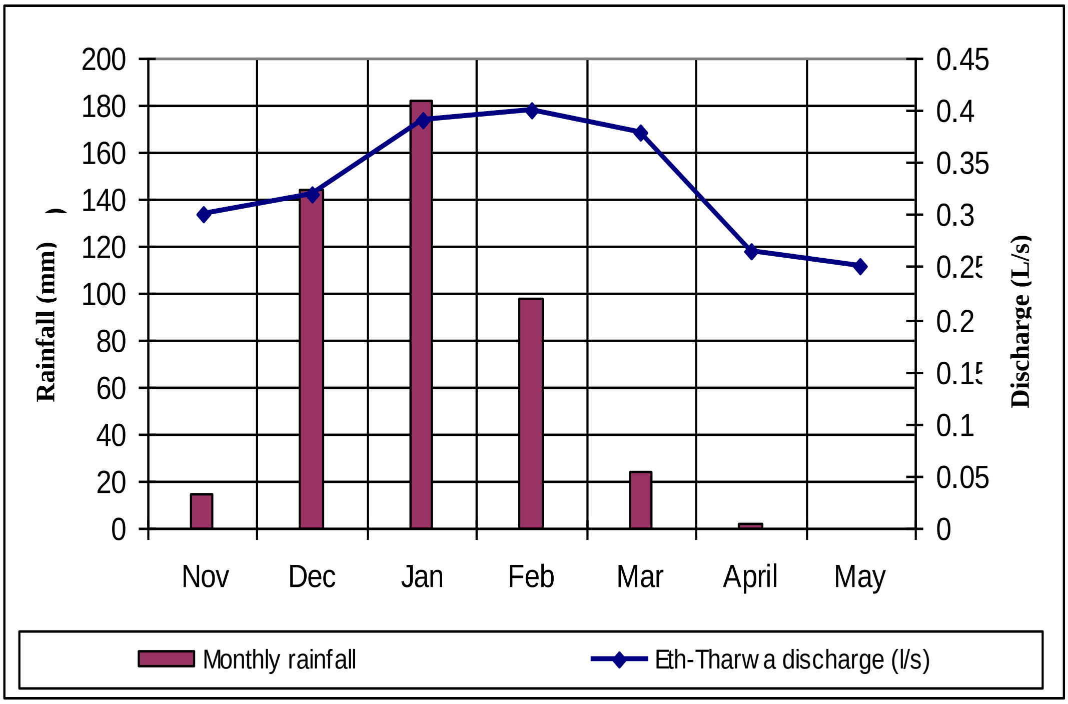


Fig 2.17: The discharge of Eth-Tharwa spring and its response to the rainfall from month to month during the year 2003/2004.

2.9. Recharge and recharge mechanisms:

Direct rainfall onto the outcrops of the aquifer and then downward percolation is the main source of recharge to the uppermost aquifer in the study area. Most of this recharge occurs in the central and higher mountains of the Hebron district. The infiltration rate decreases to the east of the district as a result of two reasons; first of all is the low rate of rainfall which do not exceed 100-200 mm/yr, second the out cropping limestone and dolomite of the uppermost aquifer which covered by almost impermeable chalks in the study area. The following factors affect the recharge value and mechanisms

2.9.1. Rainfall variations

In semi arid to arid areas, high annual variations in rainfall are common, for example at the Hebron station, the average annual rainfall for the last thirty four years (1970-2004) was around 563mm/yr (Hebron Climatic Station, 2004). However, the values for individual years lie in average between 255 mm/yr (1998/1999) and 1062.5 mm/yr (1991/1992), and thus vary by a factor of 4. This range is found in Dura, Yatta, and the other places of the study area. There is monthly and daily variation in the rainfall. The higher the average of rainfall in the months from November to March 95%, the lower is the rainfall from May to September. Daily precipitation range between 4mm to 21mm, but 55 mm may be recorded in storm events. This irregular rainfall makes it very difficult to calculate the actual recharge values.

Rainfall decreases towards the east, for example, in the last rainy season 2003/2004, 464mm/yr of rain were recorded in Hebron city, while only 325mm/yr of rain were recorded in Al-Samoo', and 285mm/yr were recorded in Yatta in the east.

2.9.2. Topography and Relief

Rainfall also depends on the topography, it is orographic precipitation. Deeply incised Wadis control the runoff, so recharge in Wadi beds with concentrated runoff has to be distinguished from recharge in the areas with Hortonian overland flow. High runoff rate during rain storms is generated by steep hill slope areas. This leads to high infiltration rates in the Wadi floors. This portion of recharge originally comes from rainfall areas not directly considered as potential recharge zones.

2.9.3. Geology

The runoff recharge is largely a function of geological parameters. For a large part of the study area, the Cenomanian – Turonian limestones support recharge. At some places in the study area, runoff is generated and proceeds to accumulate in the canyons to transform into recharge later. The zones of epi-karst in the Turonian and Cenomanian limestone formations are the contributers to infiltration recharge.

2.10. Water balance of the study area

Isohyetal method using a map of contour lines for the rainfall of the study area in the period of 1970-2004 was used to calculate the mean real rainfall (Fig. 2.18).

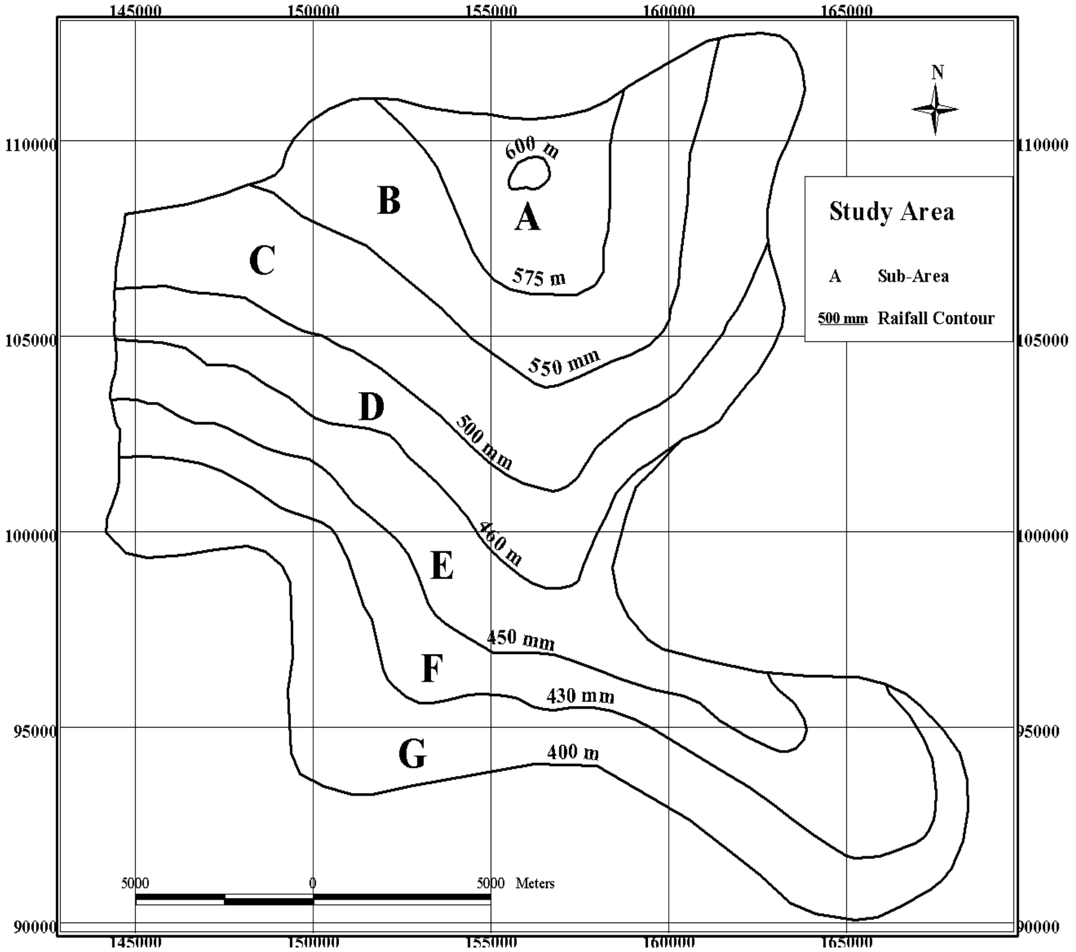


Fig 2.18: Isohyetal map of the study area in Hebron district (1970-2004).

Using this map with the suitable calculations the results of what are summarized in (Table 2.4).

Table 2.4 : The basic data used to calculate the mean annual rainfall.

Sub-area	Contour(1) P1 (mm)	Contour(2) P2 (mm)	Average ppt P_i(mm)	Area A_i (m^2)	$P_i * A_i$
A	575	600	587.5	2.08E+07	1.22E+10
B	550	575	562.5	4.13E+07	2.32E+10
C	500	550	525	5.83E+07	3.06E+10
D	460	500	480	3.55E+07	1.70E+10
E	450	460	455	3.78E+07	1.72E+10
F	430	450	440	5.74E+07	2.53E+10
G	400	430	415	4.43E+07	1.84E+10
Total				2.95E+08	1.44E+11
Pm: Average depth of the rainfall (mm)					487.2

From the Table (2.4) found that the average depth of the rainfall over the study area in Hebron district during the period 1970-2004 is 487.2 mm/yr. Taking into consideration the area of 295 km^2 for the study area, then the annual volume of the rainfall over the area (Pv) will be 143.7 Million.m^3, taking into account that the average depth of the rainfall is 487.2 mm.

2.11. Surface runoff

The non existence of surface water bodies in the study area limits the runoff to the over land flow, therefore the term runoff is used here for the surface runoff only. The measurements of the runoff in the study area are very rare and refers to (Rofe and Raffety 1963), which found to be in the range of 7-14%. Goldschmidt formula was applied for the period 1970-2004, leads to an estimated average annual runoff of 55.7 mm (16.4 Million m^3), which corresponds to about 11.4% of the average annual rainfall.

2.12. Infiltration and recharge

The movement of water through the soil surface downward is known as infiltration, which is the first step of ground recharge. This infiltrated water may be stored in the soil to be consumed by plants, may evaporate again, or may penetrate to replenish the ground water.

Calculations of the recharge using the chloride mass balance method are done in this work using the weighted average of 5.56 mg/L to represent the chloride concentration in the rain (Herut, 1992). An average of 20 mg/L was assumed to represent the chloride concentration in the groundwater. Taking into consideration that the main rainfall over the study area in the Hebron district is 563 mm/yr, and the calculated runoff is 55.7 mm/yr, the average recharge in the area of study calculated to be 141.03 mm/yr, which represents 25.05% of the annual rainfall. Also when applying Goldschmidt and Jacobs developed formula, it gives an average annual recharge of 185.3mm/yr, which is about 32.9% of the average annual rainfall. Here found that the results of the two methods are not the same and didn't give the same result.

Chapter Three

Hydrogeology

3.1. Geological History

Since the early Paleozoic era, the Tethys sea has spread to the north and west of Palestine. The Arabian Shield was subjected to earth movements which was affected in the transgression and regression of the Tethys Sea. Five major transgressions took place during the Paleozoic era. By the end of this era, desert conditions dominated over the country (Orni, 1980).

During the Mesozoic era, four other transgressions were noted in the Middle Cretaceous. These are the Triassic, Upper Triassic, Lower Jurassic, and Middle–Upper Triassic. However the most extensive transgression both in direction and duration occurred in the Middle and Upper Cretaceous era where the sea flooded and covered great parts of the West Bank (Orni, 1980).

In the Cenomanian–Turonian era, thick starta of limestone and dolomite dominated. In the Cenomanian era, Palestine was affected by volcanic activity. Towards the end of Cretaceous era, the area passed through extensive deposits of soft chalks and phosphate, particularly in the Senonian (Orni, 1980).

By the Cenozoic era, chalk and numulitic limestone have dominated in the southern and central parts of Palestine (Eocene). In the lower Miocene, tectonic movements were active, producing huge mountains in the country. Faults began to dominate and the Jordan valley outlined itself as a result. During the Pliocene, continual conditions dominated and faulting was intinsified (Orni, 1980).

By the Quaternary (Pleistocene) era, soils were formed. In the middle Pleistocene era, the last volcanic phase occurred, and in the Holocene era, some parts of the Mediterranean shore began to disappear under water. The geological events during the Quaternary outlined the general features of the West Bank (Orni, 1980).

Fig. (3.1) shows the different geological exposed rocks in the West Bank, as appear in the Hebron district the one can see the Albian-Turonian era covers the majority of the surface area which exceeds 60% of the total area of the district, the general geology of Hebron district is shown in (Fig. 3.2).

3.2 Lithology:

The majority of the exposed rocks in the West Bank are marine sediments particularly made of carbonate (such as limestone, dolomite, chalk), and Chert. These rocks extend by age from Lower Cretaceous to Quaternary. Jurassic rocks have limited exposures in the

West Bank, (Rofe & Roffety, 1965). The detailed geology of the West Bank as outlined in the Appendix (3.1), which shows the lithological units of the west bank. (Rofe & Roffety, 1963 and 1965).

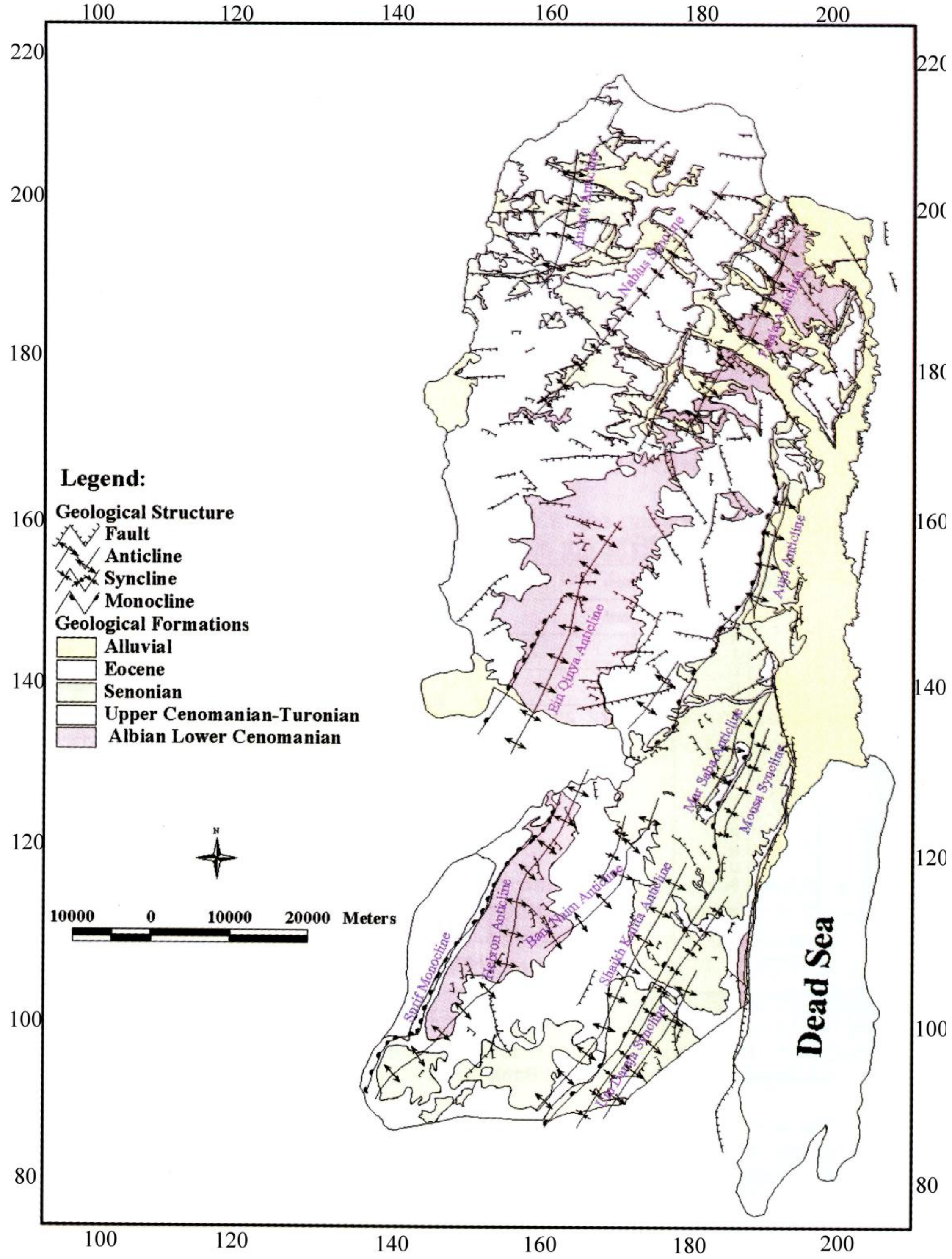


Fig. (3.1): Geological and structural map of the West Bank. (modified after Palestinian Hydrology Group, 2005; Arij, 1998 and Rofe and Raffety, 1963).

The general geology of Hebron district is shown in (Fig. 3.2).

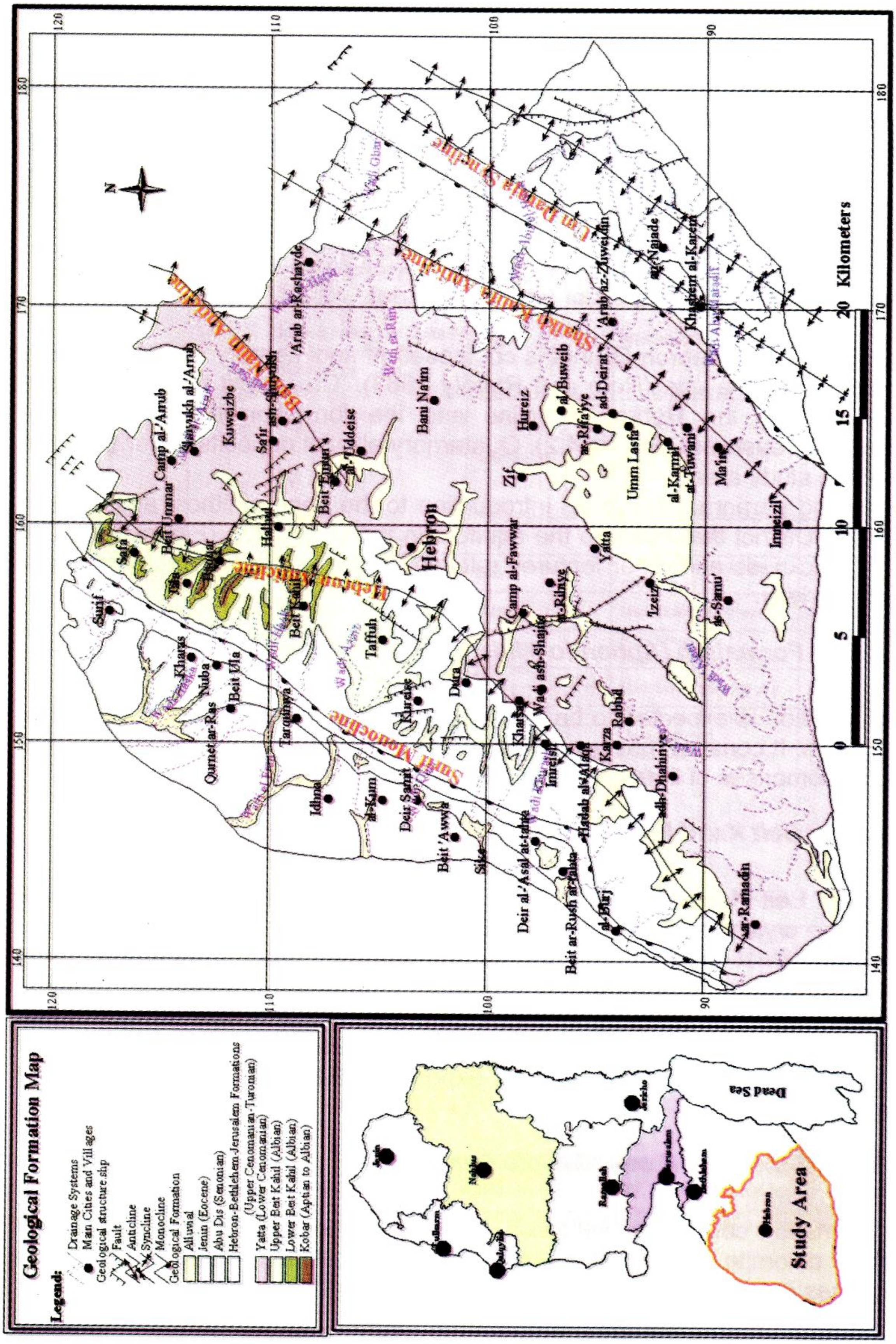


Fig. (3.2): Geological and structural map for the Hebron district. (modified after Palestinian Hydrology Group, 2005; the Geological Survey of Israel,1999; Arij ,1998; and Rofe and Raffety, 1963)

3.3 Stratigraphy:

The majority of the exposed rocks in the study area are the carbonate rocks that ranges in age from Albian to Recent (Quaternary period). Cenomanian age rocks which mainly composed of limestone and dolomite cover the widest area in the research region. Marl, limestone, sandstone and conglomerate are the main sediments of the Pliocene age rocks covered a limited area (Fig. 3.2). The rocks of the Eocene age are chalk, limestone and chert. In addition to the metamorphic rocks of Miocene age which covers a small region in the study area (Fig. 3.2). The stratigraphy of the study area ranges between Lower Beit Kahil (Kefira) and Alluvium Formations. The characteristics of these geological formations in the area are as follows:

3.3.1 Lower Beit Kahil Formation (Kefira & Giva’t Yearim)

This formation consists of massive and hard crystalline mottled dolomitic limestone with some shales and chalk. The presence of well jointed dolomitic limestone made this formation to be a good aquifer. The thickness of this formation ranges between 92 and 180 m (Baida, 1992)

3.3.2 Upper Beit Kahil Formation

This Formation is found as the upper part of the lower Cenomanian. Siliceous dolomite, chalky limestone, marl and marly limestone are the most rocks found in the Formation. The jointed limestones which capped by massive fractured limestone made it an aquifer. But the lower part of this Formation is an aquiclude. The thickness of this Formation ranges between 120 to 200m (Baida, 1992, and ARIJ, 1995).

3.3.3 Yatta Formation

This Formation consists of yellowish–gray chalky marl, limestone, dolomite and interbeded chalk. It considered to be an aquiclude. The thickness of this Formation ranges between 140 to 200m. (Rofe & Raffety, 1963)

3.3.4 Hebron Formation

This Formation is part of the lower part of Cenomanian. It consists of hard caristified gray dolomitic limestone. Hard dolomite and dolomitic limestone with silicification are found in the lower part of this Formation. As a result of a well jointed and caristification the porosity is mainly a secondary one. This makes the Formation to be a very good aquifer. The thickness of this Formation ranges between 60 and 170m. (Rofe & Raffety, 1963)

3.3.5 Bethlehem Formation

This Formation is a part of the upper Cenomanian. The upper part of this Formation is a good aquifer as a result of the highly jointed and fractured hard dolomite. But the lower part is aquiclude which consists of chalk, limestone, and dolomite. The thickness of the Formation ranges between 100 and 150m. (Rofe & Raffety, 1963)

3.3.6 Jerusalem Formation

This Formation is a good aquifer which belongs to the Turonian age, it is characterized by very tough, fine and uniform bedded limestone and dolomitic limestone that becomes highly fractured and jointed in some places. The thickness of this Formation ranges between 90 and 100m. (Baida, 1992).

3.3.7 Amman & Abu Dies formation

This Formation is an aquiclude with thickness ranges between 40 and 150m. It belongs to the Eocene - Sononian age and consists of chalk and chert. (ARIJ, 1995).

3.3.8 Jenin Subseries

This Formation is consists of chalk, numilitic limestone, reef limestone and chert, and it belongs to the Eocene age. This Formation is divided into two parts, where it is an aquifer in the limestone zones, and an aquiclude in the chalk zones. Its thickness is between 100 and 120m. (ARIJ, 1995)

3.3.9 Beida Formation

This Formation belongs to the Miocene – Pliocene age. It consists of conglomerate rocks, because of this kind of minerals it considered as a good aquifer. Its thickness is between 60 and 100m. (ARIJ, 1995).

3.3.10 Lisan Formation

Gypsum beds, thin laminated mar and chalk are the consistencies of this Formation. Its thickness is ranges between 10 and 30m and it belongs to the Pleistocene–Recent age. (ARIJ, 1995).

3.3.11 Alluvial deposits

This Formation is part of the Holocene–Recent age which consists of laminated marls and muds and some siliceous sand. Its thickness is between 0 and 20m. (ARIJ, 1995).

3.4 Water resources:

3.4.1 Hydrogeology

Hebron is located on the crest of the anticline structure extending from Beer Shiva' area in the South to Jerusalem in the North including Hebron and Bethlehem districts, forming the Hebron Mountain series. There are two main aquifer systems in the district.

3.4.2. Groundwater aquifer systems

Wells and springs water in the Hebron district are mainly originate either from the aquifers or from underground geological strata. Generally there are two main aquifer systems in the Hebron district which are:

3.4.2.1. The Lower Cenomanian Aquifer system

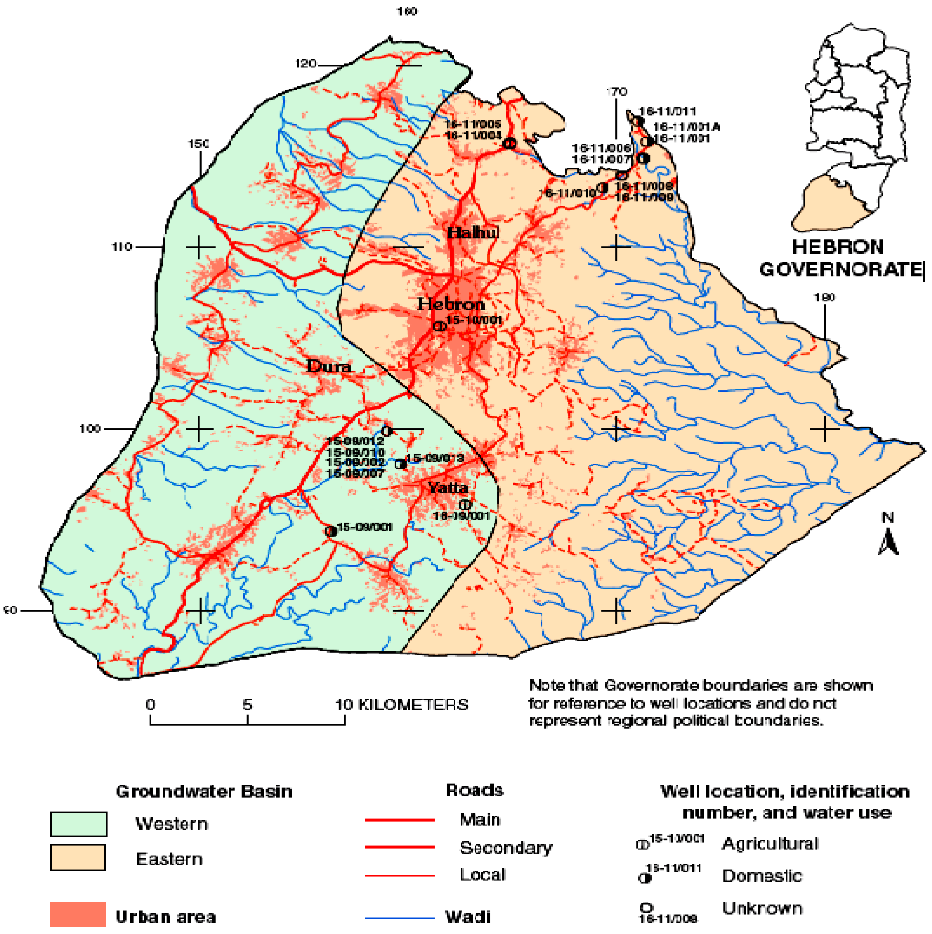
The geologic formations of this aquifer system are lower and upper Beit Kahil (Rofe & Roffety, 1963) and are mainly composed of dolomite, limestone, marly and chalky limestone, (Fig. 3.3). This system feeds the Herodion and Jerusalem boreholes and the springs in the Dead Sea area.

3.4.2.2. The Upper Cenomanian Aquifer system

This aquifer system is mainly composed of limestone, chalky limestone, and dolomite. This system feeds Al- Aroub, Sa'ir and Eth-Tharwa spring, as well as other springs in the area. It also feeds Al- Fawwar, Biet Fajjar, Samu', and Rihiya well fields.

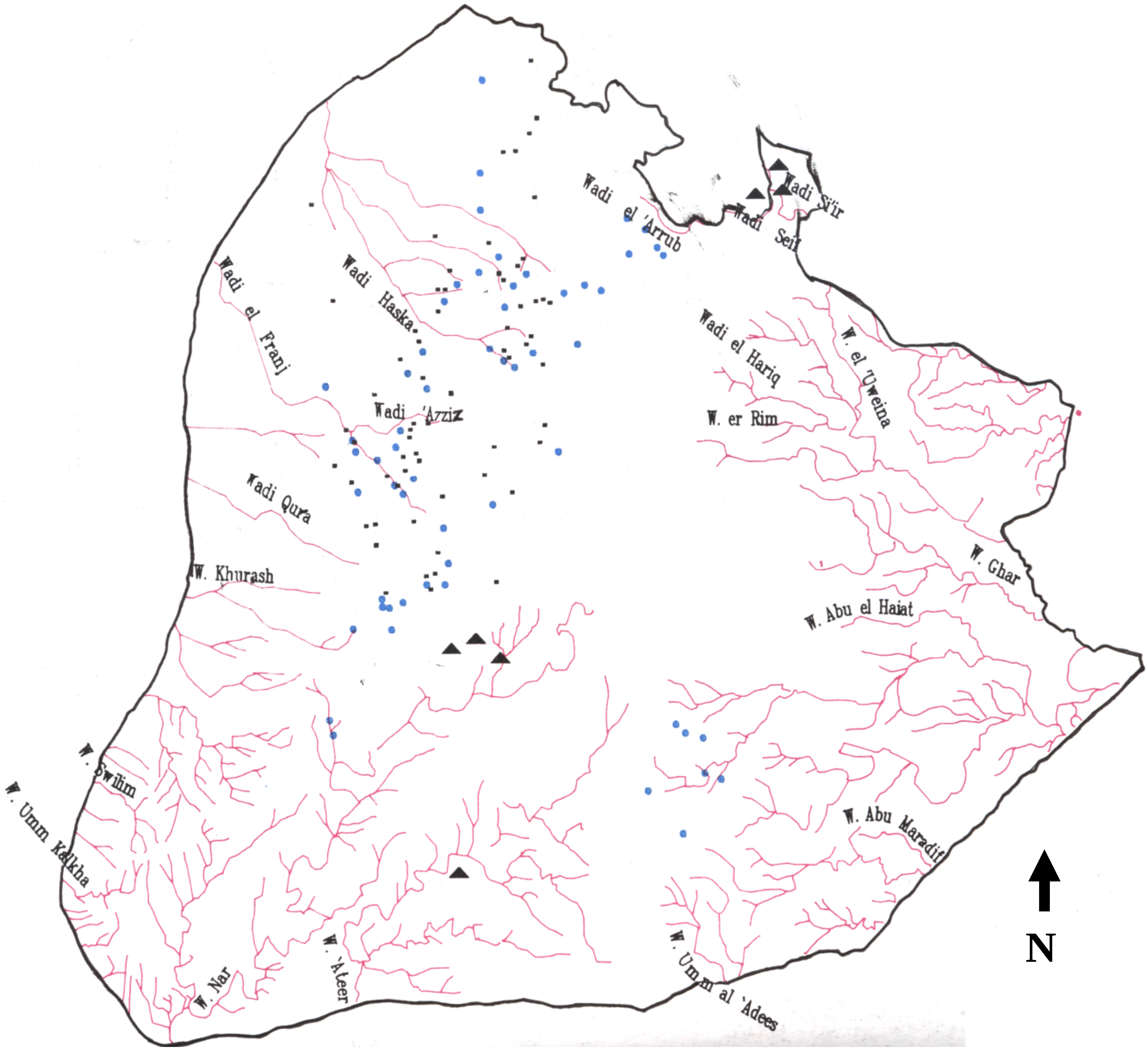
3.4.3. Groundwater Basins

The mountain aquifer is the main groundwater resource in Palestine, which composed of three main smaller aquifers; eastern, northeastern, and western. Fig. (3.3) shows the groundwater basins and exposed aquifers in the Hebron district. The majority of the district is underlain by the Jerusalem desert groundwater sub-basin which is itself underlain by the Auja–Tamaseeh and the Hebron–Beer Sheva' sub–basins of the western and eastern flank of the West Bank mountain aquifer, Fig. (3.4) shows water resources in the district.



Note that Governorate boundaries are shown for reference to well locations and do not represent regional political boundaries.

Fig. (3.3): West and East basins in Hebron district. (modified after Arij, 1995).



HEBRON DISTRICT WATER RESOURCES MAP

LEGEND:

● SPRINGS

▬ SHALLOW (TRADIRIONAL) G.W WELLS

▲ **DEEP G.W WELLS**

Ń STREAMS

SCALE: 1:250,000

Fig. (3.4): Water resources map in the Hebron district. (modified after Arij, 1995).

Chapter four

Results and interpretations

4.1 General

The water of more than 40 springs was checked for both chemical and physical characteristics. Discharge measurements were possible for the majority of the springs during the years 2003/2004 for 11 springs. Samples were collected twice, in winter and in summer to compare the results. The area of the research covered Yatta, Dora, Beit Kahil, Taffuh, Idna, Tarqumiya, Halhul, Deir-Samit, and Hebron City.

The pH ranges between 6.72 and 8.67, and EC ranges between 450 µS/cm and 2500 µS/cm, which reflected significantly variations in the concentrations of the major ions, and shows difference between the values in winter and summer.

Ca^{+2} values range between 33.7 mg/L and 210 mg/L, Na^{+1} range between 17.2 mg/L and 224 mg/L, Mg^{+2} range between 11 mg/L and 94.8 mg/L, K^{+} range between 0.14 mg/L and 59.7 mg/L. The major anions also show variations as the HCO_3^- , Cl^-, NO_3^-, SO_4^{-2}, which show ranges between 134.2 mg/L and 683.4 mg/L, 9.4 mg/L and 497 mg/L, 3 mg/L and 736.8 mg/L, and 0.7 mg/L and 163 mg/L respectively (Table 4.1).

On Piper diagram the majority of the water samples plot in the area of earth alkaline water with increased portions of alkalis with prevailing bicarbonate and with prevailing sulfate and chloride in winter and in summer (Fig. 4.1, 4.2). Mixing with wastewater leaking from cesspits and agricultural factors are responsible for the high concentrations of alkalis, chloride and sulfate.

Table 4.1: Descriptive statistics of chemical and physical parameters of the springs studied in Hebron District.

Variable	Minimum	Maximum	Average	Standard Deviation
EC (µS/cm)	450	2500	985.3	468.2
TDS (mg/L)	312.6	1246.2	674.1	322.2
pH-value	6.7	8.7	7.5	0.4
Temp (° C)	10.7	21.4	18.1	1.9
Ca^{+2} (mg/L)	33.7	210	100	39.1
Mg^{+2} (mg/L)	11	94.8	38	18.4
Na^{+1} (mg/L)	17.2	224	75.8	48.6
K^{+} (mg/L)	0.14	59.7	6.1	11.1
HCO_3^- (mg/L)	134.2	683.4	346.1	134.4
Cl^- (mg/L)	9.4	497	134.5	111.6
SO_4^{-2} (mg/L)	0.7	163	34.4	31.0
NO_3^- (mg/L)	3.0	736.8	88.7	130.9

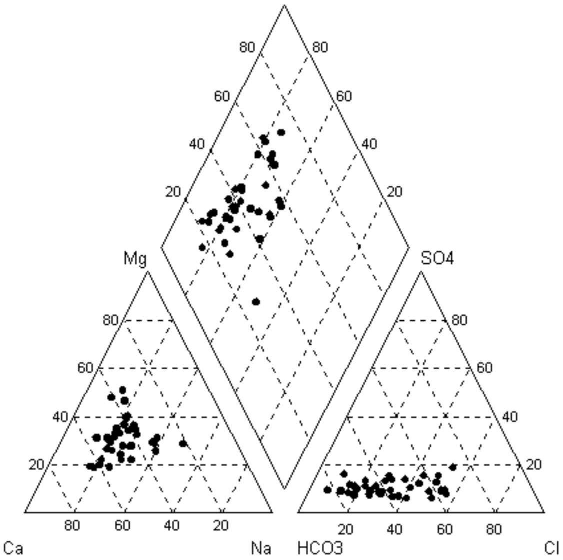


Fig. 4.1: Piper diagram for the samples collected in Summer from the study area.

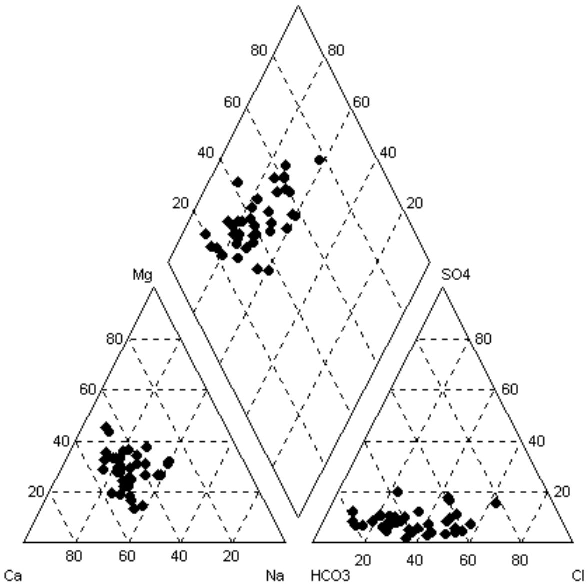


Fig. 4.2: Piper diagram for the samples collected in Winter from the study area.

4.1.1 The springs of Dura city:

30 samples were collected from 15 springs in this city during winter and summer. The EC of these springs ranges between 433 µS/cm and 1539 µS/cm with standard deviation of 310.4, pH ranges between 7.1 and 7.9, Ca^{+2} ranges between 52.9 mg/L and 171.5 mg/L, Mg^{+2} range between 11 mg/L and 61.2 mg/L. The anions show the same variations, the HCO_3^- ranged from 207.5 mg/L and 414.9 mg/L, and NO_3^- ranges between 8 mg/L and 298 mg/L, also Cl^- show 21 mg/L and 226.8 mg/L (Table 4.2).

Table 4.2: Descriptive statistics of chemical and physical parameters of the springs studied in Dura City.

Variable	Minimum	Maximum	Average	Standard Deviation
EC (µS/cm)	433	1539	826.8	310.4
TDS (mg/L)	272.3	1039.6	574.9	238.7
pH-value	7.1	7.9	7.5	0.3
Temp (° C)	10.7	21.4	18.5	2.5
Ca^{+2} (mg/L)	52.9	171.5	93.7	30.6
Mg^{+2} (mg/L)	11	61.2	35.6	15
Na^{+1} (mg/L)	17.2	97.1	50.5	22.8
K^+ (mg/L)	0.14	59.7	6	14.9
HCO_3^- (mg/L)	207.5	414.9	301.1	64.1
Cl^- (mg/L)	21	226.8	89.4	53
SO_4^{-2} (mg/L)	17	84.4	40.7	21.8
NO_3^- (mg/L)	8	298	108.7	91.5

On Piper diagram Kanar El-Sharqiyi, Knar El-Wista, Fira'a, and Al-Hijri springs plot in the area of normal earth alkaline water with prevailing bicarbonate. Al-Fredees, springs, plot in the area of earth alkaline water with bicarbonate and sulfate (or chloride). Alaqa Foqa and Hfaier springs plot in the area of earth alkaline water with increased portions of alkalis with prevailing sulfate and chloride. The other springs of this group plot in the area of earth alkaline water with increased portions of alkalis with prevailing bicarbonate like Set El-Rom, Kurza, Alaqa Tahta, Dilba, Khalt Diab, Qais, Elsa'abiya and Longor springs Appendix (4.1A).

4.1.2 The springs of Yatta group:

12 samples from 6 springs of this group were used to qualify the chemical and physical characteristics of the spring water. The EC ranges from 543 µS/cm and 1855 µS/cm, Ca^{+2}, Mg^{+2}, Cl^-, and NO_3^- show values, which range between 56.9 mg/L and 210 mg/L, and 18.5 mg/L and 39.4 mg/L, 54.7 mg/L and 266 mg/L, 71.5 mg/L and 736.8 mg/L respectively (Table 4.3).

Table 4.3: Descriptive statistics of chemical and physical parameters of the springs studied in Yatta group.

Variable	Minimum	Maximum	Average	Standard Deviation
EC µS/cm	543	1855	964.2	486.1
TDS (mg/L)	358.4	1224.3	636.4	320.8
pH-value	7.7	8	7.9	0.15
Temp (° C)	16	19	17.3	1.4
Ca^{+2} (mg/L)	56.9	210	109.2	55.9
Mg^{+2} (mg/L)	18.5	39.4	24.2	8
Na^{+1} (mg/L)	40	194.1	78.6	58.3
K^+ (mg/L)	1.1	19.3	11.6	8.6
HCO_3^- (mg/L)	134.2	207.4	174.9	30.3
Cl^- (mg/L)	54.7	266	128.3	77.9
SO_4^{-2} (mg/L)	15.4	89.5	43.1	26.7
NO_3^- (mg/L)	71.5	736.8	268.6	244.4

On Piper diagram Abu-Shabban and Al-Rifa'ya springs plot in the area of earth alkaline water with increased portions of alkalis with prevailing bicarbonate. The Karmil (A, B and C) and Tuwani springs plot in the area of earth alkaline water with increased portions of alkalis with prevailing sulfate and chloride Appendix (4.1B).

4.1.3 The springs of Idna group:

14 samples were collected from 7 springs in this group which includes Idna, Taffuh, and Tarqumiya. The EC values range between 489 µS/cm and 1653 µS/cm. The Ca^{+2}, Mg^{+2}, and Na^+ values range between 52.1 mg/L and 181.2 mg/L, 19.4 mg/L and 54.9 mg/L, 28.7 mg/L and 148 mg/L respectively. HCO_3^- ranges between 238 mg/L and 436.7 mg/L, the NO_3^- ranges between 3 mg/L and 38 mg/L, and the Cl^- ranges between 48 mg/L and 310 mg/L (Table 4.4).

Table 4.4: Descriptive statistics of chemical and physical parameters of the springs studied in Idna group.

Variable	Minimum	Maximum	Average	Standard Deviation
EC µS/cm	489	1653	1120.7	467.8
TDS (mg/L)	293.4	1018.5	694.3	278
pH-value	6.7	7.7	7.2	0.4
Temp (° C)	18.5	19.2	18.9	0.3
Ca^{+2} (mg/L)	52.1	181.2	99.5	44.2
Mg^{+2} (mg/L)	19.4	54.9	40.5	13.3
Na^{+1} (mg/L)	28.7	148	102.2	47.7
K^{+} (mg/L)	0.7	12	4.2	4.2
HCO_3^- (mg/L)	238	591.9	436.7	123.6
Cl^- (mg/L)	48	310	192.9	109.6
SO_4^{-2} (mg/L)	5	36	20.7	11.2
NO_3^- (mg/L)	3	38	15.8	14.2

On Piper diagram the Bustan, Ma’moudi, Mussallam, Sufli, Wad El-Beer springs plot in the area of earth alkaline water with increased portions of alkalis with prevailing bicarbonate. The El-Bus and Naqia springs plot in the same area with prevailing chloride and sulfate Appendix (4.1C).

4.1.4 The springs of Beit-Kahil group:

10 samples were collected from 5 springs from the area of this group in winter and summer. EC values range between 450 µS/cm and 943 µs/cm. Ca^{+2} between 33.7 mg/L and 76.2 mg/L, and Na^+ between 32 mg/L and 39 mg/L. HCO_3^- range between 225.8 mg/L and 370 mg/L, with standard deviation of 55.3, the NO_3^- between 6 mg/L and 25 mg/L, and Cl^- between 42 mg/L and 100 mg/L (Tables 4.5).

Table 4.5: Descriptive statistics of chemical and physical parameters of the springs studied in Beit-Kahil group.

Variable	Minimum	Maximum	Average	Standard Deviation
EC µS/cm	450	943	654.8	194.9
TDS (mg/L)	301.4	423.8	360.8	53.2
pH-valu	7	8.7	7.8	0.6
Temp (° C)	17.6	19.8	18.6	0.9
Ca^{+2} (mg/L)	33.7	76.2	59.3	16.7
Mg^{+2} (mg/L)	16	31.1	25.6	6.3
Na^{+1} (mg/L)	32	39	33.8	3
K^{+} (mg/L)	0.5	3	1.9	1.1
HCO_3^- (mg/L)	225.8	370	276.6	55.3
Cl^- (mg/L)	42	100	65.2	24
SO_4^{-2} (mg/L)	15.5	26	22.6	4.3
NO_3^- (mg/L)	6.0	25	14.2	9.1

On Piper diagram all the springs of this group plot the area of earth alkaline water with increased portions of alkalis with prevailing bicarbonate like Wad El-Quf (A, B and C) and Wad Elraed except Elbalad spring which plot in the area of normal earth water with prevailing bicarbonate Appendix (4.1D).

4.1.5 The springs of Hebron city:

Samples where collected from 4 springs. They show EC values ranging between 678 µS/cm and 1242 µS/cm, Ca^{+2} between 70.5 mg/L and 137.9 mg/L, Cl^- between 67 mg/L and 175mg/L, and NO_3^- between 11 mg/L and 126 mg/L (Table 4.6).

Table 4.6: Descriptive statistics of chemical and physical parameters of the springs studied in Hebron city.

Variable	Minimum	Maximum	Average	Standard Deviation
EC µS/cm	678	1242	1063.8	262.8
TDS (mg/L)	375.2	883.1	659.5	215.1
pH-value	6.7	7.8	7.2	0.5
Temp (° C)	16.3	21	17.6	2.3
Ca^{+2} (mg/L)	70.5	137.9	116.2	30.9
Mg^{+2} (mg/L)	29.2	47.6	38.6	8.7
Na^{+1} (mg/L)	33	87	71	25.7
K^+ (mg/L)	0.5	8	3.9	3.1
HCO_3^- (mg/L)	299	469.8	42	82.2
Cl^- (mg/L)	67	175	113.5	45.1
SO_4^{-2} (mg/L)	6.5	163	54.8	73.2
NO_3^- (mg/L)	11	126	51	51.2

On the Piper diagram the water of the springs Arab and Kheir Ed-Dein is form the type of earth alkaline water with increased portion of alkalis with prevailing bicarbonate. Deir Bahha spring plots in the area of earth alkaline water with prevailing bicarbonate. Sara spring plots in the area of earth alkaline water with increased portion of alkalis with prevailing sulfate and chloride Appendix (4.1E).

4.1.6 The springs of Halhul group:

6 samples from 3 springs collected in winter and summer. The value of EC ranges between 597 µS/cm and 1125 µS/cm. The Ca^{+2} ranges between 81.8 mg/L and 130.7 mg/L, Na^+ between 18 mg/L and 71 mg/L. Cl^- ranges between 30 mg/L and 136 mg/L, and NO_3^- between 6 mg/L and 26 mg/L (Table 4.7).

Table 4.7: Descriptive statistics of chemical and physical parameters of the springs studied in Halhul group.

Variable	Minimum	Maximum	Average	Standard Deviation
EC µS/cm	597	1125	888.3	268.2
TDS (mg/L)	397	694.7	527	152.1
pH-value	7.2	7.7	7.4	0.3
Temp (° C)	15.6	16.3	15.9	0.4
Ca^{+2} (mg/L)	81.8	130.7	106.1	24.5
Mg^{+2} (mg/L)	33.5	49.1	42.4	8.1
Na^{+1} (mg/L)	18	71	41.3	27.1
K^{+} (mg/L)	0.5	1	0.8	0.3
HCO_3^{-} (mg/L)	366.1	451.6	410.9	42.9
Cl^{-} (mg/L)	30	136	67.3	59.5
SO_4^{-2} (mg/L)	23.5	59.5	44.5	18.8
NO_3^{-} (mg/L)	6	26	19	11.3

On Piper diagram Hasaka and Misleh springs plot in the area of normal earth alkaline water with prevailing bicarbonate, but Eth-Tharwa spring plot in the area of earth alkaline water with increased portions of alkalis with prevailing bicarbonate Appendix (4.1F).

4.1.7 The springs of Deir-Samit group:

6 samples from 3 springs were collected. The EC range between 1642 µS/cm and 2500 µS/cm, Ca^{+2} between 137.1 mg/L and 170.7 mg/L, the Na^{+} between 127 mg/L and 224 mg/L. and Cl^{-} ranged between 410 mg/L and 497 mg/L Table (4.8).

Table 4.8: Descriptive statistics of chemical and physical parameters of the springs studied in Deir-Samit group.

Variable	Minimum	Maximum	Average	Standard Deviation
EC µS/cm	1642	2500	2047.00	431.01
TDS (mg/L)	1081	1388	1266	163.1
pH-value	6.9	7	6.94	0.06
Temp (° C)	15.8	19.8	18.20	2.12
Ca^{+2} (mg/L)	137.07	170.74	149.36	18.58
Mg^{+2} (mg/L)	67.55	94.77	84.08	14.52
Na^{+1} (mg/L)	127.00	224.00	160.33	55.16
K^{+} (mg/L)	0.50	39.00	15.17	20.82
HCO_3^{-} (mg/L)	518.7	683.4	577.7	91.8
Cl^{-} (mg/L)	410.00	497	465.7	48.3
SO_4^{-2} (mg/L)	45	85	68.3	20.8
NO_3^{-} (mg/L)	22	52.00	34.3	15.7

On Piper diagram all springs of this group plot in the area of earth alkaline water with increased portions of alkalis with prevailing sulfate and chloride Appendix (4.1G).

4.2 Environmental Isotopes Analysis

4.2.1 Introduction:

The groundwater provenance, age, quality, geochemical evolution, recharge processes, rock-water interactions, the origin of salinity and contaminant processes in general can be studied using the environmental isotopes. Water isotopic changes comes as a result of many factors, such as evaporation of water from the oceans, condensation and rain formation. The stable isotopes in the groundwater are the pointer which relates these waters to their origin, means precipitation, infiltration, surface water (Gat and Dansgaard, 1972). Also radioisotopes decay provides us with a measure of circulation time, and about the renewablity of groundwater (Gat 1996).

In this research, deuterium (^{2}H) and oxygen (^{18}O) were measured as a stable isotopes for 12 springs, and tritium (^{3}H) as a radioactive isotope for 7 springs in the study area.

4.2.2 Sampling and analysis:

In this study 12 samples were collected from 12 springs from the study area between October, 2003 January, 2004 to be analyzed for their isotopic composition (^{18}O and ^{2}H), and 7 samples from seven springs were collected during January 2004 to be analyzed for the isotopic composition (^{3}H). Samples for all isotopic composition were collected from Dura and Yatta springs. The water samples for ^{18}O and ^{2}H were collected in 50 ml dark glass bottles and 500 ml polyethylene bottles were used for ^{3}H determination.

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

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

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

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

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

The isotopic exchange reaction can be written as:

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

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

Hydrogen isotope analysis is carried out in principle the same way as for $\delta^{18}O$ but using Hydrogen of known isotopic composition as equilibrium gas. The sample is referred to the VSMOW standard. The error is specified to be 0.8‰.

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

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

and

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

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

4.2.3 Deuterium (^{2}H) – Oxygen (^{18}O) relationship:

The ^{2}H and ^{18}O in the fresh surface water and the precipitation water correlate on global state. This correlation, as a best-fit line termed meteoric line, is expressed as follows:

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

This line is actually an average of many local or regional meteoric water lines, which differ from the global line due to varying climatic and geographic parameters. The Mediterranean Meteoric Water Line MMWL), representing the ^{2}H and ^{18}O relation in our area, has the following formula:

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

In the $\delta\, ^{2}H$ - $\delta\, ^{18}O$ correlation there is the d-excess which is very important term. This term is a measure of the deuterium enrichment that exceeds the $\delta\, ^{18}O$ value by more than 8 times (Clark and Fritz 1997). Primary and secondary evaporation can be measured by the d-excess. When this value is large this means low humidity and evaporating is going fast and this takes place during hot weathers. d-excess is around 22‰ in the Mediterranean region which result from the cold and dry fronts that comes from the Atlantic Ocean to the east the Mediterranean region (Gat 1996).

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

Both Table (4.9) and Fig. (4.9) show that the isotopic contents of the water samples collected from the springs of the Hebron district plot on the Mediterranean Meteoric Water Line (MMWL) with average values of -5.64‰ for ^{18}O, -23.23‰ for ^{2}H and 21.9‰ for d-excess, which means that the water of these springs originated from the rain water. As seen in (Table 4.9) the springs of Karmil (B) and Tuwani show the most enriched isotopic composition, -5.27 and -21.6 for Karmil (B), and -5.42, -21.1 for Tuwani spring. This may took place as a result of the altitude which is the lowest for the Tuwani [720 masl] and Karmil (B) [750 masl], or may be as a result of mixing with waste water flowing from the houses near the spring of Karmil (B).

Table (4.9) shows the lowest enriched isotopic composition for Kanar El-Sharqiya [850 masl] of -5.9 ‰ ^{18}O and this may be as a result of its highest altitude. The more negative are the values of both δ ^{2}H and δ ^{18}O proposed two major explanations for their amount effect (Dansgaard, 1964):

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

Also as the clouds rises up the mountains, the heavy isotopes depleted and the residual precipitation gets isotopically lighter.

Table 4.9 : The ^{18}O and ^{2}H composition of the samples collected from Hebron district springs (from October 2003 to January 2004).

Spring	Elevation (masl)	δ ^{18}O	δ ^{2}H	d-excess
Knar El-Sharqiya	850	-5.90	-24.2	22.94
Fira'a	580	-5.57	-22.2	22.38
Al-Hijri	840	-5.77	-24.0	22.21
Dilba	840	-5.86	-23.9	22.93
Knar El-Wista	850	-5.81	-24.0	22.51
Alaqa Tahta	820	-5.44	-21.7	21.80
Kurza	790	-5.55	-21.6	22.80
Alaqa Foqa	830	-5.51	-22.7	21.40
Karmil (B)	750	-5.27	-21.6	20.60
Karmil (A)	750	-5.76	-25.8	20.30
Tuwani	720	-5.42	-21.1	22.30

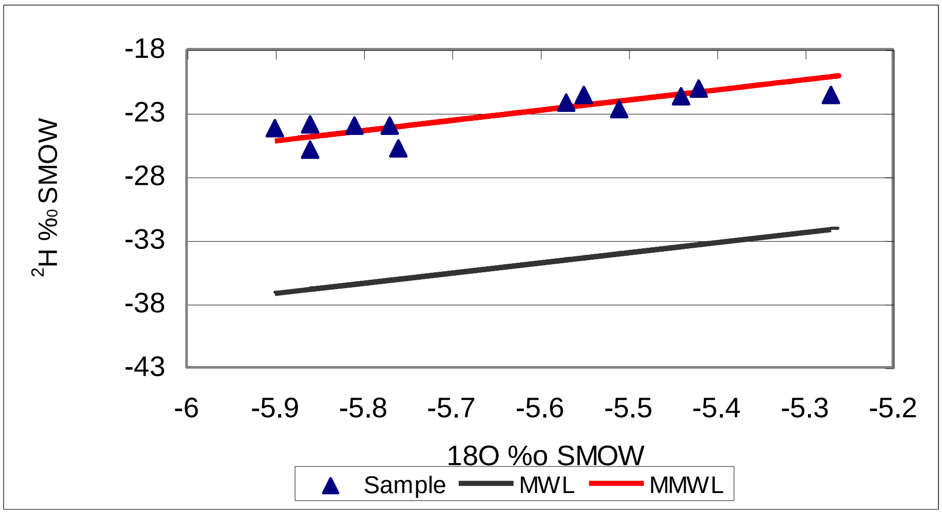


Fig. 4.3: The δ ^{18}O and δ ^{2}H relation of the samples collected from the springs of Hebron district compared to the MWL and the MMWL.

4.2.5 Tritium (^3H)

Tritium (^3H) was used to estimate the relative ages of the water The natural level of tritium in rainfall averages 2-6TU (1TU=1^3H atom in 10^{183} H atoms (Libby 1971), but varies with season and location. Above-ground nuclear weapons tests in the late 1950s and early 1960s introduced a large spike of tritium and other radioisotopes into the atmosphere (Eriksson, 1965). According to Cami and Gat (1973), the tritium concentration in the precipitation is similar for the whole West Bank and Israel, it was about 5TU during 1950s (Kaufman and Libby 1954). After 1963 the nuclear tests stopped and the concentration of tritium decreased in precipitation. The variations in tritium concentrations in the precipitation in Israel are shown in (Table 4.10). Under the assumption of piston flow recharge mode and no mixing, and based on that the half-life of the tritium is 12.3 years, the expected tritium to stay in water in the year of 1998 is calculated in (Table 4.10).

Table 4.10: The tritium concentration in the precipitation of Israel, and the expected amount of concentration remains after discharge at 1998 (Qannam 2003).

Time period	^3H in precipitation (TU)	Expected ^3H in 1998 (TU)
1950’s	5	0.4
1960	30	3.5
1961-1962	125	15.5
1963	803	112
1964	402	60
1965	261	40
1966-1968	109-113	18-21
1969-1972	59-54	12-14
1973-1981	21-41	7.4-11
1981-1991	8-15	4.3-7.6
1991	8	5.4

So and when referring to Table (4.10), water containing tritium concentration around 0.4TU in 1998 dates back to the early 1950’s. When looking to the results of tritium concentration in the water of the springs collected from the study area, found that the results ranges between 5.4TU and 4.7TU (Table 4.11), which means that all the concentrations are within the range of tritium concentrations in the water precipitation of the West Bank area, and this means that the water discharged from springs is of a very recent age, this water recharged in winter of the research year (Table 4.11).

Table 4.11: The tritium concentration in the samples collected on January 2004, from the Hebron district.

Spring name	Elevation (masl)	Tritium (^3H) (TU)	Uncertainty
Alaqa Tahta	820	4.7	0.5
Kurza	790	4.7	0.5
Alaqa Foqa	830	5.2	0.5
Karmil (A)	750	5.2	0.5
Karmil (B)	750	5.4	0.5
Tuwani	720	4.7	0.5

4.3. Water quality

4.3.1. General

Chemical, Physical and Biological characteristics are the criteria that define the water quality. Water is used for domestic, urban, agriculture and industry. So water quality needed has to satisfy the standards for each of these purposes in order to avoid any negative effects against the user. This means that the contents in water must fit the situation which never affect the health of the consumers over the life of consumption (WHO, 2004). Any of the water contents which may show short-term deviation from the standard for any use do not mean that water is not suitable, because suitability here is controlled by the amount and life of the content, and by the type of this content.

4.3.2. Water quality for domestic purposes

Domestic water is defined as the water used for drinking, bathing, cooking, washing (cleaning) and for public buildings. Water will be good for these purposes, if its physical, microbiological, and chemical characteristics fit the standard.

The first concern in the evaluation process is the physical characteristics, like turbidity, total suspended solids, odor, taste, and color. The second concern is the microbiological characteristics where people suffer always from waterborne microbiological diseases, where detection is easy and treatment is of low cost. Finally waterborne chemical diseases, which is known with high cost for detection and high cost for treatment too. So water classified as good and suitable for domestic purpose must fit the acceptable and permissible limits for its turbidity, color, odor and taste. It should be also free from pathogens. It must not be corrosive and must be free from dyeing substances, its content of hazardous chemicals must be within the permissible limits.

4.3.3. Microbiological Quality Evaluation:

Bacteria, Viruses Protozoa or parasites are the pathogens which may be found in water and make it unsuitable for domestic use. To evaluate the water quality microbiologically water samples were tested for both faecal and total coliform bacteria because they are found in high numbers in the faeces of humans and warm-blooded animals. These also don’t grow in natural water and can be used as indicator for faecal pollution. The (WHO, 2004) recommendations define the long-term count of the total coliform and faecal coliform to be zero in the water to be suitable for domestic purposes.

4.3.4. Chemical Quality Evaluation:

The concentration of the various ions which affect health when exceed the recommended limits, decide the chemical quality of water for domestic uses.

The Palestinian Water Authority (2004) or the WHO (2004) put the basis for the water quality evaluation Table (4.11).

Table (4.12): Palestinian standards and World Health Organization (WHO) guidelines for drinking water (After PWA, 2004 and WHO, 2004).

parameters	Palestinian Standards (2004)		WHO (2004)	Source or Cause
	Basic	Conditional		
T °C	8-25		12-25	Earth's temperature or chemical reaction.
pH-value	6.5-8.5	9.5	6.5-8.5	Dissolved CO_2 and the organic acids.
Na^+ (mg/L)	200	400	200	All rocks and soils, found also in sea water, brines and sewage.
Ca^{+2} (mg/L)	100	200	75	Dissolved from all rocks and soils, but especially from limestone, dolomite and gypsum.
Mg^{+2} (mg/L)	100	120	<125	All rocks especially carbonates.
K^+ (mg/L)	10	12	12	Sedimentary rocks. Wastes of man and livestock.
HCO_3^- (mg/L)	125-350	125-350	125-350	Carbonate rocks and soils. Present in sewage, ancient brines and sea water.
Cl^- (mg/L)	250	600	250	Dissolved from rocks and soils. Present in sewage, ancient brines and sea water.
SO_4^{-2} (mg/L)	200	400	250	Dissolved from rocks and soils containing gypsum, sulphide ores and other sulphur compounds.
NO_3^- (mg/l)	50	70	50	Decaying of organic materials, legume plants, sewage and fertilizers.
TDS (mg/L)	1000	1500	500-1000	
Hardness (mg/L)	500	500	500	
Total Coliform colony/100mL	0	3	0	Wastes and residues of warm-blooded animals.
Faecal Coliform Colony/100mL	0	0	0	Wastes and residues of warm-blooded animals.

So the water hardness which is caused by the reaction between divalent metallic ions and the soap to slow down the work of soaps, or reacts with negative ions to produce solid boiler scales (De Zuane, 1990). The main purpose of decreasing water hardness is the decrease of the amount of nonbiodegradable detergents used in the household. Total hardness is expressed as $CaCO_3$ in mg/L, which could be calculated using the equation below (Todd, 1980):

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

The concentrations of the cations are in mg/L.

According to its hardness, Sawyer and McCarty classified the water into soft, moderately hard, hard, and very hard waters Table (4.13).

Table (4.13) Sawyer and McCarty (1967) classification of water, based on hardness.

Hardness $CaCO_3$ mg/L	Water type
0-75	Soft
75-150	Moderately hard
150-300	Hard
>300	Very hard

4.3.5. Water Quality for Agricultural Purposes.

Water quality and quantity, the soil type, the area, the climate, the elevation, and the type of crops, together decide the suitability of water for irrigation. The growth of plants be affected by high concentration of salts in water used by changing the osmotic pressure in the root zone, which affects the water uptake by roots (a physical effect). Metabolic reactions may be affected by the presence of some toxic substances like boron (chemical effect) . The soil structure and aeration may be affected by salts which may decrease plants growth (Todd, 1980). Here the sodium adsorption ratio (SAR), the sodium percentage, the total dissolved solids, and the electrical conductivity are used to evaluate the quality of water for irrigation.

4.3.5.1. Soluble Sodium Percentage (SSP):

Sodium concentration is an important index in the evaluation of irrigation water as it has an influence on soil permeability. Alkaline (Na^{+}-CO_3^{-2}) and saline (Na^{+}-Cl^{-} or Na^{+}-SO_4^{-2}) soils are not suitable for the growth of plants, using water with high sodium concentration. High sodium ratio increases the concentration of the sodium in the soil and allows the sodium to exchange other ions in the soil particles. The sodium content is expressed in terms of the Soluble Sodium Percentage (SSP), which is defined as:

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

Where:

The concentrations of cations are in meq/L.
Based on its SSP water used for irrigation where classified as in Table (4.14).

Table (4.14): Quality classification of water for irrigation, based on SSP (Todd, 1980).

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

4.3.5.2. Sodium Adsorption Ratio (SAR).

The expression of SAR was recommended by the United States Salinity Laboratory of the department of Agriculture (Richard, 1954). The SAR is considered to be in direct relationship with the water adsorption by the soil. It is calculated according to the equation.

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

Where:

The concentrations of the cations are in meq/L.
Based on its SAR waters used for irrigation were classified as in Table (4.15).

Table (4.15): Irrigation water classification, based on SAR values (Wilcox, 1955).

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

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

4.3.5.3. Total Dissolved Solids/ Electrical Conductivity:

Osmotic pressure effects are caused by the TDS which are a function of EC. Any change in the osmotic pressure in the root zone changes the uptake rate of water into the plant. The United States Salinity Laboratory USSL (1954) classified irrigation water in groups according to EC and TDS Table (4.16).

Table (4.16): 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: can be used for irrigation with most crops on most soils.
200 – 250	250 – 750	C2	Medium salinity: can be used to irrigate plants with moderate salt tolerance if moderate amount of leaching occurs.
500 – 1500	750 – 2250	C3	High salinity: can’t be used on soils with restricted drainage. Can be used to irrigate plants with high salt tolerance.
1500 - 3000	2250 - 5000	C4	Very high salinity: not suitable for irrigation under ordinary conditions. It can be used for irrigation occasionally under very special circumstances.

The EC and SAR water classes were plotted by the United Nations UN (1995) computer program in the joint representative Wilcox graph.

4.3.6. Suitability of water for domestic and irrigation purposes

4.3.6.1 General :

Water from springs are used for domestic purposes and agriculture in Hebron district especially in summer. Dura for example depend on El-Sa'abiya and Fira'a mainly for the people potable water. Arab spring and Deir Bahha are the main springs in Hebron city which are used for drinking. The total water used in Hebron district in 1990 was 11.6 MCM , distributed as follows, 9.5 MCM for household, 1.6 MCM for industry, and 0.5 MCM for agriculture, and the district expected to need 128.36 MCM by the year 2020 to cover, 58.56 MCM for household, 14.3 MCM for industry, and 45.5 MCM for agriculture (Issac et al, 1994). This increase comes as a result of increasing need for per capita, development in both industry and agriculture, and finally as a result of people natural growth. Some springs are used for irrigation like Al-Fredees, Knar El-Wista in Dura, and Ma'moudi in Taffuh.

4.3.6.2. Possible sources of contamination.

The increase of NO_3^-, K^+, Cl^-, Na^+, SO_4^{-2} concentrations above the recommended limits of the (WHO, 2004), and the presence of coliform bacteria in water indicate contamination, originated from the mixing of the spring water with municipal wastewater. In Al-Hijri spring, or with industrial water like in Arab spring in Hebron city, or as a result of agricultural effluents like in Al-Fredees and Alaqa-Foqa in Dura. Infiltration or leakage from sewers to shallow groundwater systems are playing a main rule in the presence of contaminants in the water of the springs. Animal wastes as well as the incorrect disposal of sewage by tankers near wadis like Humsa in Dura are possible contamination sources.

Agricultural fertilizers which contain K^+, NO_3^-, and SO_4^- are the main source of contamination of water in areas of agriculture, mainly with excessive irrigation. The use of raw wastewater in irrigation is another source of contamination.

4.3.7. Quality evaluation:

The factors which will be considered in evaluating the suitability of spring water for drinking and domestic use are the presence of coliform bacteria in the springs tested for this purpose and the concentration of some ions like Cl^- which affecting the aesthetic water quality, or NO_3^- which are causing health hazardous. The factors considered to evaluate water suitability for irrigation purposes are the values of EC, SSP, and SAR.

4.3.7.1. The springs of Dura city group:

The results in Table (4.17) show that the springs in Dura are not contaminated with both faecal and total coliform bacteria, and thus they are suitable for drinking. Chemically, there are noticeable deviations from the WHO (2004) guidelines and the Palestinian Standards (2004), especially in the $NO3^-$ concentrations. The springs of Al-Hijri, Al-Fredees, Knar El-Wista, Khalt-Diab, Set El-Rom, Longor, Hfaier, Alaqa Foqa, and Alaqa Tahta (in Dura and its villages) have $[NO_3^-]$ of 91.2mg/L, 172mg/L, 96 mg/L, 144mg/L, 298mg/L, 122.7mg/L, 223.8mg/L, 249.5mg/L,and 73.8mg/L respectively, also there is noticeable deviation in the concentration of K^+ in the Longor spring 59.7mg/l, These NO_3^- and K^+ concentrations make the springs water unsuitable for drinking.

Table (4.17) shows that the water total hardness of these springs range from “hard” to “very hard”, depending on the classification of Sawyer and McCarty (1967).

The water of the springs of this group ranges from excellent to good for irrigation purposes, based on the SSP (Table 4.17). They are classified into two water classes according to the EC-SAR relationship; of low sodium-medium salinity hazard (S1-C2) as Dilba and Knar El-Sharqiya springs, and of low sodium-high salinity hazard (S1-C3) as Alaqa Foqa and Set El-Rom springs in Dura. So the water of these springs is suitable for irrigation with no limitations (Fig. 4.4).

Table (4.17): Major chemical characteristics of the Dura group springs.

Spring	Date	SAR	SSP	TH	EC	K^+	Cl^-	NO_3^-	FC	TC
			%	(mg/L $CaCO_3$)	µS/cm	mg/L	mg/L	mg/L	#./100mL	#./100mL
Elsa'abiyia	3.10.03	0.84	20.9	260.1	570	0.54	55	22	0.0	0.0
Knar El-Sharqiya	2.10.03	0.49	13.6	238.1	433	0.14	21	7.95	0.0	0.0
Fira'a	3.10.03	0.77	17.6	338.1	673	0.69	64.5	39.3	0.0	0.0
Al-Hijri	3.10.03	0.93	19.5	414.2	853	3.81	72	91.2	0.0	0.0
Al-Fredees	2.10.03	0.75	15.2	551.4	918	3.4	63	172		
Dilba	3.10.03	0.81	22.7	204.1	475	1.84	37.8	29.7	0.0	0.0
Knar El-Wista	2.10.03	0.7	15	406.2	653	0.61	51.2	96	0.0	0.0
Khalt-Diab	2.10.03	1.07	21.8	390.2	929	2.18	93.6	144	0.0	0.0
Set El-Rom	2.10.03	1.44	22.1	680.4	1539	4.36	150	298	0.0	0.0
Longor	17.1.04	1.15	22.8	430.2	966	59.7	94	122.7	0.0	0.0
Hfaier	17.1.04	1.58	28.5	420.2	1015	4.1	150	223.8		
Alaqa Foqa	17.1.04	1.81	28.3	548.0	1330	3.4	226.8	249.5	0.0	0.0
Kurza	17.1.04	1.64	36.7	219.5	503	4.26	58.6	18.4	0.0	0.0
Alaqa Tahta	17.1.04	1.55	29.1	362.2	822	0.55	92.9	73.8	0.0	0.0
Qais	17.1.04	1.24	26.1	310.2	723	0.55	110	42		

4.3.7.2. The springs of Yatta group.

Chemically and depending on the WHO (2004) and the Palestinian Standards (2004) guidelines, there are noticeable deviations in the concentration of NO_3^- in the springs of Abu-Shabban 85.3 mg/L, Al-Rifa’ya 71.5 mg/L, Tuwani 202.9 mg/L, Karmil (A) 223.3 mg/L and Karmil (B) 292 mg/L, also there are noticeable deviations in the concentration of K^+ in the Tuwani spring 18.7mg/L and Karmil (B) 19.3mg/L, which means that all of these springs do not fit the water quality limits and are not good for drinking.

The water total hardness ranges from “hard” to “very hard”, depending on the classification of Sawyer and McCarty (1967) Table (4.18). The water of these springs range from good to permissible for irrigation Table (4.18), based on the SSP values calculated. Based on the EC-SAR relationship, the water of this group can be classified into two classes, low sodium-medium salinity hazard (S1-C2) which represented two springs Abu-Shabban and Al-Rifa’ya, the other springs of this group classified as of low sodium-high salinity hazard (S1-C3) water Appendix (4.2A), The water of this group could be used for irrigation with limitations depending on the SSP and EC-SAR classifications.

Table (4.18): Major chemical characteristics of the Yatta group springs.

Spring	Date	SAR	SSP	TH	EC	K^+	Cl^-	NO_3^-
			%	(mg/L $CaCO_3$)	us/cm	mg/L	mg/L	mg/L
Abu Shabban	17.1.04	1.18	28.9	218.1	556	1.3	61.7	85.3
Al Rifa'ya	17.1.04	1.15	27.8	230.1	543	1.14	54.7	71.5
Tuwani	17.1.04	1.74	36.1	316.2	824	18.7	100	202.9
Karmil (A)	17.1.04	1.24	26.3	374.2	901	10.65	132.7	223.3
Karmil (B)	17.1.04	1.53	30.5	408.2	1106	19.3	154.9	292
Karmil (C)	17.1.04	3.22	39.4	686.4	1855	18.5	266	736.8

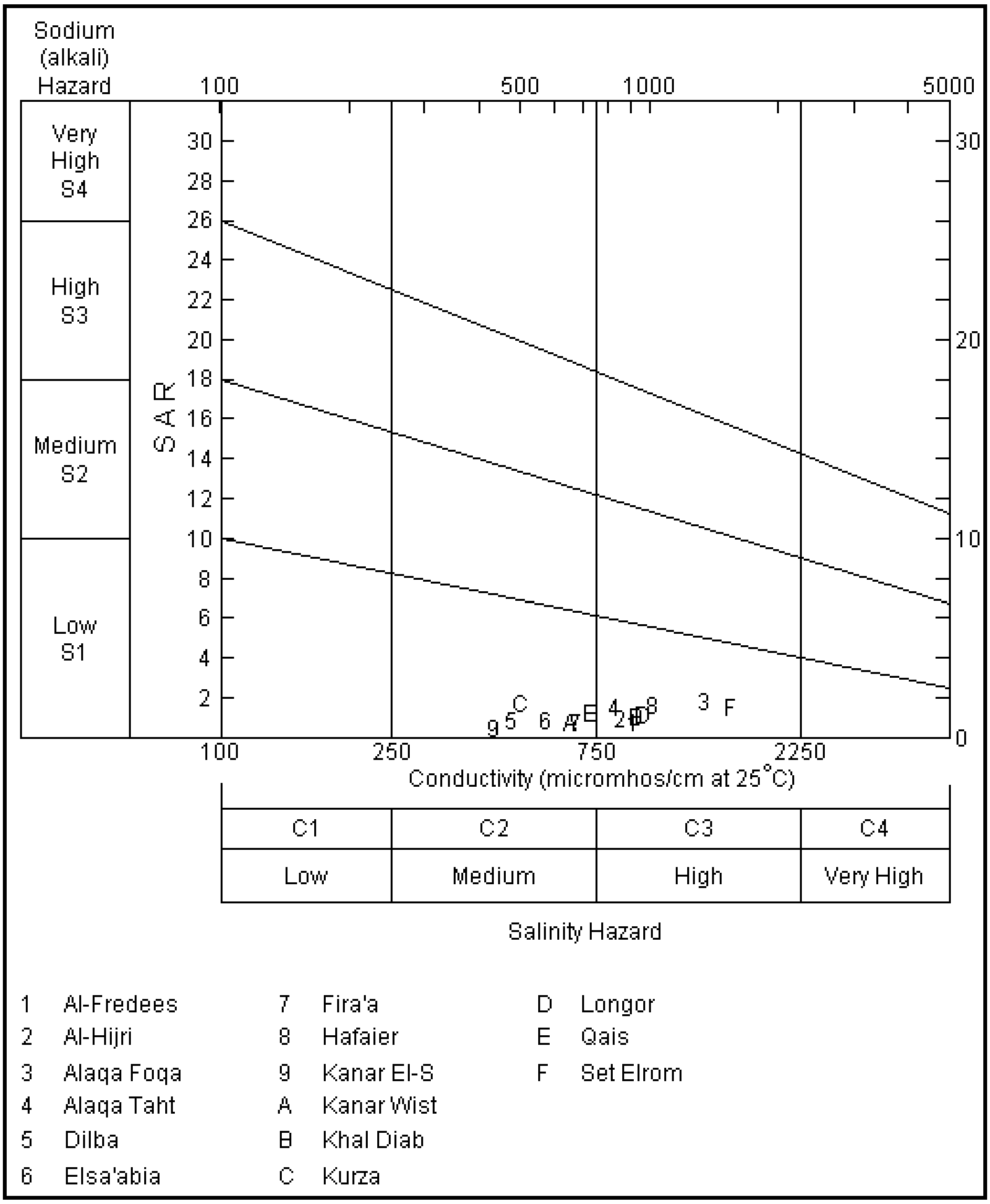


Fig. 4.4: EC-SAR classification of the springs of Dura group.

4.3.7.3. The springs of Idna group:

The results in Table (4.19) show that the Cl^- exceed the WHO (2004) and the Palestinian Standards (2004) chemical guidelines in the springs of Idna group. They show the concentrations of 280 mg/L in El-Bus spring, 310 mg/L in Naqia spring, and 285 mg/L in Wad El-Beer spring. This means that these springs are no good for drinking chemically, but the springs of Taffuh and Tarqumiya' are good for drinking from the chemical point of view as appear in . Depending on the classification of Sawyer and McCarty (1967) for the water total hardness, all the springs of this group belong to the "very hard" water type except the springs of Bustan and Ma'moudi in Taffuh area which are of "hard" water type. The water of Idna group springs are good for irrigation except the Sufli spring in Tarqumiya', which has 40.5 value of the SSP to be classified as of permissible water for irrigation (Table 4.19).

The water of the majority of this group is characterized of low sodium-high salinity hazard (S1-C3) based on the EC-SAR relationship. Bustan and Ma'moudi water is of low sodium-medium salinity hazard (S1-C2) Appendix (4.2B). The water of the majority of the springs is suitable for irrigation with limitations.

Table (4.19): Major chemical characteristics of the Idna group springs.

Spring	Date	SAR	SSP	TH	EC	K^+	Cl^-	NO_3^-
			%	(mg/L $CaCO_3$)	μs/cm	mg/L	mg/L	mg/L
Wad el- beer	26.2.04	2.3	32.9	614.4	1653	12	285	38
Naqiah	26.2.04	2.81	38.3	526.3	1522	3	310	22
El-bus	26.2.04	2.85	39.6	502.3	1490	7	280	30
Ma'moudi	3.10.03	0.86	23.2	210.1	489	0.7	48	9.6
Bustan	27.2.04	1.34	29.4	264.1	557	1	47	3
Sufli	26.2.04	2.65	40.5	400.2	1137	5	185	5
Mussallam	26.2.04	1.96	33.3	390.2	997	1	195	3

4.3.7.4. The springs of Beit Kahil group:

Depending on the WHO (2004) and the Palestinian Standards (2004) chemical guidelines, all the springs of this group are suitable for drinking because the concentration of the NO_3^- and Cl^- are below the permitted limits. The concentrations of the ions in El-Balad spring for example are 10 mg/L, and 44 mg/L respectively. The water of all the springs is "hard" except for Wad El-Quf (B), which is of "very hard" water (Table 4.20).

The water of the springs of Beit Kahil group is of good SSP for irrigation as in Beit Kahil (A, B, C) springs, and of permissible for El-Balad spring, but the water of Wad El-Raed is of good SSP for irrigation (Table 4.20). The water of this group is classified into two classes, based on the EC-SAR relationship. The majority of the springs are of low sodium-medium salinity hazard (S1-C2) such as Wad El-Raed and Wad El-Quf (C). Only El-Balad spring is of low sodium-high salinity hazard (S1-C3) water Appendix (4.2C). So the water of Beit-Kahil group is suitable for irrigation depending on the SSP and EC-SAR classifications with limitations.

Table (4.20): Major chemical characteristics of the Beit Kahil group springs.

Spring	Date	SAR	SSP	TH	EC	K^+	Cl^-	NO_3^-
			%	(mg/L $CaCO_3$)	µS/cm	mg/L	mg/L	mg/L
El-Balad	27.2.04	0.83	19.8	296.1	943	1	44	10
Wad El-Quf (C)	27.2.04	0.98	26	200.1	506	0.5	42	6
Wad El - Raed	27.2.04	1.1	29.5	176.1	450	3	75	7
Wad El-Quf (B)	27.2.04	0.96	22.0	310.1	724	2	100	25
Wad El-Quf (A)	27.2.04	0.85	21.03	284.1	651	3	65	23

4.3.7.5. The springs of Hebron city group:

The Table (4.21) shows that the springs of Kheir Ed-Dein in the center of the city exceeded the WHO (2004) and the Palestinian Standards (2004) chemical guidelines for NO_3^-. The concentration of NO_3^- 126 mg/l which means that this spring is no more suitable for drinking. The other springs are good for drinking from the chemical point of view. The Sawyer and McCarty (1967) classification of water, based on total hardness, show that the water of this group is “hard” type, except Arab spring which is “very hard” water type. The springs of Hebron city group are classified from excellent to good for irrigation purposes based on the SSP. The SSP value for Deir Bahha spring is 19.66 which means excellent water for irrigation (Table 4.21).

Depending on the EC-SAR relationship, the water of the springs of this group is classified into two types, low sodium-medium salinity hazard (S1-C2) for only one spring Deir Bahha, and low sodium-high salinity hazard (S1-C3) for the others. The water of this group is suitable for irrigation according to the SSP and EC-SAR relationship classification Appendix (4.2D).

Table (4.21): Major chemical characteristics of the Hebron city group springs.

Spring	Date	SAR	SSP	TH	EC	K^+	Cl^-	NO_3^-
			%	(mg/L $CaCO_3$)	µs/cm	mg/L	mg/L	mg/L
Sarah	27.2.04	1.65	26.98	526.4	1242	4	175	37
Kheir Ed-Dein	27.2.04	1.63	26.71	524.3	1218	3	110	126
Arab	27.2.04	1.6	28.56	450.3	1117	8	102	30
Deir Bahha	27.2.04	0.83	19.66	296.2	678	0.5	67	11

4.3.7.6. The springs of Halhul group:

The water of these springs show normal concentrations of the ions $Cl^-$and NO_3^-, which make this water good for drinking, based on the WHO (2004) and the Palestinian Standards (2004) chemical guidelines. The Sawyer and McCarty (1967) classification of water, based on total hardness shows that the water of all springs of this group are of “very hard” water type (Table 4.22).

The SSP values calculated for the springs of this group show that this water ranges from excellent as in Misleh and Hasaka springs in Halhul area, to good as in Eth-Tharwa spring (Table 4.22). This means that the water of this group is good for irrigation.

The EC-SAR Appendix (4.2E) shows two types of water, the Misleh spring water is of low sodium-medium salinity hazard (S1-C2), and the Eth-Tharwa and Hasaka springs of low sodium-high salinity hazard (S1-C3). The water of the springs is suitable for irrigation with limitations.

Table (4.22): Major chemical characteristics of the Halhul group springs.

Spring	Date	SAR	SSP	TH	EC	K^+	Cl^-	NO_3^-
			%	(mg/L $CaCO_3$)	µs/cm	mg/L	mg/L	mg/L
Hasaka	27.2.04	0.76	16.2	402.3	943	1	30	25
Eth-Tharwa	27.2.04	1.34	23.4	510.4	1125	1	136	26
Misleh	27.2.04	0.39	8.9	406.3	597	0.5	36	6

4.3.7.7. The springs of Deir Samit group:

Table (4.23) shows that the concentrations of (NO_3^-, Cl^-, and K^+) in El-Semia spring exceed the WHO (2004) and the Palestinian Standards (2004) chemical guidelines with values of 52 mg/L, 497 mg/L, and 39 mg/L respectively, which means that this spring is no more good for drinking. The [Cl^-] in the Al-Biarah spring is 410 mg/L, and Allaton spring 490 mg/L, which means that all the springs of this group are unsuitable for drinking from the chemical point of view.

The sawyer and McCarty (1967) classification of water depending on the water total hardness show that all these springs to be of “very hard” with values range from 620.4 mg/L $CaCO_3$ to 796.5 mg/L $CaCO_3$) (Table 4.23).

The SSP values of the springs of this group show that the water could be classified as good for irrigation (Table 4.23). The EC-SAR relationship Appendix (4.2F) classified the water of Al-Biarah and El-Semia springs in Deir Samit of low sodium-high salinity hazard (S1-C3), and the Allaton spring in Beit Awwa, of low sodium-very high salinity hazard (S1-C4). So all the springs of this group are suitable for irrigation with limitations, especially Allaton spring.

Table (4.23): Major chemical characteristics of the Deir Samit group springs.

Spring	Date	SAR	SSP	TH	EC	K^+	Cl^-	NO_3^-
			%	(mg/L $CaCO_3$)	µs/cm	mg/L	mg/L	mg/L
El-Semia	26.2.04	2	29.5	796.5	1999	39	497	52
Albiarah	26.2.04	2.22	31.4	620.4	1642	6	410	29
Allaton	26.2.04	3.58	39.7	740.4	2500	0.5	490	22

4.4. Statistical analyses

4.4.1. The water parameters interrelationships:

To distinguish the interrelationships between the different analyzed parameters of the samples collected from the springs; a linear correlation was performed, and the correlation matrix is shown in Appendix (4.3). Depending on the data appears in the correlation matrix, the interrelationships between the variables could be classified into the following classes:

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

Parameters	Correlation coefficient
SI-dolomite versus SI-calcite	0.965
SI-dolomite versus SI-aragonite	0.965
TDS mg/L versus EC µS/cm	0.955
Total hardness mg/L $CaCO_3$ versus TDS mg/L	0.924
SI-gypsum versus SO_4^{-2} mg/L	0.930
Total hardness mg/L $CaCO_3$ versus EC µS/cm	0.928
TDS mg/L versus Ca^{+2} mg/L	0.915
EC µS/cm versus Na^{+1} mg/L	0.924
EC µS/cm versus Cl^{-1} mg/L	0.914
Total hardness mg/L $CaCO_3$ versus Ca^{+2} mg/L	0.917
TDS mg/L versus Na^{+1} mg/L	0.903
Ca^{+2} /HCO_3^{-1} versus NO_3^{-1} mg/L	0.938

Fig. (4.5) shows the high correlation between TDS and EC where the majority of the samples plot around the line with R-square of 0.91, and Appendix (4.4A) show the correlation between TDS and Ca^{+2} with R-square of 0.84 because Ca^{+2} play a good rule in the TDS value.

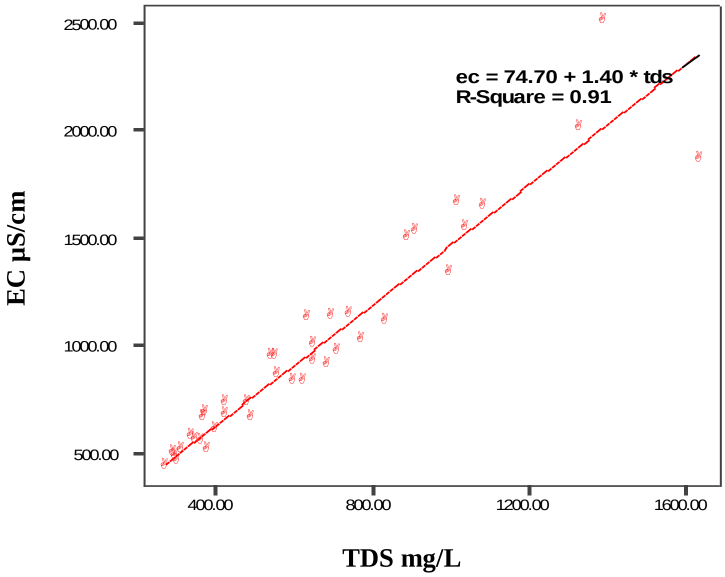


Fig. 4.5: Relationship between TDS and EC in class (I) of very high significant relationship.

Class (II) (High significant relationship): This class includes all the variables that have correlation coefficient between 0.9 and 0.80.

Parameters	Correlation coefficient
Na^{+1} mg/L versus Cl^{-1} mg/L	0.895
Total hardness mg/L $CaCO_3$ versus Mg^{+2} mg/L	0.876
TDS mg/L versus Cl^{-1} mg/L	0.858
EC µS/cm versus Ca^{+2} mg/L	0.855
SI-gypsum versus Ca^{+2} mg/L	0.853
EC µS/cm versus Mg^{+2} mg/L	0.829
Total hardness mg/L $CaCO_3$ versus Cl^{-1} mg/L	0.811
SI-aragonite versus pH-value	0.816
SI-calcite versus pH-value	0.813

The correlation between Cl^{-1} and Na $^{+1}$ is appear in class (II) with R-square of 0.8 Appendix (4.4B) and this give a clear picture about the origin of the majority of these ions. The halite minerals or the see spray may play a good rule here.

Class (III) (good relationship): This class includes all the variables that have correlation coefficient between 0.8 and 0.7.

Parameters	Correlation coefficient
Mg^{+2} mg/L versus Cl^{-1} mg/L	0.795
TDS mg/L versus Mg^{+2} mg/L	0.740
Total hardness mg/L $CaCO_3$ versus Na^{+1} mg/L	0.784
SI-gypsum versus Total hardness mg/L $CaCO_3$	0.778
Ca^{+2} mg/L versus SO_4^{-2} mg/L	0.767
Total hardness mg/L $CaCO_3$ versus SO_4^{-2} mg/L	0.764
SI-gypsum versus TDS mg/L	0747
SI-dolomite versus pH-value	0767
Mg^{+2} mg/L versus HCO_3^{-1} mg/L	0.753
Ca^{+2} mg/L versus Na^{+1} mg/L	0.750
TDS mg/L versus SO_4^{-2} mg/L	0.746
SI- anhydrite versus SI-gypsum	0.731
TDS/EC versus NO_3^{-1} mg/L	0761

Appendix (4.4C) show that Mg^{+2} play a medium rule in the value of the TDS which appear from the distribution of the samples around the line, R-square is 0.55.

Class (IV) (medium relationship): This class includes all the variables that have correlation coefficient between 0.6 and 0.7.

Parameters	Correlation coefficient
SI- anhydrite versus SO_4^{-2} mg/L	0.695
EC µS/cm versus HCO_3^{-1} mg/L	0.687
Mg^{+2} mg/L versus Na^{+1} mg/L	0.673
EC µS/cm versus SO_4^{-2} mg/L	0.660
SI-gypsum versus EC µS/cm	0.666
Cl^{-1} mg/L versus HCO_3^{-1} mg/L	0.655
Total hardness mg/L $CaCO_3$ versus HCO_3^{-1} mg/L	0.642
SAR versus Na^{+1} mg/L	0.633
Ca^{+2} mg/L versus Mg^{+2} mg/L	0.617
SO_4^{-2} mg/L versus NO_3^{-1} mg/L	0.615
SI-gypsum versus NO_3^{-1} mg/L	0.604
Cl^{-1} mg/L versus Ca^{+2} mg/L	0.697

A medium relationship between Na^{+1} and SAR with correlation coefficient value of 0.633, Appendix (4.4D) show the relation between these variables with R-square of 0.4.

Class (V) (acceptable relationship): This class includes all the variables that have correlation coefficient between 0.5 and 0.6.

Parameters	Correlation coefficient
Na^{+1} mg/L versus HCO_3^{-1} mg/L	0.594
Ca^{+2} mg/L versus NO_3^{-1} mg/L	0.583
TDS mg/L versus HCO_3^{-1} mg/L	0.513
Mg^{+2} mg/L versus SO_4^{-2} mg/L	0.567
SI- anhydrite versus Ca^{+2} mg/L	0.560
SI- anhydrite versus NO_3^{-1} mg/L	0.552
SAR versus Cl^{-1} mg/L	0.532
SAR versus EC µS/cm	0.528
Na^{+1} mg/L versus SO_4^{-2} mg/L	0.514
TDS mg/L versus NO_3^{-1} mg/L	0.562
SI-gypsum versus Na^{+1} mg/L	0.506

All the pairs of variables in class five correlate weakly with each other with correlation coefficient values from 0.594 to 0.506, Appendix (4.4E) show the correlation between TDS and HCO_3^{-1} and the distribution of the samples around the line with R-square of 0.26 and this is an acceptable relationship.

Class (VI) (poor relationship): This class includes all the variables that have correlation coefficient < 0.5, the variables which not in any of the above classes.

4.4.2. Cluster analysis:

Cluster analysis is an exploratory data analysis tool for solving classification problems. Its object is to sort cases into groups, or clusters, so that the degree of association is strong between members of the same cluster and weak between the members of different clusters. Each cluster thus describes, in terms of the data collected, the class to which its members belong; and this description may be abstracted through use from the particular to the general class or type.

The program SPSS.10.0 under windows is used here to classify the samples in this research into clusters and here are the clusters found with the main and major correlations between the parameters of the different clusters.

This method is used to group the samples of this study depending on the common characteristics between the samples using the major chemical parameters (cations and anions).

In this method the consequence of the concentration of the ions used as the similarity measures to group the higher the similarity in one group, depending on the correlations between the samples of the same group.

To apply this analytical method both the excel program and the SPSS 10.0 were used and five clusters appeared. Here are the general characteristics of these clusters and the graphs.

4.4.2.1. Cluster (I):

This cluster includes 23.1% of the study samples with average EC and pH of 502.8 µS/cm and 7.8 respectively. It is dominated by calcium cation (47.3% of the total cations) and the bicarbonate anion (61.5% of the total anions) (Fig. 4.6).

The main characteristics of this cluster are:

$$Ca^{+2} > Mg^{+2} > Na^{+1} > K^{+1}$$
$$HCO_3^{-1} > Cl^{-1} > NO_3^{-1} > SO_4^{-2}$$
$$(Na^{+1}/ Cl^{-1})<1$$

Where the concentrations are in (meq/L).

Detailed descriptive statistics of the hydrochemical parameters are shown in (Table 4.24).

Table 4.24: Descriptive statistics of cluster (I).

Variable	Minimum	Maximum	Mean	Std.Dev.	N
HCO_3^- mg/L	134.24	274.59	227.13	43.55	9
NO_3^- mg/L	6.00	85.30	28.60	29.52	9
SO_4^{-2} mg/L	15.40	25.50	20.04	4.22	9
Cl^{-1} mg/L	21.00	75.00	50.42	15.57	9
K^{+1} mg/L	0.14	4.26	1.49	1.35	9
Na^{+1} mg/L	17.20	56.00	33.76	10.81	9
Mg^{+2} mg/L	11.04	26.24	19.37	4.48	9
Ca^{+2} mg/L	33.67	69.74	55.13	9.70	9
T °C	16.10	21.40	18.89	1.54	9
EC µS/cm	433.00	570.00	502.78	46.90	9
pH- value	7.39	8.67	7.78	0.39	9
TDS mg/L	272.30	376.90	322.04	35.98	9
SAR	0.49	4.10	1.56	1.13	9
Total hardness mg/L	176.13	260.14	217.41	24.12	9
SI-calcite	-0.07	0.95	0.30	0.31	9
SI-aragonite	-0.22	0.80	0.15	0.31	9
SI-dolomite	-0.42	2.00	0.41	0.75	9
SI-gypsum	-2.69	-2.20	-2.39	0.15	9
SI-anhydrite	-2.93	-2.44	-2.63	0.15	9
Na/Cl	0.43	0.96	0.69	0.15	9
Ca/HCO_3	0.15	0.42	0.25	0.08	9
Ca/Mg	1.51	6.32	3.08	1.34	9
Ca/SO_4	2.07	3.7	2.82	0.6	9
TDS/EC	0.59	0.75	0.64	0.05	9

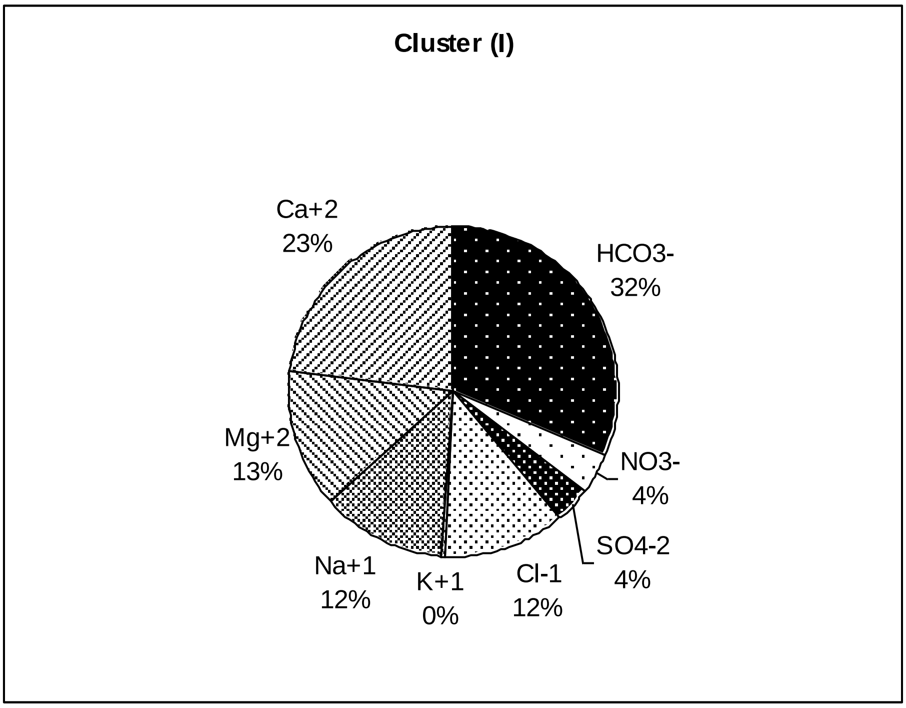


Fig. 4.6: The presentation percentage graph of the cluster (I).

4.4.2.2. Cluster (II):

This cluster is dominated by calcium cation (47 % of the total cations) and the bicarbonate anion (74 % of the total anions) representing 20.5 % of the research samples with average EC and pH of 705.3 µS/cm and 7.6 respectively. Cl^- is 12% and Mg^{+2} is 17% of the samples of this group Appendix (4.5A).

The general characteristics of this group are:

$$Ca^{+2} > Mg^{+2} > Na^{+1} > K^{+1}$$
$$HCO_3^{-1} > Cl^{-1} > NO_3^{-1} > SO_4^{-2}$$
$$HCO_3^{-1} > Ca^{+2}$$
$$(Na^{+1}/ Cl^{-1})<1$$

Where the concentrations are in (meq/L).

Table (4.25) show a descriptive statistics of the parameters of this group.

Table 4.25: Descriptive statistics of cluster (II).

Variable	Minimum	Maximum	Mean	Std.Dev.	N
HCO_3^- mg/L	250.18	370.00	307.10	42.91	8
NO_3^- mg/L	6.00	96.00	31.54	29.22	8
SO_4^{-2} mg/L	14.50	36.50	23.19	6.63	8
Cl^{-1} mg/L	36.00	110.00	67.21	25.88	8
K^{+1} mg/L	0.50	3.00	1.11	0.91	8
Na^{+1} mg/L	18.00	50.00	33.90	8.81	8
Mg^{+2} mg/L	29.16	49.09	33.53	6.97	8
Ca^{+2} mg/L	62.52	100.20	77.25	11.17	8
T ° C	15.70	20.40	17.90	1.60	8
EC µS/cm	597.00	943.00	705.25	104.45	8
pH- value	7.01	8.00	7.60	0.33	8
TDS mg/L	367.70	540.00	437.14	60.73	8
SAR	0.39	3.79	1.13	1.09	8
Total hardness mg/L	284.15	406.25	330.95	49.07	8
SI-calcite	-0.28	0.80	0.36	0.33	8
SI-aragonite	-0.42	0.65	0.21	0.33	8
SI-dolomite	-0.70	1.48	0.61	0.69	8
SI-gypsum	-2.45	-1.97	-2.26	0.14	8
SI-anhydrite	-2.70	-2.21	-2.50	0.14	8
Na/Cl	0.39	0.75	0.53	0.11	8
Ca/HCO_3	0.19	0.34	0.25	0.04	8
Ca/Mg	1.67	2.64	2.35	0.34	8
Ca/SO_4	2.5	4.86	3.51	0.84	8
TDS/EC	0.55	0.75	0.62	0.07	8

4.4.2.3. Cluster (III):

In this cluster bicarbonate show the highest percentage in the anions (55.6% of the total anions) and calcium is the higher the percentage cation (61% of the total cations), this cluster represents 15.4% of the study samples with EC and pH values of 876.8 µS/cm and 7.5 respectively. Appendix (4.5B) shows the percentage of the parameters in this cluster.

The general characteristics of this cluster are:

$$Ca^{+2} > Mg^{+2} > Na^{+1} > K^{+1}$$
$$HCO_3^{-1} > Cl^{-1} > NO_3^{-1} > SO_4^{-2}$$
$$Ca^{+2} > HCO_3^{-1}$$

Where the concentrations are in (meq/L).

Table 4.26: Descriptive statistics of the parameters of cluster (III):

Variable	Minimum	Maximum	Mean	Std.Dev.	N
HCO_3^- mg/L	152.55	414.94	291.88	101.92	6
NO_3^- mg/L	25.00	223.30	131.37	79.32	6
SO_4^{-2} mg/L	36.00	75.20	50.12	13.53	6
Cl^{-1} mg/L	30.00	132.70	81.77	35.15	6
K^{+1} mg/L	0.55	18.70	6.35	7.05	6
Na^{+1} mg/L	35.00	71.20	51.83	15.35	6
Mg^{+2} mg/L	6.00	58.00	33.72	14.25	6
Ca^{+2} mg/L	95.39	111.42	101.77	5.86	6
T °C	16.30	19.20	18.33	1.13	6
EC µS/cm	822.00	943.00	876.83	51.03	6
pH- value	7.07	8.02	7.50	0.41	6
TDS mg/L	550.00	685.00	609.88	52.54	6
SAR	0.71	1.74	1.16	0.43	6
Total hardness mg/L	316.22	551.47	403.45	80.23	6
SI-calcite	0.00	0.65	0.32	0.27	6
SI-aragonite	-0.15	0.50	0.17	0.27	6
SI-dolomite	-0.22	1.34	0.39	0.57	6
SI-gypsum	-1.94	-1.71	-1.85	0.09	6
SI-anhydrite	-2.18	-1.95	-2.09	0.09	6
Na/Cl	0.41	1.17	0.71	0.25	6
Ca/HCO_3	0.26	0.63	0.40	0.16	6
Ca/Mg	1.72	5.03	3.46	1.31	6
Ca/SO_4	1.33	3.1	2.15	0.58	6
TDS/EC	0.58	0.76	0.70	0.07	6

4.4.2.4. Cluster (IV):

Calcium cation (46% of the total cations) and bicarbonate anion of (53.5% of the total anions) are dominate in this cluster with EC and pH values of 1066.1 µS/cm and 7.4 respectively, this group represents 17.9% of the samples of the study Appendix (4.5C).

The general characteristics of this group are:

$$Ca^{+2} > Na^{+1} > Mg^{+2} > K^{+1}$$
$$HCO_3^{-1} > Cl^{-1} > NO_3^{-1} > SO_4^{-2}$$
$$(Na^{+1} + K^{+1}) / Cl^{-1} > 1$$

Where the concentrations are in meq/L.

Table 4.27: Descriptive statistics of the parameters of cluster (IV):

Variable	Minimum	Maximum	Mean	Std.Dev.	N
HCO_3^- mg/L	207.47	567.49	392.27	128.23	7
NO_3^- mg/L	3.00	292.00	100.36	116.56	7
SO_4^{-2} mg/L	12.00	84.40	41.27	25.02	7
Cl^{-1} mg/L	94.00	195.00	145.27	38.20	7
K^{+1} mg/L	1.00	59.66	13.97	21.07	7
Na^{+1} mg/L	55.00	122.00	80.07	21.08	7
Mg^{+2} mg/L	25.76	50.06	38.88	9.20	7
Ca^{+2} mg/L	77.76	130.67	108.10	20.04	7
T ° C	15.60	21.00	18.16	1.85	7
EC µS/cm	966.00	1137.00	1066.14	70.81	7
pH- value	7.01	7.97	7.40	0.37	7
TDS mg/L	634.30	835.40	719.73	69.54	7
SAR	1.15	2.65	1.69	0.49	7
Total hardness mg/L	390.26	510.35	430.00	40.62	7
SI-calcite	0.02	0.69	0.35	0.27	7
SI-aragonite	-0.13	0.54	0.20	0.27	7
SI-dolomite	-0.02	1.32	0.51	0.47	7
SI-gypsum	-2.61	-1.58	-2.01	0.37	7
SI-anhydrite	-2.85	-1.82	-2.25	0.36	7
Na/Cl	0.46	0.76	0.56	0.11	7
Ca/HCO_3	0.14	0.58	0.32	0.16	7
Ca/Mg	1.55	4.70	2.99	1.12	7
Ca/SO_4	1.38	6.48	3.46	1.8	7
TDS/EC	0.57	0.76	0.68	0.07	7

4.4.2.5. Cluster (V):

This cluster is dominated by calcium cation (45% of the total cations), the chloride ion is the major an ion (55% of the total anions) and bicarbonate anion is 34% of the total an ions Appendix (4.5D). The parameters of this cluster represents 23.1% of the study samples with EC and pH values of 1725.6 µS/cm and 7.2 respectively.

The general characteristics of this group are:

$$Ca^{+2} > Na^{+1} > Mg^{+2} > K^{+1}$$
$$Cl^{-1} > HCO_3^{-1} > NO_3^{-1} > SO_4^{-2}$$
$$HCO_3^{-1} = Ca^{+2}$$

$$(Na^{+1} + K^{+1})/ Cl^{-1} > 1$$

Where the concentrations are in (meq/L).

Table 4.28: Descriptive statistics of the parameters of cluster (V):

Variable	Minimum	Maximum	Mean	Std.Dev.	N
HCO_3^- mg/L	158.65	683.42	460.36	150.06	9
NO_3^- mg/L	22.00	736.80	164.09	239.32	9
SO_4^{-2} mg/L	25.00	89.50	56.97	23.79	9
Cl^{-1} mg/L	150.00	497.00	323.87	118.12	9
K^{+1} mg/L	0.50	39.00	10.42	12.02	9
Na^{+1} mg/L	86.10	224.00	142.70	43.48	9
Mg^{+2} mg/L	39.37	94.77	61.99	19.54	9
Ca^{+2} mg/L	113.02	210.02	152.11	32.73	9
T ° C	10.70	20.10	17.63	3.01	9
EC µS/cm	1330.00	2500.00	1725.56	352.09	9
pH- value	6.72	7.97	7.23	0.43	9
TDS mg/L	887.40	1633.60	1142.33	251.96	9
SAR	1.44	3.58	2.47	0.69	9
Total hardness mg/L	502.30	796.48	635.03	99.70	9
SI-calcite	0.07	0.93	0.33	0.33	9
SI-aragonite	-0.08	0.78	0.18	0.33	9
SI-dolomite	-0.25	1.70	0.51	0.63	9
SI-gypsum	-2.17	-1.42	-1.78	0.24	9
SI-anhydrite	-3.77	-1.67	-2.24	0.61	9
Na/Cl	0.26	0.73	0.49	0.14	9
Ca/HCO_3	0.21	1.32	0.41	0.35	9
Ca/Mg	1.48	5.34	2.74	1.32	9
Ca/SO_4	1.87	5.03	3.02	1.14	9
TDS/EC	0.56	0.88	0.67	0.10	9

The domination of HCO_3^{-1} in 76.9% of the total samples of this study and the Na/Cl very low ratio show that the water in the study area infiltrate in a carbonate rocks of limestone, sandstone, and marly limestone. The domination of Cl^{-1} in cluster five may came as a result of contamination and the mixing of water with waste water that enters directly from the surrounding houses.

4.4.3. Correlated variables for the different clusters.

4.4.3.1. Correlated variables for Cluster (I):

Table 4.29: Shows the variables of cluster (I) with their correlation coefficient.

Variable	Correlation coefficient
Ca^{+2}/HCO_3^{-1} versus NO_3^{-1} meq/L.	0.922
SAR versus Cl^{-1} meq/L.	0.831
SI-calcite versus pH-value	0.951
SI-aragonite versus pH-value	0.951
SI-dolomite versus pH-value	0.956
SI-dolomite versus SI-calcite	0.983
TDS mg/L versus Na^{+1} meq/L.	0.906

As appear in Table (4.29) there is an excellent relationship between some of the variables. In this cluster (Ca^{+2}/HCO_3^{-1}) correlate NO_3^{-1} with correlation coefficient of 0.922, SAR correlate Cl^{-1} with correlation coefficient of 0.831, TDS correlate Na^{+1} with correlation coefficient of 0.906, and SI-dolomite correlate SI-calcite with correlation coefficient of 0.983.

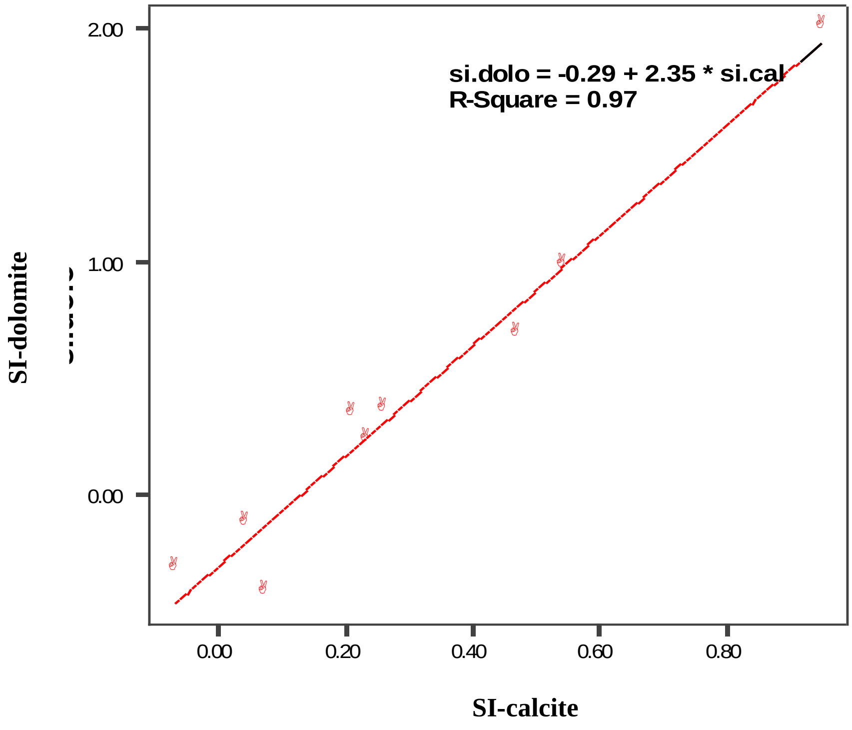


Fig. 4.7: Relationship between SI-dolomite and SI-calcite in cluster (I).

Fig. (4.7) shows the relation between SI-dolomite and SI-calcite in cluster (I) with R-square of 0.97 and correlation coefficient of 0.983. The relation between NO_3^{-1} and Ca/HCO_3^{-1} in cluster (I) with correlation coefficient of 0.922 appear in Table (4.29), leaching and dissolution play a good rules here, especially if the sample collected exactly after rain fall to recharge a new water with CO2 to form an acid, or by cleaning the surface area and the soil.

Schoeller diagram shows that the concentrations of the ions are very close to each other for the springs of this cluster except NO_3^{-1} for Al-Rifa'ya and Abu Shabban springs which appear to be higher than the others (Fig. 4.8).

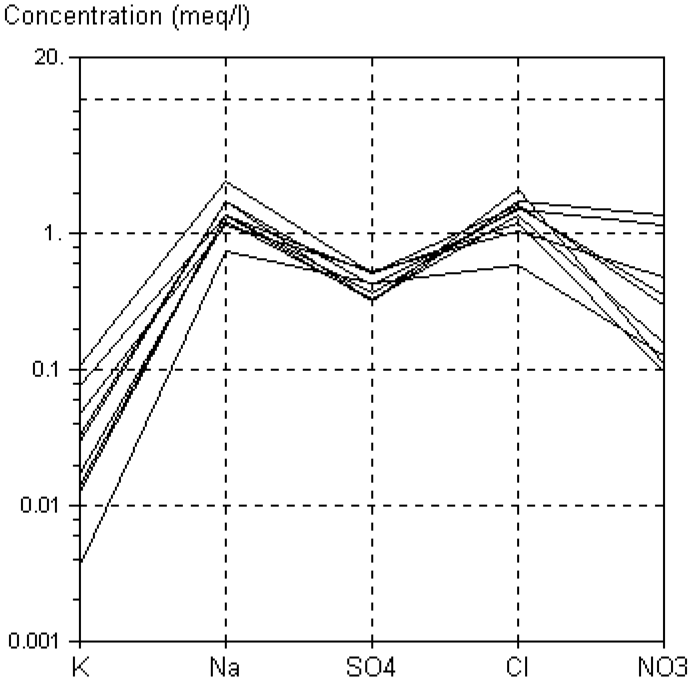


Fig. 4.8: Schoeller diagram plot for the samples of cluster (I).

4.4.3.2. Correlated variables for Cluster (II):

Table 4.30: Shows the variables of cluster (II) with their correlation coefficient.

Variable	Correlation coefficient
Cl^{-1} meq/L versus Na^{+1} meq/L	0.876
Total hardness (mg/L $CaCO_3$) versus Mg^{+2} meq/L	0.872
SI-gypsum versus SO_4^{-2} meq/L	0.978
SI-anhydrite versus SO_4^{-2} meq/L	0.978
Total hardness (mg/L $CaCO_3$) versus Ca^{+2} meq/L	0.864
EC µS/cm versus SAR	0.954
TDS/EC versus Ca^{+2} meq/L	0.912
TDS mg/L versus NO_3^{-1} meq/L	0.729

As appear in Table (4.30), there is an excellent relationship between the variables. In this cluster EC µS/cm correlate SAR with correlation coefficient of 0.954, Total hardness (mg/L $CaCO_3$) correlate Ca^{+2} meq/L with correlation coefficient of 0.864, and SI-gypsum correlate SO_4^{-2} meq/L with correlation coefficient of 0.978. Ca^{+2} play a good rule in the value of the TDS (Fig. 4.9) show the distribution of the samples around the line with R-square value of 0.83.

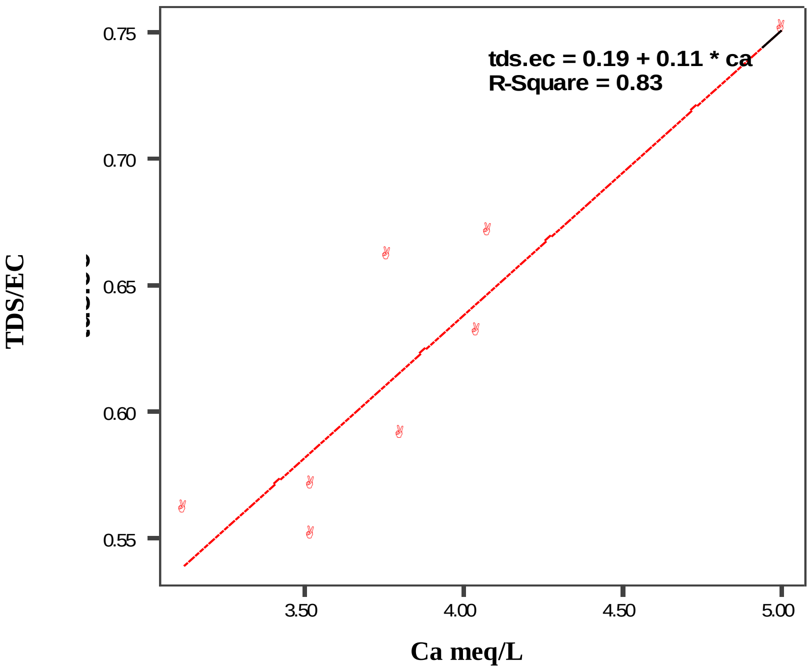


Fig. 4.9: Relationship between TDS/EC and Ca^{+2} in cluster (II).

A good correlationship between Na^{+1} and Cl^{-1} and a very good correlationship between total hardness and Ca^{+2} ,an excellent correlationship between SAR and EC in cluster (II). The concentrations of the ions appear in Appendix (4.6A), Cl^{-1} concentration is the highest for the majority of the springs in this cluster, and K^{+1} is the lowest concentration.

4.4.3.3. Correlated variables for Cluster (III):

Table 4.31: Shows the variables of cluster (III) with their correlation coefficient.

Variable	Correlation coefficient
SI-calcite versus pH-value	0.958
SI-aragonite versus pH-value	0.957
SI-dolomite versus SI-calcite	0.948
SI-dolomite versus SI-aragonite	0.948
pH-value versus NO_3^{-1} meq/L	0.850
SAR versus Na^{+1} meq/L	0.992
Total hardness(mg/L $CaCO_3$) versus Mg^{+2} meq/L	0.968
TDS mg/L versus NO_3^{-1} meq/L	0.884
TDS/EC versus Cl^{-1} meq/L	0.909
TDS mg/L versus Cl^{-1} meq/L	0.744

As appear in Table (4.31), there is a very excellent relationship between the variables. In this cluster Na^{+1} mg/L correlate SAR with correlation coefficient of 0.992 and R-square value of 0.98. (Fig. 4.10), Mg^{+2} meq/L correlate Total hardness(mg/L $CaCO_3$) with correlation coefficient of 0.968.

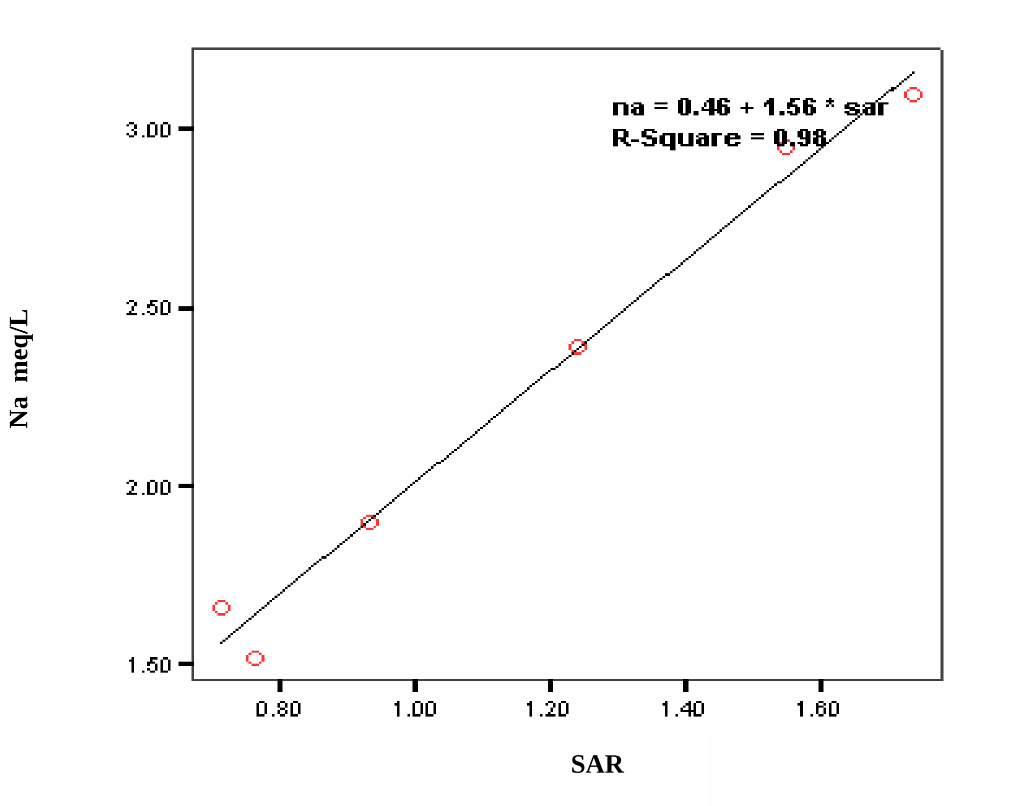


Fig. 4.10: Relationship between SAR and Na^{+1} in cluster (III).

In this cluster the EC of the springs ranges from 966 µS/cm to 1137 µS/cm, the concentration of the Cl^{-1} is the lowest for the Longor spring Appendix (4.6B).

4.4.3.4. Correlated variables for Cluster (IV):

Table 4.32: Shows the variables of cluster (IV) with their correlation coefficient.

Variable	Correlation coefficient
pH-value versus NO_3^{-1} meq/L	0.928
SAR versus Na^{+1} meq/L	0.992
Mg^{+2} meq/L versus HCO_3^{-1} meq/L	0.819
SI-calcite versus pH-value	0.937
SI-aragonite versus pH-value	0.941
SI-dolomite versus pH-value	0.861
SI-gypsum versus SO_4^{-2} meq/L	0.928
SI-dolomite versus K^{+1} meq/L	0.891
SI-gypsum versus Ca^{+2} meq/L	0.880
SI-anhydrite versus SO_4^{-2} meq/L	0.928
SI-anhydrite versus Ca^{+2} meq/L	0.881
TDS mg/L versus NO_3^{-1} meq/L	0.838
TDS/EC versus NO_3^{-1} meq/L	0.848

As appear in Table (4.32), there is a very excellent relationship between the variables. In this cluster SAR correlate Na^{+1} meq/L with correlation coefficient of 0.992 and R-square value of 0.98 (Fig. 4.11), NO_3^{-1} correlate TDS with correlation coefficient of 0.838.

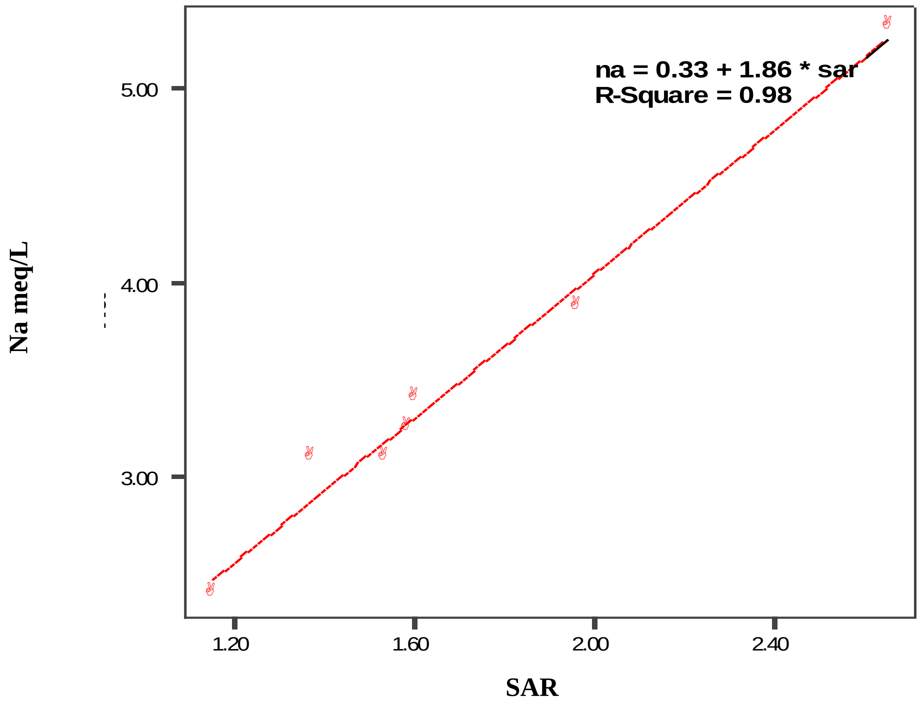


Fig. 4.11: Relationship between SAR and Na^{+1} in cluster (IV).

Appendix (4.6C) show the concentration of the ions for seven springs, the Fig show that the concentration of the K^{+1} is the lowest for the majority of the springs in this cluster. The pH of the water of the springs in this cluster ranges from 7.0 to 8.0.

4.4.3.5. Correlated variables for Cluster (V):

As appear in Table (4.32), there is a very excellent relationship between the variables. In this cluster total hardness (mg/L $CaCO_3$) correlate SO_4^{-2} meq/L with correlation coefficient of 0.857, TDS correlate SO_4^{-2} meq/L with correlation coefficient of 0.878. SAR correlate Na^{+1} meq/L with correlation coefficient of 0.962 and R-square value of 0.93 (Fig. 4.12).

Table 4.33: Shows the variables of cluster (V) with their correlation coefficient.

Variable	Correlation coefficient
SAR versus Na^{+1} meq/L	0962
Total hardness(mg/L $CaCO_3$) versus SO_4^{-2} meq/L	0.857
SI-gypsum versus SO_4^{-2} meq/L	0.948
SI-gypsum versus Ca^{+2} meq/L	0.813
SI-dolomite versus SI-aragonite	0962
SI-dolomite versus SI-calcite	0.962
TDS mg/L versus SO_4^{-2} meq/L	0.878

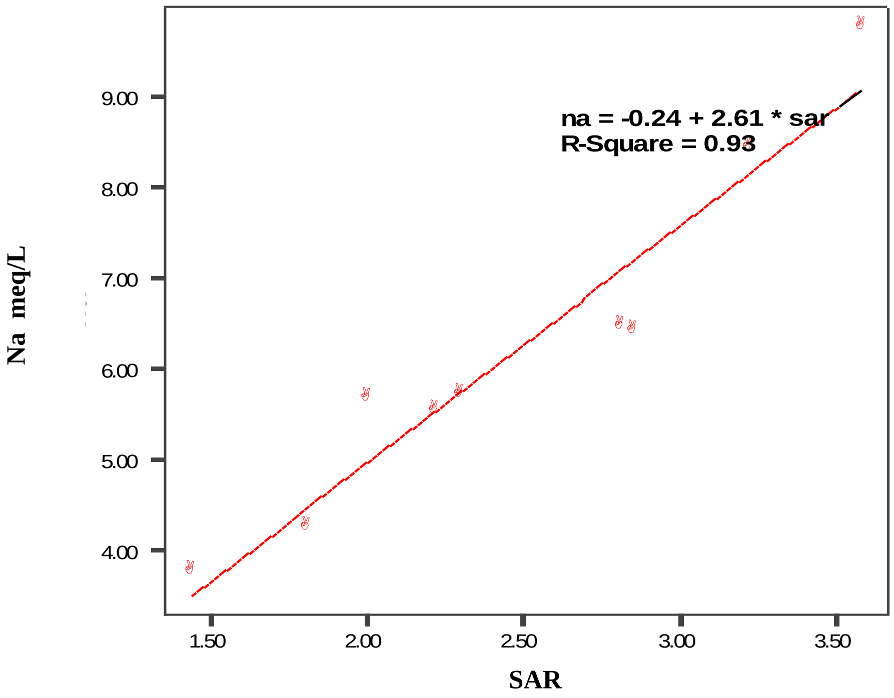


Fig. 4.12: Relationship between SAR and Na^{+1} in cluster (V).

Appendix (4.6D) shows Schoeller diagram for the springs of cluster five, K^{+1} is of the lowest concentration for the majority of the springs in this cluster, the concentrations of the ions are close to each other, the EC for the springs of this cluster ranges from 1330 µS/cm to 2500 µS/cm. The mean of the concentrations of the ions for the clusters is appear in (Table 4.34), and (Fig. 4.13).

Table 4.34: The mean of the concentrations of the ions in the clusters.

Cluster	K^{+1} (meq/L)	Na^{+1} (meq/L)	Cl^{-1} (meq/L)	NO_3^{-1} (meq/L)	Ca^{+2} (meq/L)	Mg^{+2} (meq/L)	SO_4^{-2} (meq/L)	HCO_3^{-1} (meq/L)
Cluster I	0.04	1.47	1.42	0.46	2.75	1.59	0.42	3.72
Cluster II	0.03	1.47	1.90	0.51	3.85	2.76	0.48	5.03
Cluster III	0.16	2.25	2.31	2.12	5.08	2.77	1.04	4.78
Cluster IV	0.36	3.48	4.10	1.62	5.39	3.20	0.86	6.43
Cluster V	0.27	6.21	9.14	2.65	7.59	5.10	1.19	7.55

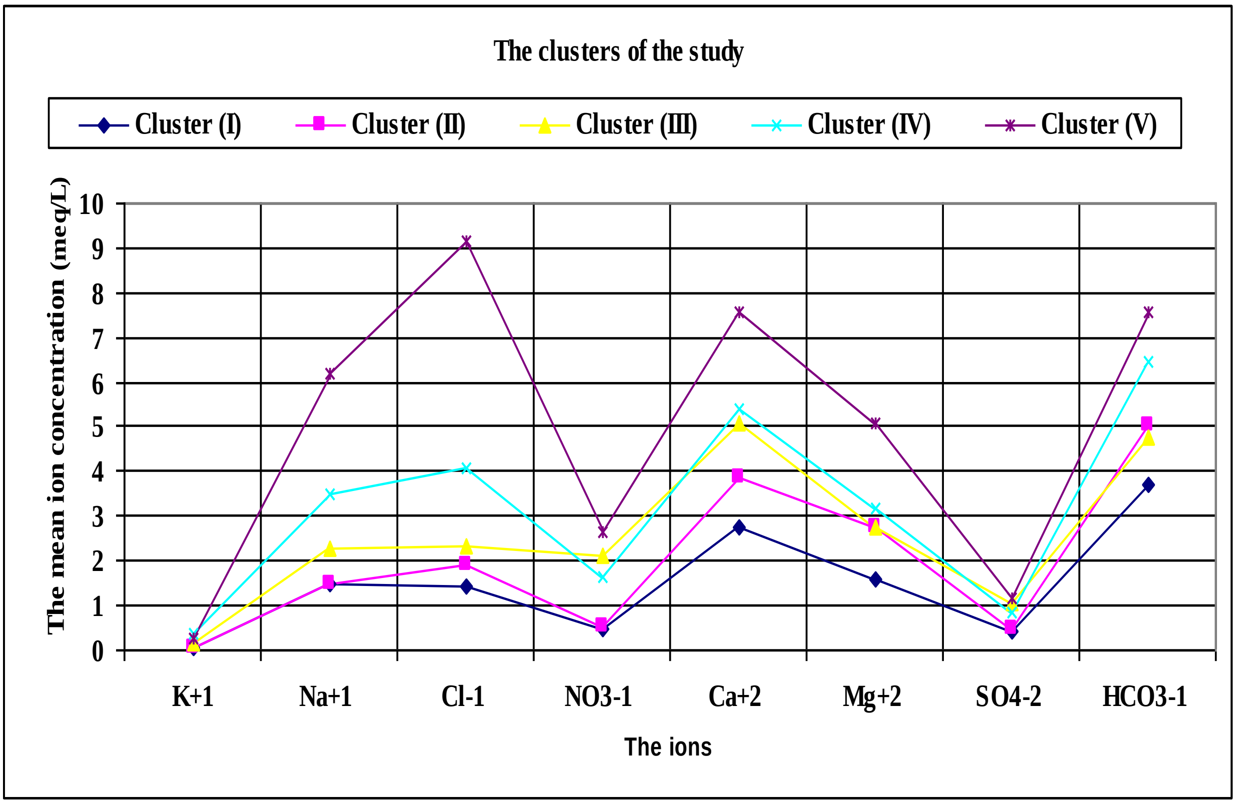


Fig. 4.13: The clusters of the study samples.

4.4.4. Variation in water quality from season to another:

The water of the springs in this study is of winter precipitation source (recharge water) so this will produce seasonal variation. The samples collected in winter should have a less concentration of a major and minor ions as a result of dilution by the recharge water from precipitation.

The first type of seasonal variation is of a higher winter concentrations of K^{+1}, Na^{+1}, Cl^{-1}, SO_4^{-2}, and NO_3^{-1} as well as higher EC. Waste water here play a good rule by mixing with water recharging to the aquifer, and this mixing increase in winter as a result of continuous flow of precipitation and a continuous recharging, which is not found in summer (Fig. 4.14), The second type appear in many of the springs in this study. Al-Hijri spring show a lower winter ion concentration than summer, and also the EC, except for NO_3^{-1} ion which appear to be higher in winter and this is as a result of evaporation (gaseous loss) as ammonia (Fig. 4.15),

Some samples show a less concentration of SO_4^{-2}, Na^{+1}, and NO_3^{-1} in summer than in winter and this is as a result of evaporation, K^{+1} also in some samples show low concentration in summer than in winter and this is as a result of sorption by plants, so reasons which may convert the logical ions concentration in water from season to another are.

1. Gaseous loss as NH_4^{+1} for NO_3^{-1}.
2. Loss of some ions by plant sorption like K^{+1}.

3. Mixing with waste water which increase the ion concentration in the upsent of water flow by recharge (no dilution).
4. Precipitation of some mineral phases.
5. Ion exchange.
6. Adsorption and absorption.
7. Substitution.
8. Dissolution of mineral phases.

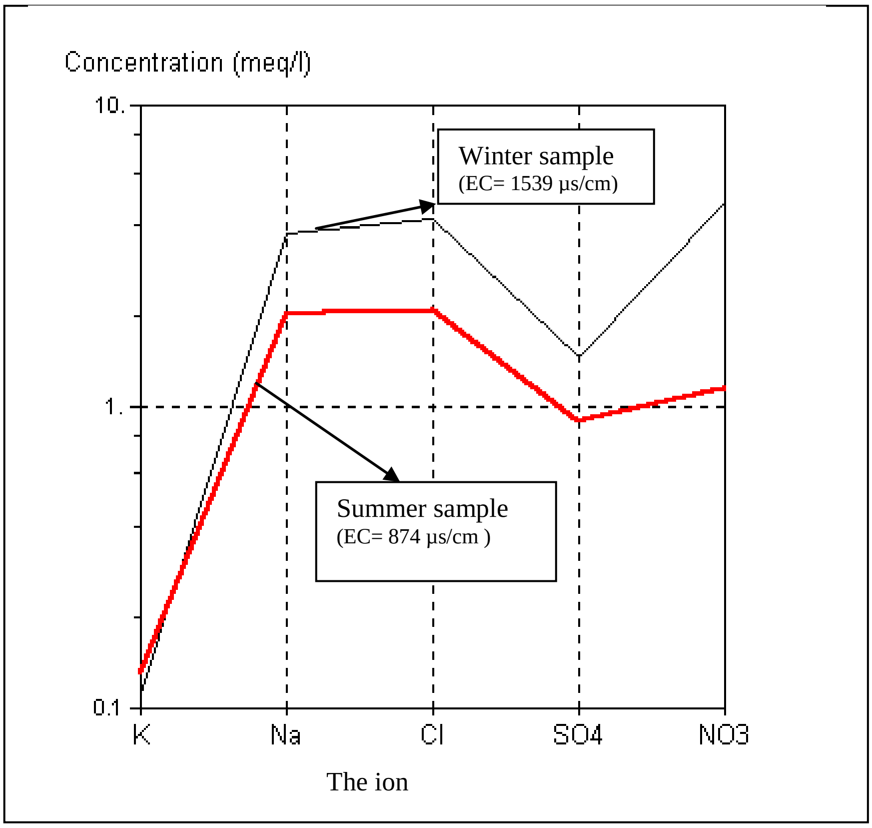


Fig. 4.14: Schoeller diagram plot for the samples collected in winter and summer from Set El-Rom spring.

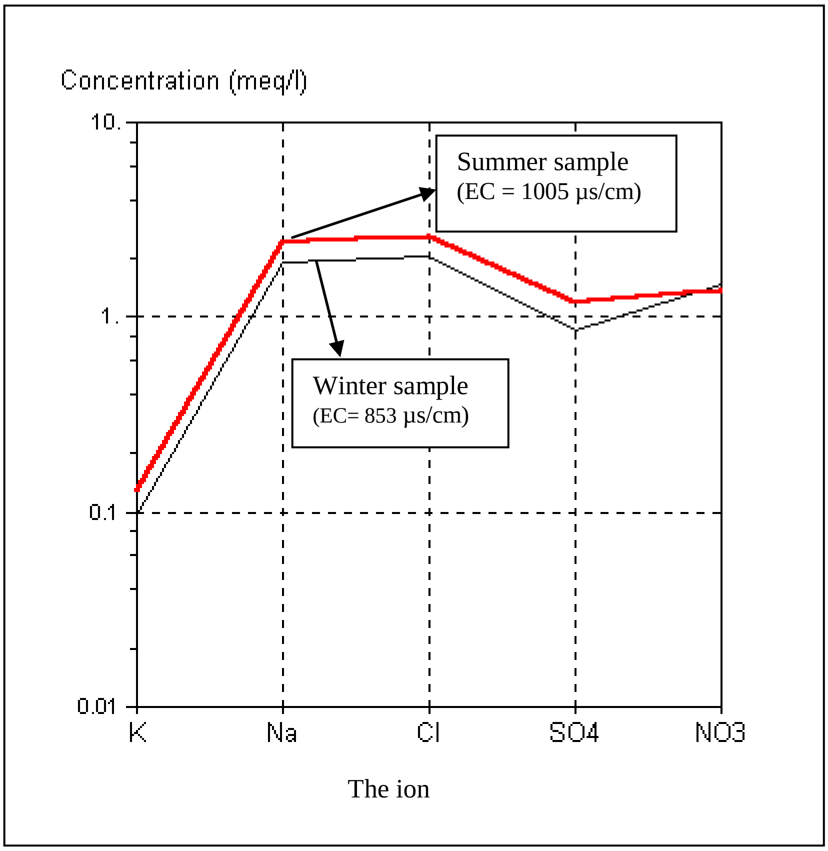


Fig. 4.15: Schoeller diagram plot for the samples collected in winter and summer from Al-Hijri spring.

Chapter five

Thermodynamics calculations

Water genesis

5.1. General

The most abundant water type of the West Bank springs is the " earth alkaline water with prevailing bicarbonate", which is dominated by Ca^{+2} and HCO_3^{-1} ions. This water type originates from the interaction of the meteoric water with the soil horizon and the underlying carbonate aquifer. Other water types are derived from the earth alkaline water with prevailing HCO_3^{-1} by one of the following process.

a) Water–rock interaction (leaching, dissolution/precipitation of the various mineral phases).
b) Ion exchange.
c) Mixing with waste water, agricultural effluents, sea water, connate water and deep brine water.

Water-rock interaction and mixing with waste water and agricultural effluents are the most important factors affecting the water genesis of the springs in the West Bank. The effect of these factors is evaluated the determination of the saturation indices of the water.

5.1.1. Saturation indices:

One method for expressing the extent of chemical equilibrium between the water and the mineral phases of the aquifer materials makes use of saturation indices. The equation that represents the degree of water saturation with respect to a certain mineral is:

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

Where:-

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

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

a) SI value = 0: The water is in equilibrium with respect to the particular mineral.
b) SI value >0 : The water is over saturated with respect to that mineral, and thus tends towards its precipitation.

c) SI value <0 : The water is under saturated with respect to that mineral and tends toward its dissolution.

The PCWATEQ (Rollin, 1988) soft-ware was used to perform the thermodynamic calculations of (SI). The minerals considered in the calculation, with their essential thermodynamic data are listed in (Table 5.1).

Table (5.1): the mineral phases considered in the thermodynamic calculations of saturation indices.

Mineral	Dissolved Species	constant
Anhydrite	$CaSO_4 \longrightarrow Ca^{+2}_{(aq)} + SO_4^{-2}{}_{(aq)}$	$4.86 * 10^{-5}$
Aragonite	$CaCO_3 \longrightarrow Ca^{+2}_{(aq)} + CO_3^{-2}{}_{(aq)}$	$4.94 * 10^{-9}$
Calcite	$CaCO_3 \longrightarrow Ca^{+2}_{(aq)} + CO_3^{-2}{}_{(aq)}$	$3.52 * 10^{-9}$
Dolomite	$CaMg(CO_3)_2 \longrightarrow Ca^{+2}_{(aq)} + Mg^{+2}{}_{(aq)} + CO_3^{-2}{}_{(aq)}$	$1.07 * 10^{-17}$
Gypsum	$CaSO_4.2H_2O \longrightarrow Ca^{+2}_{(aq)} + SO_4^{-2}{}_{(aq)} + H_2O_{(aq)}$	$2.49 * 10^{-5}$

5.1.2. Corrosivity and scale forming:

The ΔpH which is a mean of evaluating water quality data to determine if the water has a tendency to be corrosive or scale forming was calculated using PHREEQC software. The ΔpH is giving by:

$$\Delta pH = pH - pH_C$$

Where:

pH is measured pH-value and pH_C is the pH-value at equilibrium with calcite.

Agressivity and scale forming of water could be neglected when the water, which shows ΔpH values between (–0.2 and +0.2). As their deviations are tolerable the water could be classified as balanced water (Merkel and Planer – Friedrich, 2002). ΔpH values > 0.2 indicates a water of scale forming tendency while ΔpH values < -0.2 indicates aggressive water (Merkel and Planer – Friedrich, 2002).

The saturation indices were also used as an other indicator of water Agressivity or scale forming. Table (5.2) presents a typical range of SI of calcite that may be encountered in a drinking water and a description of the nature of the water and general recommendations regarding treatment (Wilkes University, 2002).

Table (5.2): classification of the water corrosion potential based on the calcite (SI) values and recommended treatment.

Saturation Indices (SI)	Description	General recommendations
-5.0	Severe corrosion	Treatment recommended
-4.0	Moderate corrosion	Treatment recommended
-3.0	Moderate corrosion	Treatment recommended
-2.0	Moderate corrosion	Treatment should considered
-1.0	Corrosion Mild	Treatment should considered
-0.5	Corrosion Mild	Treatment probably not needed
0.0	Balanced	Treatment typically not needed
0.5	Some faint coating	Treatment typically not needed
1.0	Mild scale forming	Some aesthetic problems
2.0	Mild scale forming	Some aesthetic considered
3.0	Moderate scale forming	Treatment should considered
4.0	Severe scale forming	Treatment probably required
5.0	Severe scale forming	Treatment required

5.1.3. The Expanded Durov Diagram:

This diagram is based on the 90 of the major ions in meq/L . The total of these positive and negative ions equal 100% . The values of the cations and anions are plotted in the appropriate triangular and projected into the square of the main field . The importance of this diagram is that it displays some possible geochemical processes that could affect the water genesis and this diagram for both cations and anions plotted by Aquachem software. The fields and line on the diagram show the classifications of Lloyd and Heathcote (1985). Below is a summary about the theory behind the divisions in the diagram as given in (Lloyd and Heathcote, 1985) .

field (1) : HCO_3^{-1} and Ca^{+2} dominant , frequently indicates recharging waters in limestone, sandstone, and other aquifers.
field (2) : this water type is dominated by Ca^{+2} and HCO_3^{-1} ions, association with dolomite. If Na^{+1} is significant, an important ion exchange is presumed.
Field (3): HCO_3^{-1} and Na^{+1} are dominated , indicates ion – exchanged water, although the generation of CO_2 at depth can produce HCO_3^{-1} where Na^{+1} is dominant under certain circumstances .
Field (4): SO_4^{-2} is dominant , or anions discriminate and Ca^{+2} dominant, Ca^{+2} and SO_4^{-2} dominant, frequently indicates a recharge water in lava and a gypsyferous deposits, otherwise a mixed water or water exhibiting simple dissolution may be indicated.
Field(5): no dominant an ion or cation, indicates water exhibiting dissolution or mixing.
Field(6): SO_4^{-2} dominant or disicriminant and Na^{+1} dominant; is a water type that is not frequently encountered and indicates probable mixing influence.
Field(7): Cl^{-1} and Na^{+1} dominant is frequently encountered unless cement pollution is prsent. Otherwise the water may result from reverse ion exchange of Na-Cl waters.
Field(8): Cl^{-1} dominant anion and Na^{+} dominant cation, indicate that the groundwaters be related to reverse ion exchange of Na-Cl waters.
Field(9): Cl^{-1} and Na^{+} dominant frequently indicate end-point waters.

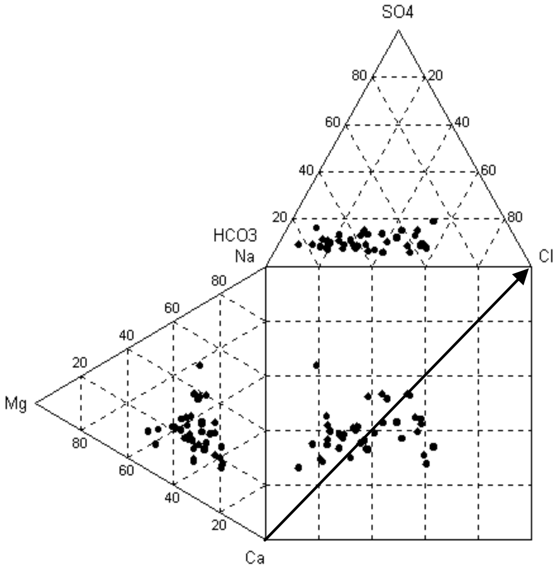


Fig. 5.1: Durov diagram for the samples collected in Summer.

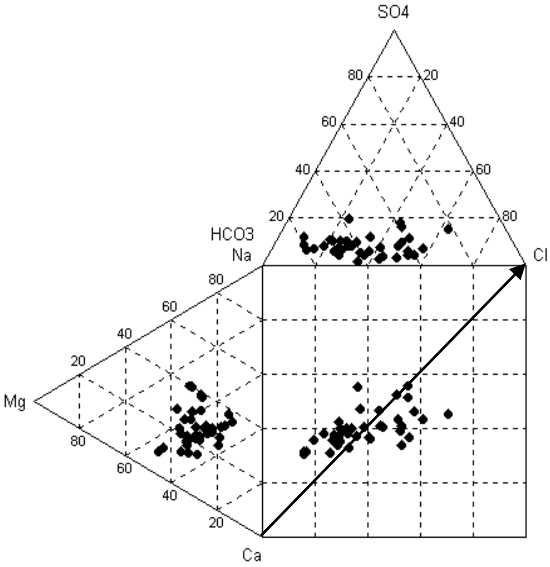


Fig. 5.2: Durov diagram for the samples collected in Winter.

The water of the springs of Hebron district is unsaturated with respect to the sulphate mineral phases considered (Gypsum and Anhydrite), 90% of the water of these springs is oversaturated with respect to calcite the majority of these spring are saturated with respect to dolomite and aragonite Tables (5.3 to 5.9).

The water from the majority of the springs plot in field (2) and field (5) on the Durov Diagram along the mixing-dissolution line (Fig. 5.1 and 5.2), this suggests that the water type of this group which collected either in summer or winter is of a recharge area, the shift in plot may be as a result of mixing with waste water or simple dissolution of carbonate minerals.

5.2. The water genesis in the different groups

5.2.1. The springs of Dura group:

The water of the springs of Dura group is unsaturated with respect to the sulphate mineral phases considered (Gypsum and Anhydrite), also Al-Hijri, Dilba, Alaqa Foqa, Kurza, Alaqa Tahta, and Qais springs are unsaturated with respect to aragonite, and the water of Dilba spring is unsaturated with respect to calcite and dolomite. Finally the water of Al-Hijri, Kurza, Alaqa Tahta and Qais is undersaturated with respect to dolomite, which means that these minerals couldn’t have enough time to reach the equilibrium state. Other springs have enough time to reach the state of equilibrium (Table 5.3).

Table 5.3: Saturation indices of the water of the springs of Dura group with respect to some mineral phases.

Spring	Date	Saturation indices				
		Calcite	Aragonite	Dolomite	Gypsum	Anhydrite
Elsa'abiya	3.10.03	0.21	0.07	0.34	-2.42	-2.66
Knar El-Sharqiya	2.10.03	0.54	0.39	0.98	-2.35	-2.59
Fira'a	3.10.03	0.45	0.31	0.8	-2.25	-2.49
Al-Hijri	3.10.03	0	-0.15	-0.11	-1.94	-2.18
Al-Fredees	2.10.03	0.65	0.5	1.34	-1.71	-1.95
Dilba	3.10.03	-0.07	-0.22	-0.32	-2.28	-2.51
Knar El-Wista	2.10.03	0.29	0.14	0.45	-1.97	-2.21
Khalt-Diab	2.10.03	0.49	0.34	0.69	-1.87	-2.12
Set El-Rom	2.10.03	0.93	0.78	1.70	-1.6	-1.84
Longor	17.1.04	0.67	0.52	1.32	-2.1	-2.34
Hfaier	17.1.04	0.39	0.25	0.49	-1.58	-1.82
Alaqa Foqa	17.1.04	0.11	-0.04	0.03	-1.77	-2.03
Kurza	17.1.04	0.07	-0.08	-0.42	-2.2	-2.44
Alaqa Tahta	17.1.04	0.04	-0.11	-0.22	-1.86	-2.1
Qais	17.1.04	0.07	-0.08	-0.03	-2.38	-2.62

The water from this group plots in field (1), (2) and (5) on the Durov Diagram along the mixing-dissolution line (Fig. 5.3), this suggests that the water type of field (1) is of a recharge area, the shift in plot of the other water may be as a result of mixing with waste water or simple dissolution of carbonate minerals.

5.2.2. The springs of Yatta group:

The water of the entire springs of Yatta group is over saturated with respect to dolomite, calcite and aragonite, except Abu Shabban springs which show negative SI with respect to the same minerals. The other springs, Al Rifa'ya, Tuwani, Karmil (A), and Karmil (B) show under saturation with respect to anhydrite and gypsum (Table 5.4).

Table 5.4: Saturation indices of the water of the springs of Yatta group with respect to some mineral phases.

Spring	Date	Saturation indices				
		Calcite	Aragonite	Dolomite	Gypsum	Anhydrite
Abu Shabban	17.1.04	0.04	-0.10	-0.13	-2.47	-2.71
Al Rifa'ya	17.1.04	0.47	0.32	0.68	-2.34	-2.59
Tuwani	17.1.04	0.55	0.4	0.66	-1.83	-2.07
Karmil (A)	17.1.04	0.45	0.30	0.49	-1.93	-2.17
Karmil (B)	17.1.04	0.69	0.54	0.94	-1.79	-2.04

The water of the majority of the springs of the Yatta group plots in field (5) along the mixing-dissolution line on the Durov Diagram Appendix (5.1A). This suggests that the water of these springs is exhibiting simple dissolution or mixing.

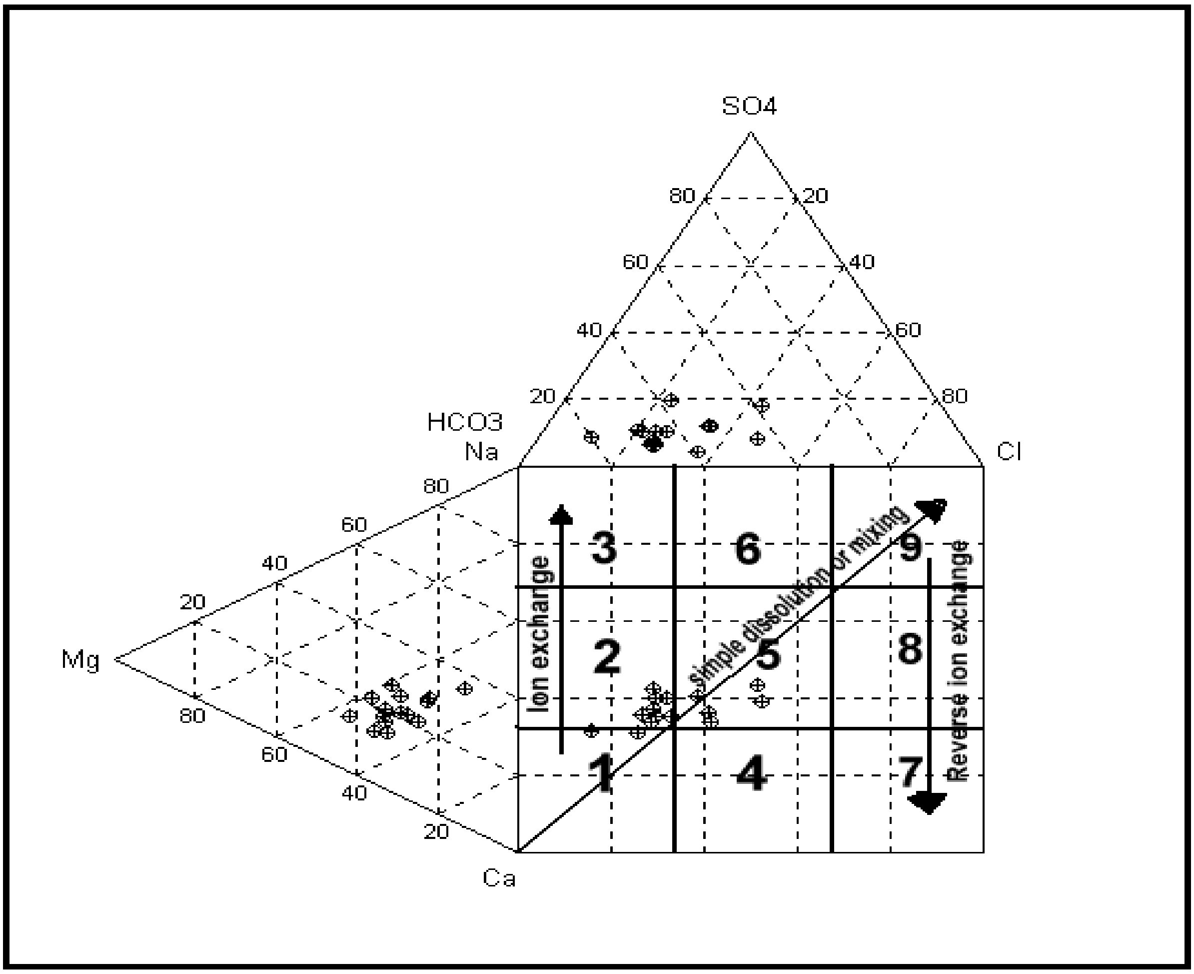


Fig. 5.3: Plot of the springs of the Dura group in the Hebron district on Durov Diagram.

5.2.3. The springs of Idna group.

The water of this group is over saturated with respect to dolomite and calcite, and under saturated with respect to anhydrite, aragonite and gypsum, Naqia and Ma’moudi springs are over saturated with respect to aragonite, also Wad El-Beer and Mussallam springs are under saturated with respect to dolomite (Table 5.5).

Table 5.5: Saturation indices of the water of the springs of Idna group with respect to some mineral phases.

Spring	Date	Saturation indices				
		Calcite	Aragonite	Dolomite	Gypsum	Anhydrite
Wad el- beer	26.2.04	0.07	-0.08	-0.25	-1.85	-2.09
Naqiah	26.2.04	0.60	0.45	1.13	-2.04	-2.28
El-bus	26.2.04	0.08	-0.07	0.11	-2.17	-2.41
Ma'moudi	3.10.03	0.26	0.11	0.36	-2.49	-2.73
Bustan	27.2.04	0.09	-0.06	0.13	-2.99	-3.23
Sufli	26.2.04	0.02	-0.13	0.12	-2.61	-2.85
Mussallam	26.2.04	0.05	-0.09	-0.02	-2.33	-2.57

The water from the majority of the springs of Idna group plot in field “5” along the mixing - dissolution line on the Durov Diagram. This suggests a simple dissolution or mixing, because no dominant anion or cation in the water of these springs. The water from the other two springs plots in field ”2” on the Durov Diagram which suggests that the water type of these springs (Ma’moudi and Bustan) is of ion exchange type Appendix (5.1B).

5.2.4 The springs of Beit Kahil group:

The water of all the springs of Beit Kahil group are oversaturated with respect to dolomite, calcite and aragonite except Wad El-Quf (B) spring which is under saturated with respect to the minerals above, and the water of all the springs of this group is under saturated with respect to anhydrite and gypsum. (Table 5.6)

Table 5.6: Saturation indices of the water of the springs of Beit Kahil group with respect to some mineral phases.

Spring	Date	Saturation indices				
		Calcite	Aragonite	Dolomite	Gypsum	Anhydrite
El-Balad	27.2.04	0.8	0.65	1.48	-2.22	-2.46
Wad El-Quf (C)	27.2.04	0.23	0.09	0.23	-2.29	-2.52
Wad El - Raed	27.2.04	0.95	0.8	2.00	-2.69	-2.93
Wad El-Quf (B)	27.2.04	-0.28	-0.42	-0.7	-2.27	-2.51
Wad El-Quf (A)	27.2.04	0.52	0.37	0.99	-2.27	-2.51

The water of Wad El-Quf (C) and El-Balad springs of this group plots in field “2” on Durov Diagram, which suggest a mixing water type or ion exchange. Wad El-Quf (B) spring and Al-Raed spring plots in field “5” which suggests simple dissolution or mixing, El-Balad spring takes place at the line between field ‘2’ and ‘5’ Appendix (5.1C).

5.2.5 The springs of Hebron city group:

The water of all the springs of Hebron city group is under saturated with respect to the following minerals (anhydrite, aragonite, calcite, dolomite and gypsum) except Arab and Deir Bahha springs which are oversaturated with respect to aragonite, calcite and dolomite (Table 5.7).

Table 5.7: Saturation indices of the water of the springs of Hebron city group with respect to some mineral phases.

Spring	Date	Saturation indices				
		Calcite	Aragonite	Dolomite	Gypsum	Anhydrite
Sarah	27.2.04	-0.19	-0.34	-0.63	-1.28	-1.53
Kheir Ed-Dein	27.2.04	0.05	-0.1	-0.11	-2.66	-2.91
Arab	27.2.04	0.36	0.21	0.45	-1.94	-2.17
Deir Bahha	27.2.04	0.49	0.34	0.83	-2.45	-2.7

All the springs of this group show a shift from field “1” on the Durov Diagram along the mixing-dissolution line, Sara spring plots in field “5” , in the area of simple dissolution or mixing fields, Arab, Kheir Ed-Deen and Deir Bahha plots in field “2”, which suggests mixing with wastewater or ion exchange Appendix (5.1D).

5.2.6 The springs of Halhul group:

The water of Halhul group in Hebron district is oversaturated with respect to all the carbonate mineral phases considered (aragonite, calcite, and dolomite), and the water of all the springs of this group is undersaturated with respect to anhydrite and gypsum (Table 5.8).

Table 5.8: Saturation indices of the water of the springs of Halhul group with respect to some mineral phases.

Spring	Date	Saturation indices				
		Calcite	Aragonite	Dolomite	Gypsum	Anhydrite
Hasaka	27.2.04	0.23	0.08	0.19	-1.8	-2.05
Eth - Tharwa	27.2.04	0.26	0.11	0.28	-1.7	-1.95
Misleh	27.2.04	0.52	0.36	1.03	-2.23	-2.48

The water of Misleh and Hasaka springs plot in field “1”, which suggests that the water type of these springs is of a recharge area. Eth-Tharwa spring plots in field “5” a long the mixing-dissolution line suggesting simple dissolution or mixing water Appendix (5.1E).

5.2.7 The springs of Deir Samit group:

The water of all the springs of Deir Samit group in the Hebron district is oversaturated with respect to all the carbonate mineral phases considered (aragonite, calcite and dolomite), except Al-Biarah spring which is undersaturated with respect to aragonite mineral. The water of all the springs of this group is undersaturated with respect to sulphate mineral phases considered (anhydrite and gypsum) (Table 5.8)

Table (5.8):Saturation indices of the water of the springs of Deir Samit group with respect to some mineral phases.

Spring	Date	Saturation indices				
		Calcite	Aragonite	Dolomite	Gypsum	Anhydrite
El-Semia	26.2.04	0.15	0.00	0.29	-1.58	-2.13
Albiarah	26.2.04	0.08	-0.07	0.13	-1.89	-3.77
Allaton	26.2.04	0.21	0.06	0.47	-1.71	-1.95

The water of the Deir Samit group springs plots in the field “5” on the Durov Diagram a long the mixing-dissolution line Appendix (5.1F). This suggests a mixing or simple dissolution area.

Chapter six

6.1. Conclusion and Recommendations

The study area is divided into three topographical areas; The eastern desert, the mountains in the center and the western hills.

The rainfall on the central highlands averages 680mm/y at Halhul and becomes less than 100mm/y at the Dead Sea.

The majority of the exposed rocks in the study area are the carbonate rocks that range in age from Albian to Recent age. Cenomanian age rocks which mainly composed limestone and dolomite are cover the widest area in the research region, Pliocene age rocks covered a limited area.

The major sediments in the rocks of the study area are: limestone, dolomite, marl limestone, sandstone, conglomerate, chalk, chert and a little of metamorphic rocks of the Miocene age.

Only two main aquifer systems found in the district which are the upper Cenomanian and the lower Cenomanian aquifer systems.

The majority of the district is underlain by the Jerusalem desert ground water sub-basin which is itself underlain by the Auja-Tamaseeh and the Hebron Beer Sheva' sub-basins of the western and eastern flank of the West Bank mountain aquifer.

The springs in the study area are divided as follows:

1. Hebron city group	2. Idna group
3. Dura city group	4. Beit-Kahil group
5. Yatta group	6. Halhul group
7. Deir-Samit group	

The water samples gathered from the springs in the study area were analyzed for the major and minor ions, 12 springs only were analyzed for faecal and total coliform and discharge measurements, some of these springs analyzed for ^{2}H, ^{18}O, and ^{3}H, the area of recharge were limited to measure the runoff, recharge and precipitation.

Most of the samples of the springs show unsaturation with respect to gypsum and anhydrite, and the majority of them are saturated with respect to calcite, aragonite and dolomite.

Piper classification of water samples show five types, 51.16% of the springs plot in the area of earth alkaline water with increased portion of alkalis with prevailing bicarbonate, 23.6% of the springs plot in the area of earth alkaline water with increased portion of alkalis with prevailing sulfate and chloride, 16.3% of the springs plot in the area of normal earth alkaline water with prevailing bicarbonate, 4.65% of the springs plot in the area of normal earth alkaline water with bicarbonate and sulfate (or chloride), 4.65% of the springs plot in the area of alkaline water with prevailing SO_4^{-2} – Cl^-.

Durov diagram appear the simple dissolution, the mixing process and the ion exchange of Na^{+1} with Ca^{+2} and Mg^{+2}. Depending on the results Durov diagram give five different categories of, 48.8% of the springs indicates water exhibiting dissolution-or mixing because no dominant an ion or cation, 34.9% of the springs give a water type which dominated by Ca^{+2} and HCO_3^{-1} ions, association with dolomite and ion exchange is probable if Na^{+1} is significant, 9.4% of the springs give HCO_3^{-1} and Ca^{+2} dominant, frequently indicates recharging waters in limestone, sandstone and other aquifers, 4.7% of the springs indicates that Cl^{-1} is dominant an ion and Na^{+1} is dominant cation, which indicates a reverse ion exchange of Na-Cl waters, 2.4% of the springs indicates that SO_4^{-2} is dominant or disicriminant and Na^{+1} dominant which indicates probable mixing influence.

The water quality evaluation for drinking purposes show that All the samples tested for the biological contamination are free from both faecal and total coliform, 69.8% of the spring water classified as very hard water, 30.2% as hard water, 51.2% of the springs are unsuitable for drinking and for domestic purposes, 39.5% of the samples collected from the springs contain nitrate concentrations higher than the standards permissible limits, 16.3% of the samples collected from the springs contain chloride concentrations higher than the standards permissible limits, 9.3% of the samples collected from the springs contain potassium concentrations higher than the standards permissible limits, This contamination came from the waste water of the discharges, the cesspits and the irrigation.

Depending on the SSP and the water hardness all the springs water is suitable for irrigation with no limitations and range from excellent to good, and the EC-SAR relationship of the springs show that 34.9% of the spring’s water is of low sodium-medium salinity hazard (S1-C2), 58.1% of the spring’s water is of low sodium-high salinity hazard (S1-C3), 2.3% of the spring’s water is of low sodium-high salinity hazard (S1-C4).

The staple isotopic composition (H^2 and O^{18}) of the water lies on the Mediterranean meteoric water line. This suggests the meteoric origin of the water.
H^3 analysis shows that the water of these spring contains between 5-6TU which indicates the relative recent age of the water.

Calculations using the available data of the period 1970-2004 estimated the average annual runoff, recharge and precipitation to be 55.7mm/y (11.4% of the precipitation), 141mm/y (25% of the precipitation), and 487mm/y respectively.

Discharge measurements were possible for 12 springs, 66.7% of these springs show a peak of maximum discharge in February, the others show the peak in March, all the springs show a quick response to the precipitation except Elsa’abia spring which means that it is of big storage.

The water parameters interrelationships between the different analyzed parameters of the samples collected from the springs show a linear correlation between the variables which classify the relationship from very high significant relationship with correlation coefficient >= 0.9 to poor relationship with correlation coefficient < 0.5 showing the High significant relationship, good relationship, medium relationship and the acceptable relationship.

Cluster analysis using the programs SPSS.10.0 and excel under windows classified the samples in this research into five clusters depending on the common characteristics between the variables of the same cluster and here are the general characteristics of these clusters.

Cluster (I):

This cluster includes 23.1% of the study samples with average EC and pH of 502.8 µS/cm and 7.8. It is dominated by calcium cation (47.3% of the total cations) and the bicarbonate anion (61.5% of the total anions).
The main characteristics of this cluster are:

$Ca^{+2} > Mg^{+2} > Na^{+1} > K^{+1}$

$HCO_3^{-1} > Cl^{-1} > NO_3^{-1} > SO_4^{-2}$

$(Na^{+1}/ Cl^{-1}) < 1$

Cluster (II):

This cluster is dominated by calcium cation (47 % of the total cations) and the bicarbonate anion (74 % of the total anions) representing 20.5 % of the research samples with average EC and pH of 705.3 µS/cm and 7.6 respectively. Cl^- is 12% and Mg^{+2} is 17% of the samples of this group.

The general characteristics of this group are:

$Ca^{+2} > Mg^{+2} > Na^{+1} > K^{+1}$

$HCO_3^{-1} > Cl^{-1} > NO_3^{-1} > SO_4^{-2}$

$HCO_3^{-1} > Ca^{+2}$

$(Na^{+1}/ Cl^{-1}) < 1$

Cluster (III):

In this cluster bicarbonate ion is the higher the percentage anion (55.6% of the total anions) and calcium is the higher the percentage cation (61% of the total cations), this cluster represents 15.4% of the study samples with EC and pH values of 876.8 µS/cm and 7.5 respectively.

The general characteristics of this cluster are:

$Ca^{+2} > Mg^{+2} > Na^{+1} > K^{+1}$

$HCO_3^{-1} > Cl^{-1} > NO_3^{-1} > SO_4^{-2}$

$$Ca^{+2} > HCO_3^{-1}$$

Cluster (IV):

Calcium cation of (46% of the total cations) and bicarbonate anion of (53.5% of the total anions) are dominate in this cluster with EC and pH values of 1066.1 µS/cm and 7.4 respectively, this group represents 17.9% of the samples of the study.

The general characteristics of this group are:

$$Ca^{+2} > Na^{+1} > Mg^{+2} > K^{+1}$$
$$HCO_3^{-1} > Cl^{-1} > NO_3^{-1} > SO_4^{-2}$$
$$(Na^{+1} + K^{+1})/ Cl^{-1} > 1$$

Cluster (V):

This cluster is dominated by calcium cation (45% of the total cations), the chloride ion is the major an ion (55% of the total anions) and bicarbonate anion is 34% of the total an ions. The parameters of this cluster represents 23.1% of the study samples with EC and pH values of 1725.6 µS/cm and 7.2 respectively.

The general characteristics of this group are:

$$Ca^{+2} > Na^{+1} > Mg^{+2} > K^{+1}$$
$$Cl^{-1} > HCO_3^{-1} > NO_3^{-1} > SO_4^{-2}$$
$$HCO_3^{-1} = Ca^{+2}$$
$$(Na^{+1} + K^{+1})/ Cl^{-1} > 1$$

The domination of HCO_3^{-1} in 76.9% of the total samples of this study show that the water in the study area infiltrate in a carbonate rocks of limestone, sandstone, and marly limestone. The domination of Cl^{-1} in cluster three came as a result of contamination and the mixing of water with waste water that enters directly from the surrounding houses.

Scatterplot shows an excellent relationship between some of the variables In cluster (I), (Ca^{+2}/HCO_3^{-1}) correlate NO_3^{-1} with correlation coefficient of 0.922, SAR correlate Cl^{-1} with correlation coefficient of 0.831, and SI-dolomite correlate SI-calcite with correlation coefficient of 0.983.

Scatterplot shows an excellent relationship between the variables in cluster (II) EC µS/cm correlate SAR with correlation coefficient of 0.954, Total hardness (mg/L $CaCO_3$) correlate Ca^{+2} mg/L with correlation coefficient of 0.864, and SI-gypsum correlate SO_4^{-2} mg/L with correlation coefficient of 0.978.

Scatterplot shows a very excellent relationship between the variables in cluster (III), Na^{+1} mg/L correlate SAR with correlation coefficient of 0.992, Mg^{+2} mg/L correlate Total hardness(mg/L $CaCO_3$) with correlation coefficient of 0.968.

Scatterplot shows a very excellent relationship between the variables in cluster (IV) SAR correlate Na^{+1} mg/L with correlation coefficient of 0.992, NO_3^{-1} correlate TDS with correlation coefficient of 0.838.

Scatterplot shows a very excellent relationship between the variables in cluster (V). TDS correlate SO_4^{-2} meq/L with correlation coefficient of 0.878, SAR correlate Na^{+1} mg/L with correlation coefficient of 0.962.

Schoeller diagram for the clusters:

Schoeller diagram shows that the concentrations of the ions are very close to each other for the springs of this cluster except NO_3^{-1} for Al-Rifa'ya and Abu Shabban springs which appear to be higher than the others.

Schoeller diagram shows the concentrations of Cl^{-1} is the highest for the majority of the springs in this cluster, and K^{+1} is the lowest concentration.

In this cluster the EC of the springs ranges from 966 µs/cm to 1137 µs/cm, the concentration of the Cl^{-1} is the lowest for the Longor spring.

Schoeller diagram shows the concentration of the ions for seven springs, the concentration of the K^{+1} is the lowest for the majority of the springs in this cluster. The pH of the water of the springs in this cluster ranges from 7.0 to 8.0.

In Schoeller diagram of cluster five, K^{+1} is of the lowest concentration for the majority of the springs in this cluster, the concentrations of the ions are close to each other, the EC for the springs of this cluster ranges from 1330 µs/cm to 2500 µs/cm.

Variation in water quality from season to another.

The water of the springs in this study is of winter precipitation source (recharge water) so this will produce seasonal variation. The samples collected in winter should have a less concentration of a major and minor ions as a result of a dilution by the recharge water from precipitation.

This appear in many of the springs in this study. Al-Hijri spring show a lower winter ion concentration than summer, and also the EC, except for NO_3^{-1} ion which appear to be higher in winter and this is as a result of evaporation (gaseous loss) as ammonia, this is the first type of seasonal variation, the second type is of a higher winter concentrations of K^{+1}, Na^{+1}, Cl^{-1}, SO_4^{-2}, and NO_3^{-1} as well as higher EC. Waste water here play a good role by mixing with water recharging to the aquifer, and this mixing increase in winter as a result of continuous flow of precipitation and a continuous recharging, which is not found in summer.

Some samples show a less concentration of SO_4^{-2}, Na^{+1}, and NO_3^{-1} in summer than in winter and this is as a result of evaporation, K^{+1} also in some samples show low concentration in summer than in winter and this is as a result of sorption by plants, so reasons which may convert the logical ions concentration in water from season to another are.

9. Gaseous loss as NH_4^{+1} for NO_3^{-1}.
10. Loss of some ions by plant sorption like K^{+1}.
11. Mixing with waste water which increase the ion concentration in the upsent of water flow by recharge (no dilution).

12. Precipitation of some mineral phases.
13. Ion exchange.
14. Adsorption and absorption.
15. Substitution.
16. Dissolution of mineral phases.

6.2. General recommendations

Because the majority of the study area is urban, the water of the springs is still under dangerous of the contamination, and to prevent this dangerous the following recommendations may play a good rule.

- It is recommended to keep the barnyards, pastures, sewers, septic tanks and drain fields far away from the surrounding area of the springs because when located above or near them the water of the springs should be contaminate.

- It is recommended to keep the recharge area clean and out of pollution sources, because Surface water runoff can carry pollutants long distances where they can come into contact with spring sources.

- It is recommended to keep the drainage ditch which intercepts and diverts surface water runoff away from and below the spring source.

- It is recommended to built a fence to keep livestock and wildlife away from the water intake system uphill from the spring source.

- Warning signs posted to prevent human tampering must be near the spring.

- The watershed is recommended to be under the control of the operator either by direct ownership or protective covenants.

- The water is recommended to be delivered to a storage tank without coming into contact with the surface of the ground by intercepting The spring flow with a system of perforated pipes installed within the water bearing strata and laid in gravel packed trenches, and this tank must be observed for cleaning.

- A spring water is recommend to be tested for coliform and nitrate from time to time, depending on the source and protection of the springs water.

- Springs water must be out of being contaminated with Sewage and animal wastes contain many pathogens such as protozoa, bacteria and viruses. Specific examples include Cholera, Typhoid, Hepatitis A, Giardiasis and Dysentery.

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6.4 Appendices

Appendix 1.1: The physical and chemical analysis of the sampled springs in the study area during winter and summer of the years 2003-2004.

No.	spring	Date	pH	EC µS/cm	Temp ° C	Ca^{+2}	Mg^{+2}	Na^{+}	K^{+}	HCO_3^{-}	Cl^{-}	$SO4^{-2}$	$NO3^{-}$
1	Elsa’abiya	3.10.03	7.59	570	19.3	60.92	26.24	31.20	0.54	250.18	55.00	17.40	22.00
2	Knar El-Sharqiya	2.10.03	7.94	433	19.7	56.11	23.81	17.20	0.14	250.18	21.00	21.00	7.95
3	Fira'a	3.10.03	7.65	673	19.7	80.96	33.04	32.70	0.69	299.00	64.50	21.70	39.30
4	Al-Hijri	3.10.03	7.1	853	19	97.79	41.31	43.70	3.81	329.51	72.00	41.10	91.20
5	Al-Fredees	2.10.03	7.86	918	18.8	100	58	38.20	3.40	274.59	63.00	75.20	172.00
6	Dilba	3.10.03	7.4	475	21.4	52.90	17.50	26.70	1.84	207.47	37.80	25.50	29.70
7	Knar El-Wista	2.10.03	7.4	653	20.4	100.20	37.90	32.50	0.61	299.00	51.20	36.50	96
8	Khalt-Diab	2.10.03	7.71	929	18	106.61	30.13	48.70	2.18	239.51	93.60	42.50	144.00
9	Set El-Rom	2.10.03	7.77	1539	20.1	171.54	61.23	86.10	4.36	396.63	150.00	70.00	298.00
10	Longor	17.1.04	7.74	966	17.9	92.18	48.60	55.00	59.66	414.94	94.00	32.20	122.70
11	Hfaier	17.1.04	7.61	1015	18.6	116.23	31.59	74.40	4.1	231.88	150.00	84.40	223.80
12	Alaqa Foqa	17.1.04	7.24	1330	10.7	124.93	57.35	97.10	3.40	366.12	226.80	54.20	249.00
13	Kurza	17.1.04	7.39	503	17.1	69.74	11.04	56.00	4.26	268.49	58.60	24.60	18.40
14	Alaqa Tahta	17.1.04	7.07	822	19.2	100.20	27.22	67.90	0.55	378.32	92.90	47.80	73.80
15	Qais	17.1.04	7.32	723	16.8	75.35	29.65	50.00	0.55	311.11	110.00	17.00	42.00
16	Abu Shabban	17.1.04	7.71	556	18.9	56.91	18.47	40.00	1.3	134.24	61.7	15.4	85.3
17	Al Rifa'ya	17.1.04	8.01	543	16.1	60.12	19.44	40.00	1.14	195.26	54.7	20.1	71.5
18	Tuwani	17.1.04	8.02	824	17.7	95.39	18.95	71.2	18.7	152.55	100.0	50.00	202.9
19	Karmil (A)	17.1.04	7.71	901	19	111.42	23.33	55	10.65	201.37	132.7	36	223.3
20	Karmil (B)	17.1.04	7.97	1106	16.1	121.04	25.76	71.1	19.3	207.47	154.9	47.8	292
21	Karmil (C)	17.1.04	7.97	1855	16.1	210.02	39.37	194.1	18.5	158.65	266	89.5	736.8
22	Wad el- beer	26.2.04	6.72	1653	19.2	181.16	39.37	131	12	591.89	285	36	38
23	Naqiah	26.2.04	7.55	1522	19	120.24	54.92	148	3	433.24	310	33	22
24	El-bus	26.2.04	7.02	1490	19	113.03	53.46	147	7	463.75	280	25	30
25	Ma'moudi	3.10.03	7.72	489	18.7	52.10	19.44	28.7	0.68	237.98	48.00	15.90	9.55
26	Bustan	27.2.04	7.37	557	18.5	58.52	28.67	50	1	335.61	47	5	3
27	Sufli	26.2.04	7.01	1137	19.2	77.76	50.06	122	5	567.49	185	12	5
28	Mussallam	26.2.04	7.08	997	18.7	93.79	37.91	89	1	427.14	195	18	3
29	El-Balad	27.2.04	8	943	18	70.54	29.16	33	1	370	44	26	10
30	Wad El-Quf (A)	27.2.04	7.93	651	17.6	62.52	31.10	33	3	250.2	65	25	23
31	Wad El-Quf (B)	27.2.04	7.01	724	18.5	76.15	29.16	39	2	262.4	100	21.3	25
32	Wad El-Quf (C)	27.2.04	7.61	506	19.8	53.71	16.04	32	0.5	274.6	42	25	6
33	Wad el - Raed	27.2.04	8.67	450	19	33.67	22.36	32	3	225.8	75	15.5	7
34	Sarah	27.2.04	6.72	1242	16.5	137.87	44.23	87	4	469.9	175	163	37
35	Kheir Ed-Dein	27.2.04	6.94	1218	16.3	131.46	47.63	86	3	469.9	110	6.5	126
36	Arab	27.2.04	7.22	1117	21	125.05	33.53	78	8	445.5	102	35	30
37	Deir Bahha	27.2.04	7.78	678	16.5	70.54	29.16	33	0.5	299	67	14.5	11
38	Hasaka	27.2.04	7.24	943	16.3	105.81	33.53	35	1	414.9	30	50.6	25
39	Eth-Tharwa	27.2.04	7.19	1125	15.6	130.66	44.71	71	1	451.6	136	59.5	26
40	Misleh	27.2.04	7.69	597	15.7	81.76	49.09	18	0.5	366.1	36	23.5	6
41	El-Semia	26.2.04	6.91	1999	19	170.74	89.91	130	39	530.9	497	85	52
42	Albiarah	26.2.04	6.9	1642	19.8	137.07	67.55	127	6	518.7	410	45	29
43	Allaton	26.2.04	7	2500	15.8	140.28	94.77	224	0.5	683.4	490	75	22

Appendix 1.1:(continue)

No	Sample ID	Date	Y	X	pH	EC	Temp	Na^{+1}	K^{+1}	Mg^{+2}	Ca^{+2}	NH_4^{+1}	Cl^{-1}	SO_4^{-2}	NO_3^{-1}	HCO_3^{-1}
			N……….E			µS/cm	°C	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)
1	Abu Shabban	02/07/2004	93700	165500	7.46	454	21.5	33	0.3	17	44.1	0	61.7	15	86	73.2
2	Alaqa Foqa	20/07/2004	96400	150700	7.16	1533	22.1	106.1	2.1	53.5	136	0.4	195	76	147	347.8
3	Alaqa Tahta	20/07/2004	95800	150200	7.27	941	21.1	80.7	0.8	34	64.1	0	131.2	46	25	274.6
4	Al-Biarah	03/07/2004	103200	146400	7.04	1827	22.1	120.2	6.1	89.9	152	0	358	80	75.2	427.1
5	Alfredees	20/07/2004	99800	152000	7.96	731	19.9	67.5	4	29.2	48.1	0.1	81.5	42	68	189.2
6	Al-Hijri	02/07/2004	100000	156000	7.16	1005	19	56.3	5	34	112	0	92.2	57	85.1	317.3
7	Allaton	03/07/2004	101400	145400	7.36	2290	22.3	293.7	0.9	89.9	112	0.2	446.7	90	6.7	512.6
8	Al-Rifa'ya	02/07/2004	95200	164600	7.82	577	18.5	27.2	1	19.4	64.1	0	56.7	34	49.5	170.9
9	Arab	21/05/2004	104380	159100	6.73	1076	20.7	79.8	4.1	38.4	128.3	0	80.1	70	70.7	433.2
10	Deir Bahha	03/07/2004	105600	157300	7.97	711	17.5	30.4	0.4	43.7	56.1	0.1	58.8	24	63.4	219.7
11	Dilba	01/07/2004	99140	154860	7.69	495	19	27.7	2.1	24.3	56.1	0	42.5	26	21.1	280.7
12	El-Balad	03/07/2004	108800	158400	7.52	990	18.7	33.9	0.8	46.2	72.1	0.1	50.3	36	32.5	323.4
13	El-Bus	03/07/2004	106900	146100	7.67	698	21.5	155.8	25.5	68	112	0	283.6	70	55.2	427.1
14	Elsa'abiya	20/07/2004	104200	153300	7.66	621	19.1	33.5	0.7	24.3	48.1	0.2	39	20	20.9	250.2
15	El-Semia	03/07/2004	103600	146800	6.96	2240	20.9	147.6	40.3	97.2	176	0.2	354.5	125	147.5	457.7
16	Eth-Tharwa	03/07/2004	110500	159600	7.64	1287	18.1	71.2	1.1	58.3	144	0.1	127.6	90	75	414.9
17	Fira'a	20/07/2004	105900	151500	7.61	743	19.6	36	1	34	72.1	0	63.8	26	26	292.9
18	Hasaka	20/05/2004	108200	158500	6.77	747	16.8	46	2.5	35.5	101	0.1	53.9	46	46.9	378.3
19	Hfaier	20/07/2004	97000	153000	7.91	1396	21.4	63.7	4.7	58.3	128	0.4	148.9	72	187	244.1
20	Karmil(A)	02/07/2004	92600	163000	7.67	1256	19.5	54	4.2	29.2	160	0	166.6	32	229	183.1
21	Karmil(B)	02/07/2004	92600	163000	7.78	1431	19.5	66.1	7.2	38.9	168	0.1	163.1	38	276.5	183.1
22	Karmil(C)	02/07/2004	92600	163000	7.89	1931	19	105.9	7.3	43.7	212	0.1	241.1	116	282.5	213.6
23	Knar Sharqiya	20/07/2004	101500	154900	8.12	482	20.1	15	0.1	34	48.1	0	24.8	24	20.4	256.3
24	Knar Wista	20/07/2004	101600	155200	7.98	865	20.2	42.1	0.1	29.2	96.2	0	63.8	43	71.4	335.6
25	Kurza	20/07/2004	94300	149900	7.4	536	21.2	24.2	0.3	14.6	80.2	0.2	14.2	24	23.2	268.5
26	Longor	20/07/2004	101900	156900	7.84	1210	23.1	67.6	4.3	53.5	120	0.1	92.2	46	111.6	421
27	Ma'moudi	20/07/2004	104500	153900	7.82	534	19	16.3	0.8	19.4	56.1	0.2	28.4	20	19.4	225.8
28	Misleh	21/05/2004	111400	161200	7.32	532	15.9	20.8	0.2	26.2	77	0	35.5	36	28.4	286.8
29	Mussallam	02/07/2004	108800	151100	7.2	1108	21	86.3	1.2	31.6	108	0.1	166.6	33	18.8	372.2

Appendix 1.1:(continue)

No	Sample ID	Date	Y	X	pH	EC	Temp	Na^{+1}	K^{+1}	Mg^{+2}	Ca^{+2}	NH_4^{+1}	Cl^{-1}	SO_4^{-2}	NO_3^{-1}	HCO_3^{-1}
			N……..…E			µS/cm	°C	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)
30	Naqiah	02/07/2004	107100	147000	7.98	1657	19.7	170.9	2.8	58.3	128	0.1	304.9	50	34	439.3
31	Qais	20/07/2004	96800	152600	7.32	741	19.8	43.9	0.6	38.9	72.1	0	81.5	29	18.2	292.9
32	Set-E-Rom	20/07/2004	102500	152500	7.81	874	21.3	46.6	5.1	24.3	120	0.1	74.5	43	72	305.1
33	Sufli	02/07/2004	101400	145400	7.28	1231	21.4	115.6	5.6	46.2	88.2	0	156	40	21.8	445.4
34	Tuwani	02/07/2004	91300	165000	7.92	853	19	51.1	6.3	29.2	80.2	0.1	99.3	42	202	122
35	Wad El-Beer	02/07/2004	107500	146800	6.1	1473	19.5	98.4	14.3	41.3	152	0.1	180.1	45	86.9	457.7
36	Wad El-Raed	03/07/2004	108600	157900	8.36	509	19.8	27.5	1.9	26.7	44.1	0.1	48.2	21	25.2	183.1
37	Wad Quf (A)	21/05/2004	108800	157300	7.32	609	17.9	35.6	0.2	35.5	55.3	0	60.9	24	65.9	213.6
38	Wad Quf (B)	20/05/2004	108700	157300	6.83	712	18.9	32	2.2	29.6	79.4	0.1	73	28	78.1	219.7
39	Wad Quf (B)	20/05/2004	109000	157400	6.86	503	20.1	42	0.6	24.8	48.1	0	41.8	22	31.6	274.6

Appendix 1.2: The mean monthly discharge measurements (L/s) for 11 springs from the study area through the years 2003/2004.

No	spring	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1	Ma'moudi	0.600	0.540	0.690	0.700	0.720	0.630	0.610	0.604	0.57	0.54	0.51	0.48
2	Elsa'abiya	1.060	1.150	1.200	1.250	1.290	1.263	1.281	1.215	1.12	1.076	1.02	0.95
3	Knar El-Sharqiya	0.150	0.157	0.162	0.170	0.193	0.182	0.132	0.120	0.09	0.07	0.06	0.053
4	Fira'a	0.950	0.980	1.010	1.040	1.060	1.003	0.952	0.923	0.82	0.69	0.61	0.52
5	Dilba	0.800	0.920	0.900	1.050	1.055	1.009	0.878	0.822	0.81	0.8	0.78	0.76
6	Hasaka	0.640	0.730	0.800	0.920	0.950	0.901	0.773	0.760	0.63	0.55	0.51	0.47
7	Knar El-Wista	0.150	0.180	0.190	0.210	0.230	0.216	0.207	0.202	0.18	0.16	0.13	0.09
8	Longor	2.180	2.185	2.190	2.200	2.220	2.245	2.000	1.935	1.89	1.86	1.81	1.78
9	Eth - Tharwa	0.270	0.300	0.320	0.390	0.400	0.378	0.265	0.250	0.24	0.236	0.228	0.21
10	Misleh	0.030	0.034	0.038	0.040	0.042	0.050	0.046	0.044	0.03	0.021	0.016	0.013
11	Deir Bahha	0.098	0.121	0.121	0.125	0.130	0.132	0.130	0.129	0.117	0.107	0.103	0.095

Appendix 3.1: General stratigraphy of the West Bank (Qannam, 2003).

Geological time scale				Group		Formation		Lithology	Thickness (M)	Hydrostatigraphy
Era	System		Epoch	Palestinian	Israeli	Palestinian	Israeli			
CENOZOIC	QUATENARY		Holocene	Recent	Kurkar	Alluvium	Alluvium	Marl, Alluvium, Gravel	Variable	Aquifer
						gravel	River gravel	Thinly laminated marl with gypsum bands	200+	
			Pleistocene	Lisan	Dead Sea	Lisan	Lisan	Conglomerate	0-200	Aquifer
	TERTIARY	NEOGENE	Pliocene- Miocene	Beida	Saqia	Beida	Bit Nir & Ziglag	Reef limestone, bedded limestone, chalk with limestone undifferentiated	100-500	Aquifer in limestone and Aquiclude in chalk
		PALEOGENE	Eocene	Belqa	Avidat	Reef nummulitic limestone	Zora'	Mar, chalk & clay		Aquiclude
			Paleocene		Mount Scopus	nummulitic limestone	Taqiya	Yellowish chalk		Aquiclude
MESOZOIC		SENONIAN	Mastrichtian			Khan Al-Ahmar and Zerqa	Ghareb	Chalk with back chert		Aquiclude
			Campanian			Amman & Abu-Dies	Mishash	Chalk		Aquiclude
			Santonian				Menuha	Limestone and dolomite (Karstic)	90-120	Aquifer
	CRETACEOUS		Turonian	Ajlun	Judea	Jerusalem	Bina	Hard gray porous dolomite	90-100	Aquifer
			CENOMANIAN			Bethlehem	Weradim	Chalky limestone, chalk & marl	30-40	Aquitard
							Kfar Shaul	Karstic limestone & dolomite	110-140	Aquifer
						Hebron	Aminadav	Marl, clay, and marly limestone	10-20	Aquiclude
						Yatta	Moza	Limestone, chalky limestone and dolomite	120-140	Aquifer
							Beit Meir	Limestone inter-bedded with marl		Aquiclude
			ALBIAN			Upper Beit Kahil	Kesalon	Limestone inter-bedded with marl	30-50	Aquifer
							Soreq	Dolomite inter-bedded with marl	110-170	Aquifer
						Lower Beit Kahil	Giva't Yearim	Limestone, dolomite	20-70	Aquifer
							Kefira	Limestone, dolomite, & marly limestone	120-180	Aquifer

Appendix (4.1): Piper diagram for the groups of the study area.

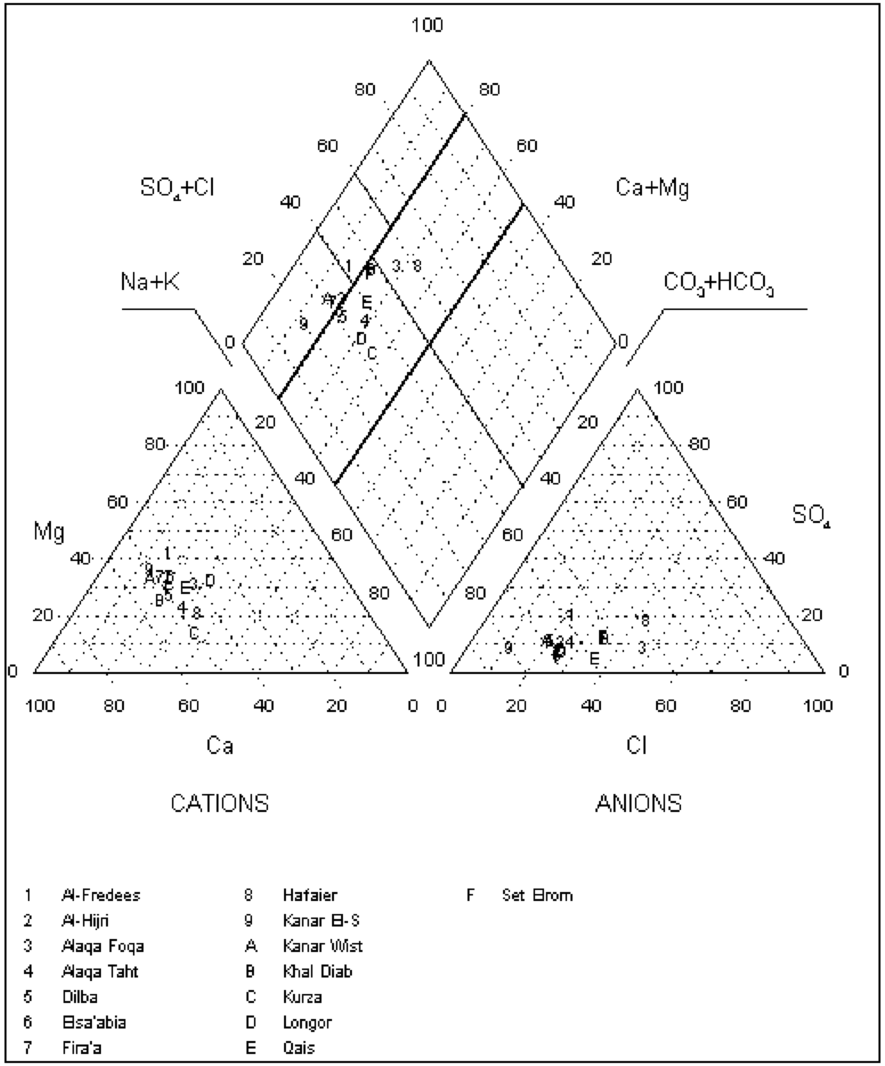


Fig. A: Piper plot showing the springs of the Dura group.

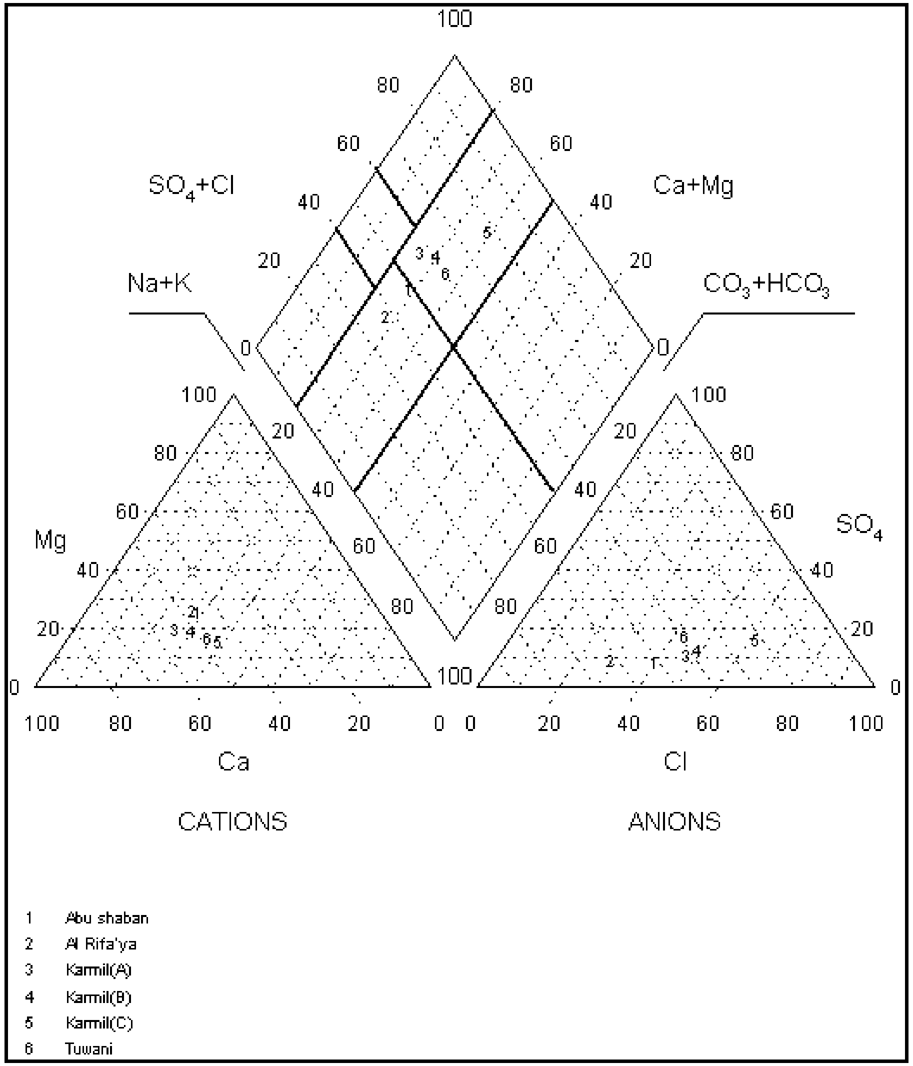


Fig. B: Piper plot showing the springs of the Yatta group.

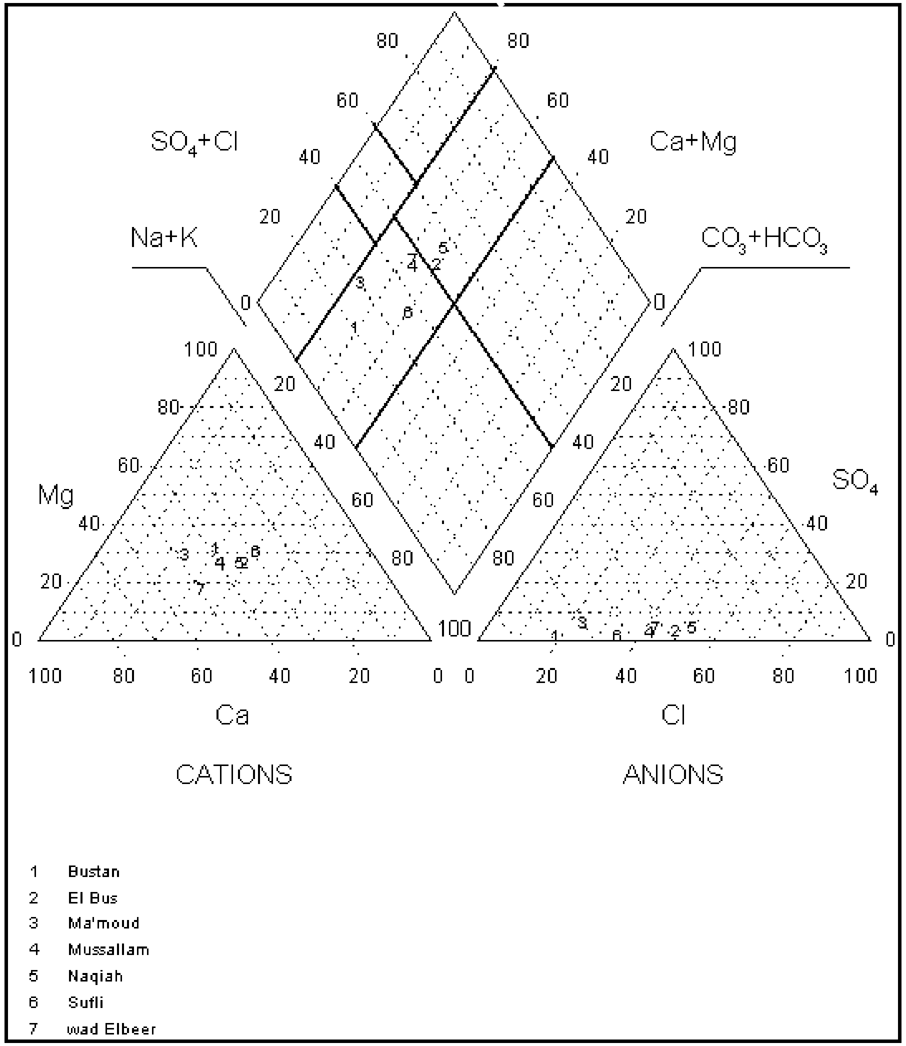


Fig. C: Piper plot showing the springs of the Idna group.

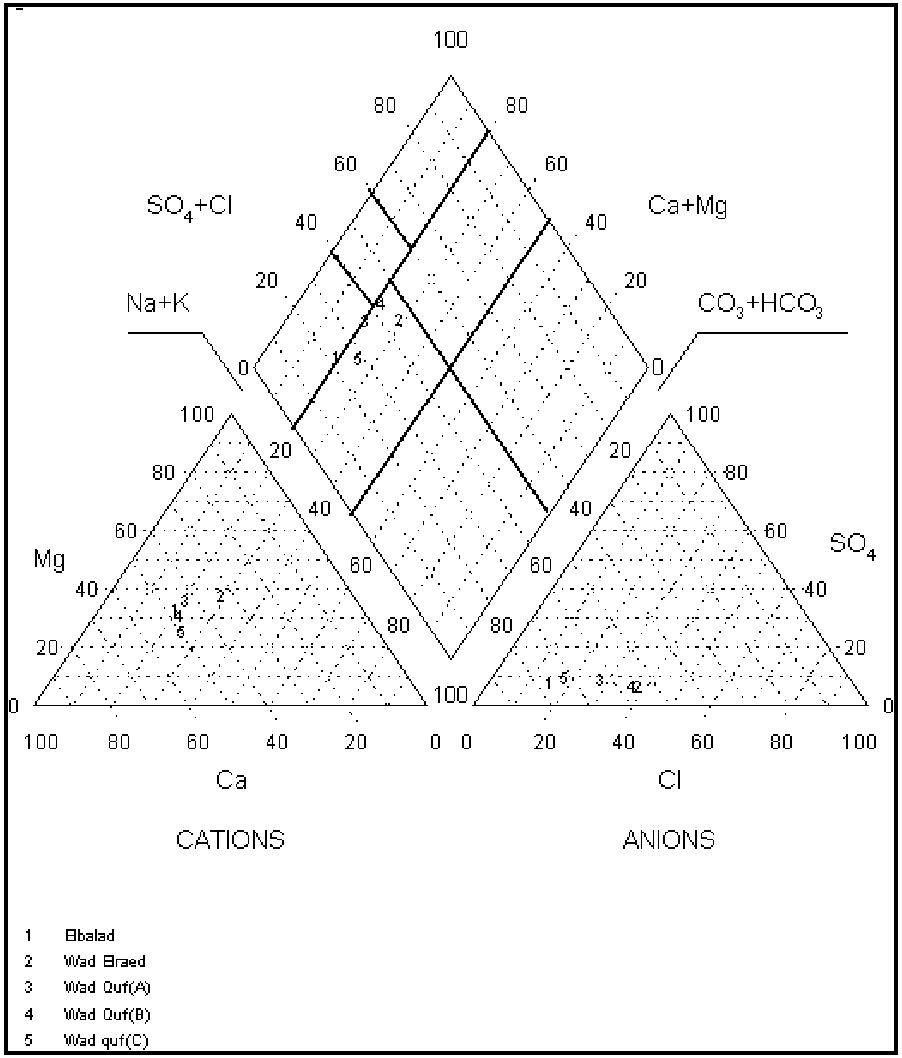


Fig. D: Piper plot showing the springs of the Beit-Kahil group.

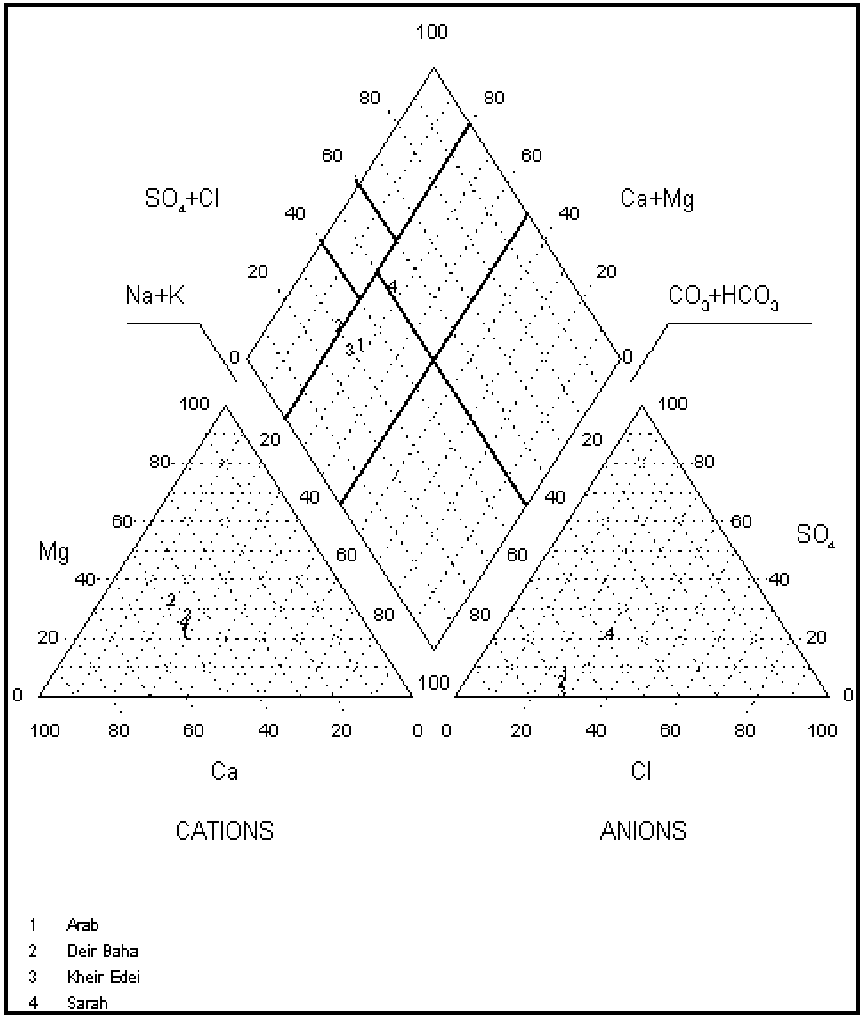


Fig. E: Piper plot showing the springs of the Hebron City group.

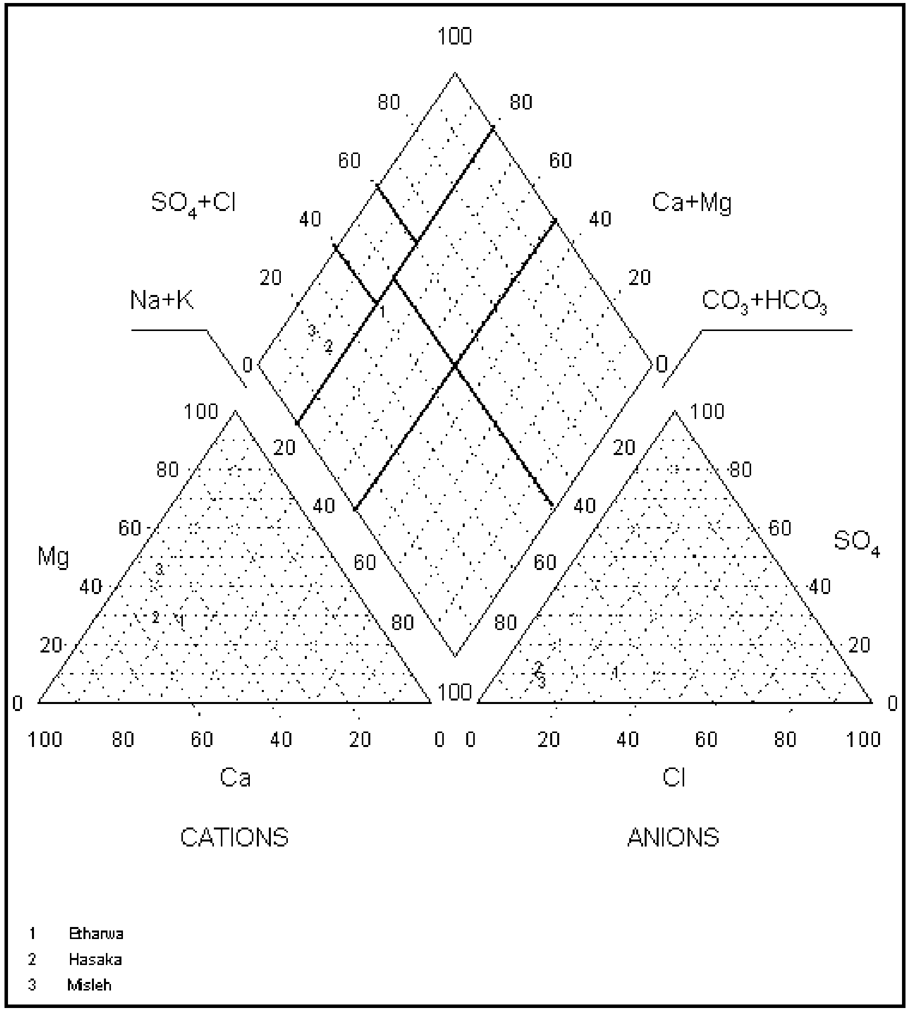


Fig. F: Piper plot showing the springs of the Halhul group.

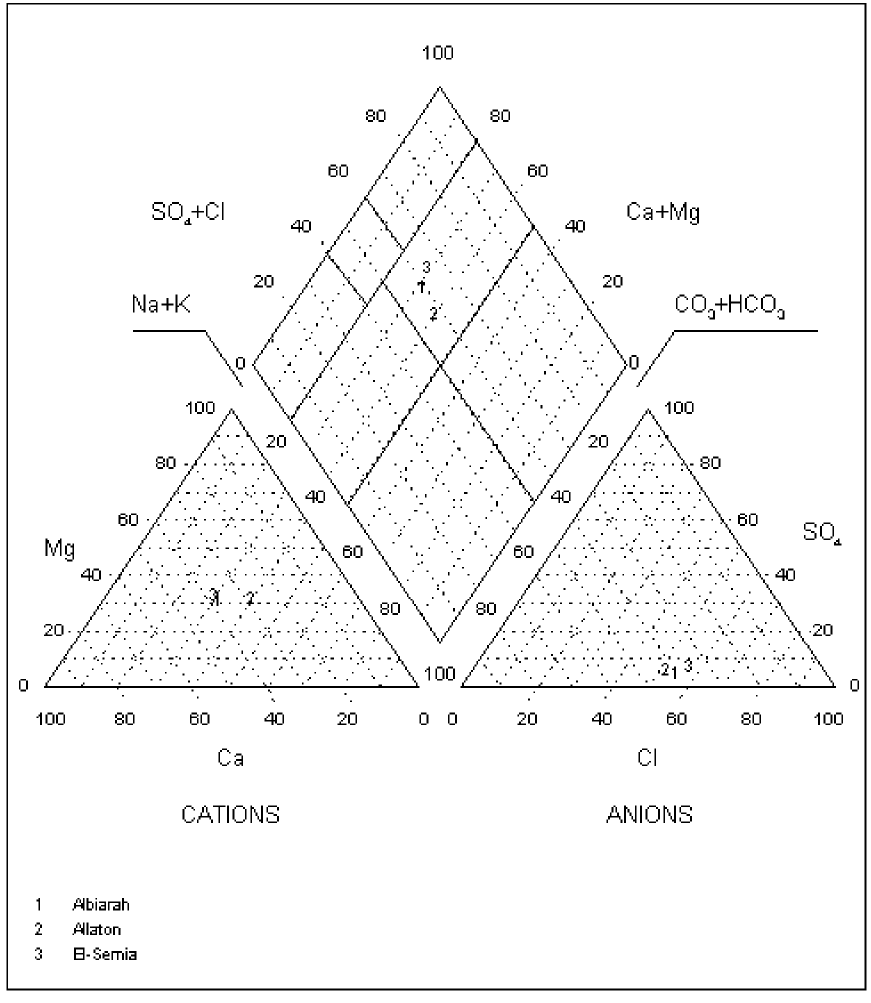


Fig. G: Piper plot showing the springs of the Dei-Samit group.

Appendix (4.2): EC-SAR classification of the springs in the study area.

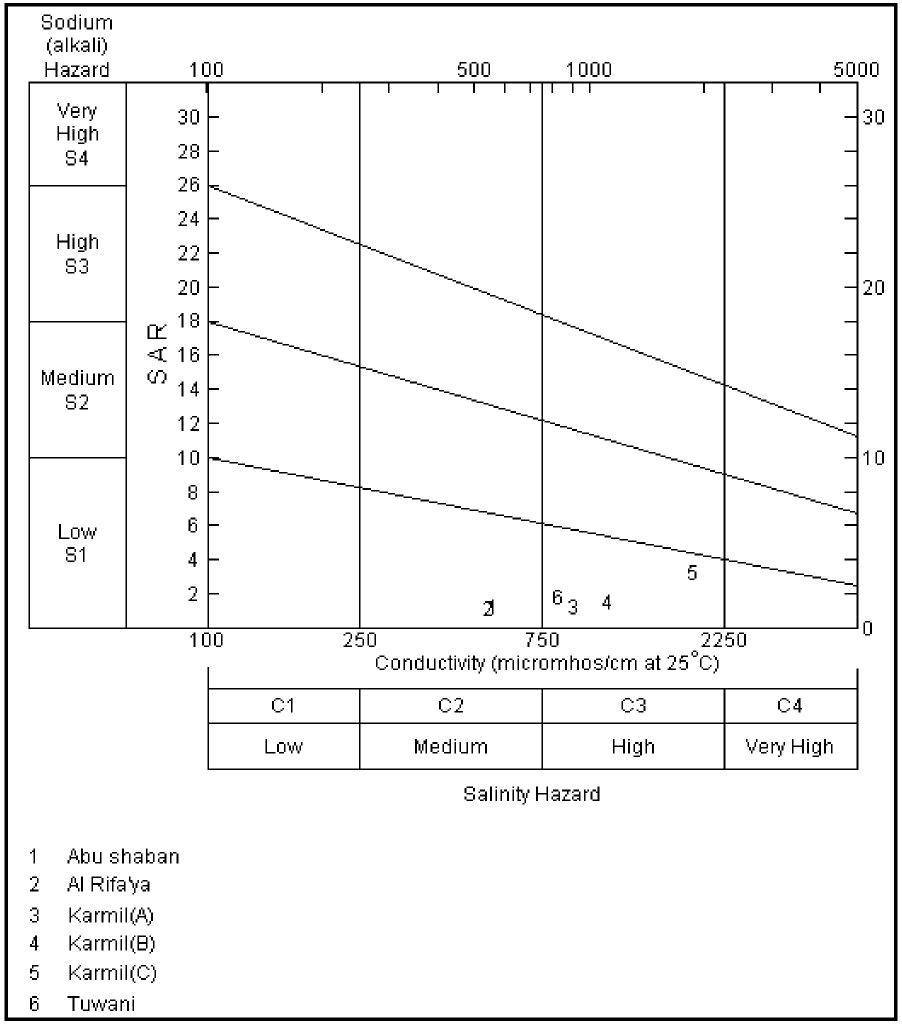


Fig. A: EC-SAR classification of the springs of the Yatta group.

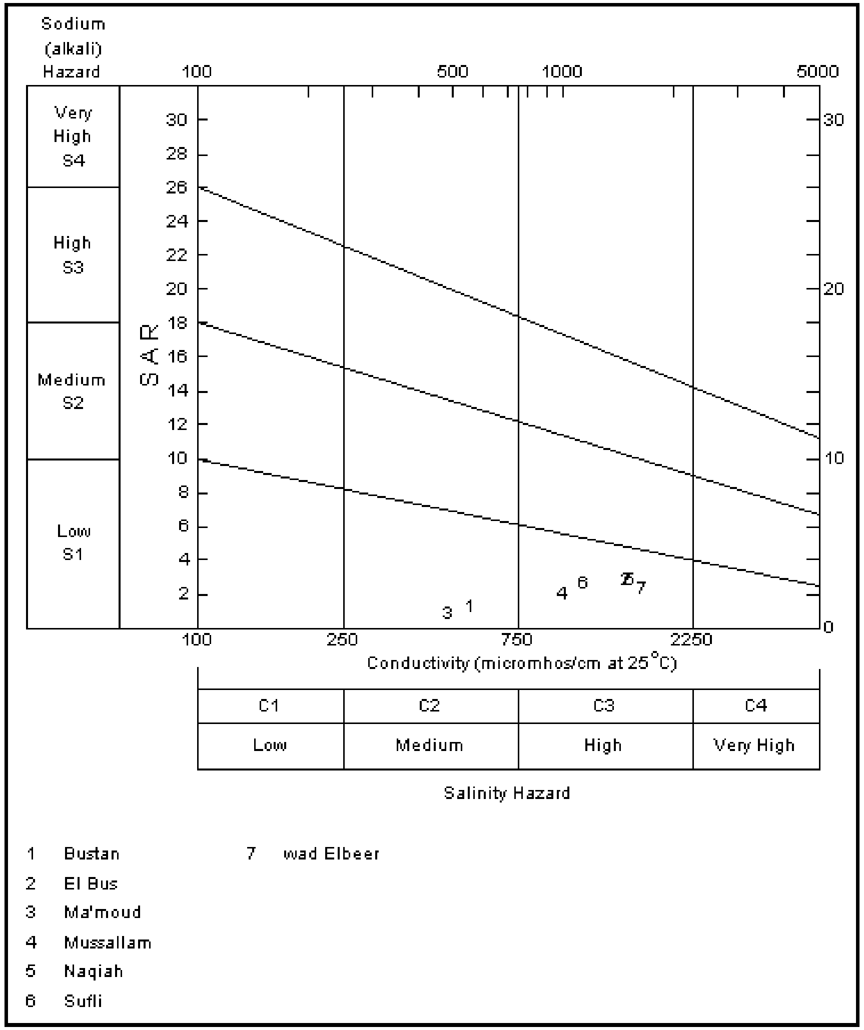


Fig. B: EC-SAR classification of the springs in the Idna group.

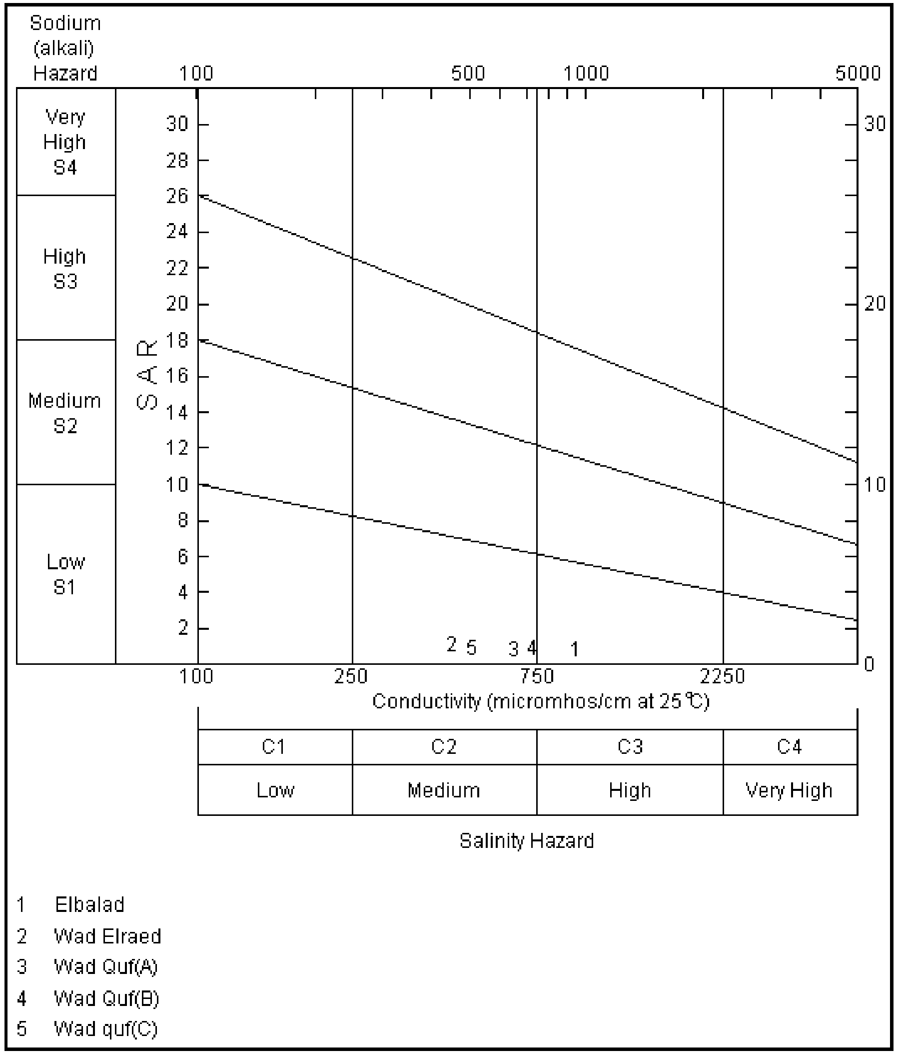


Fig. C: EC-SAR classification of the springs in the Beit Kahil group.

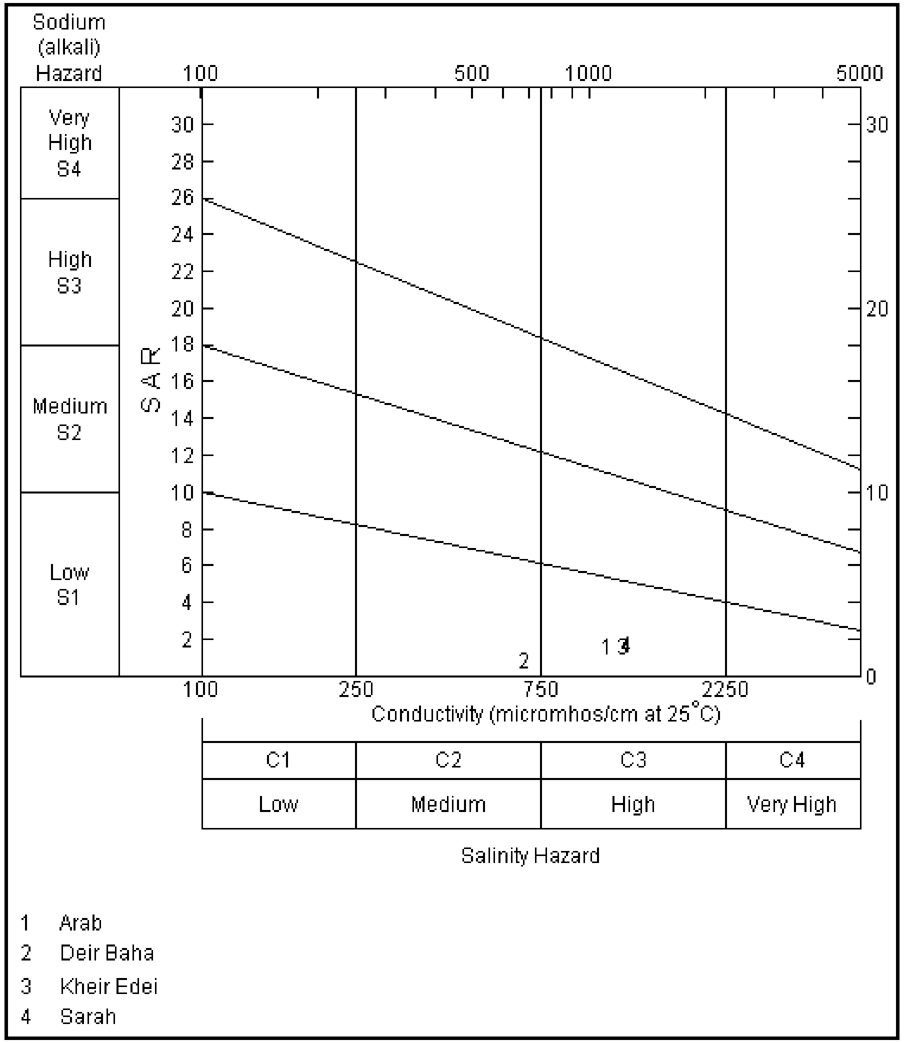


Fig. D: EC-SAR classification of the springs in the Hebron city group.

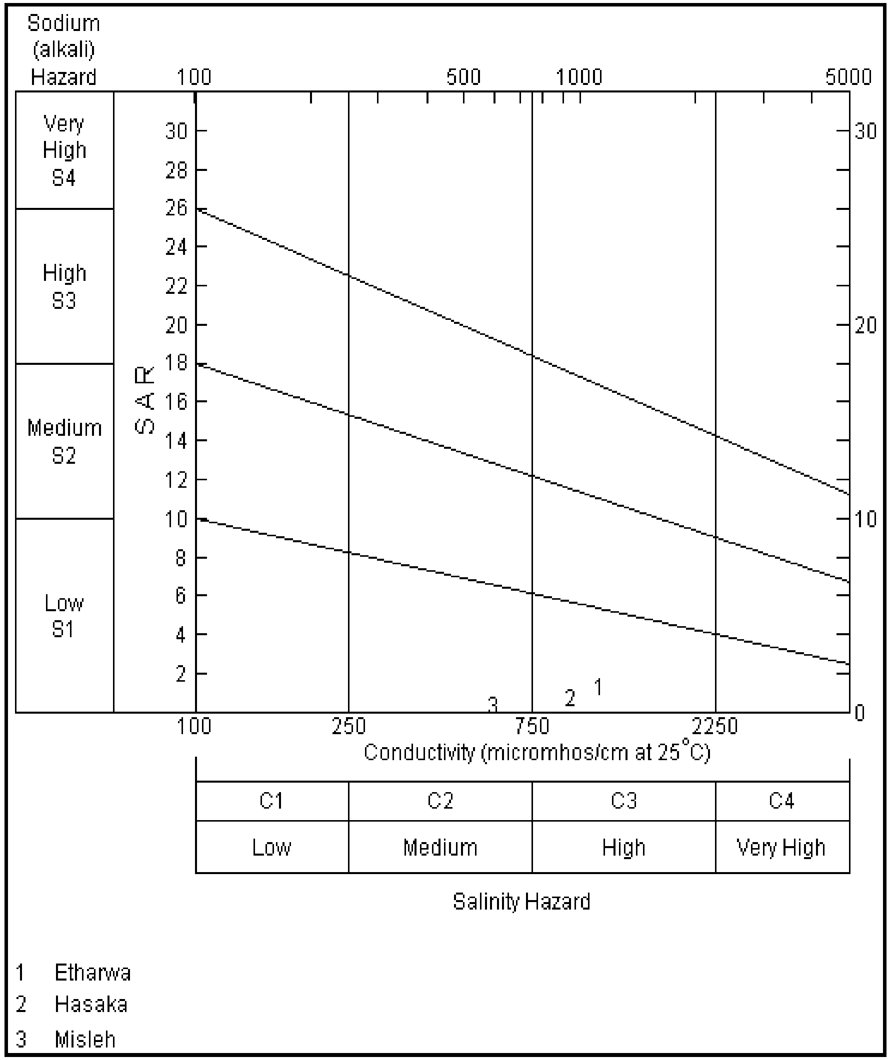


Fig. E: EC-SAR classification of the springs in the Halhul group.

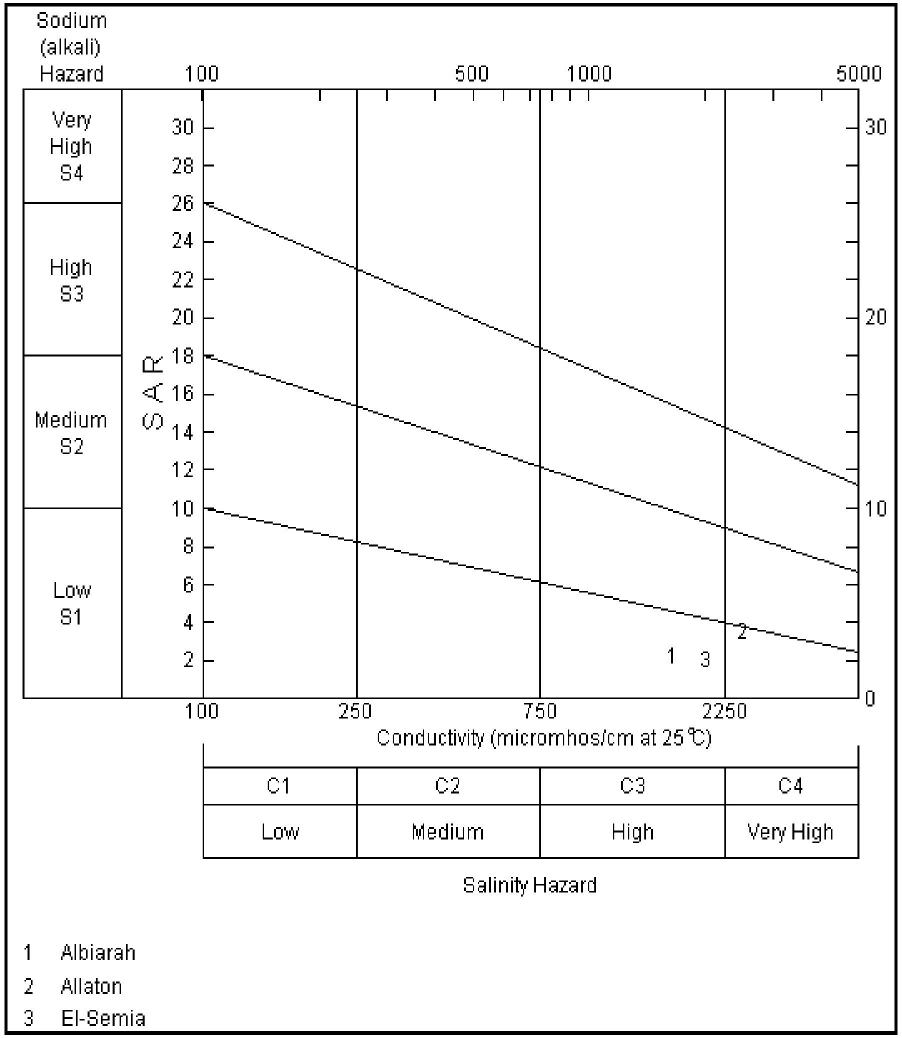
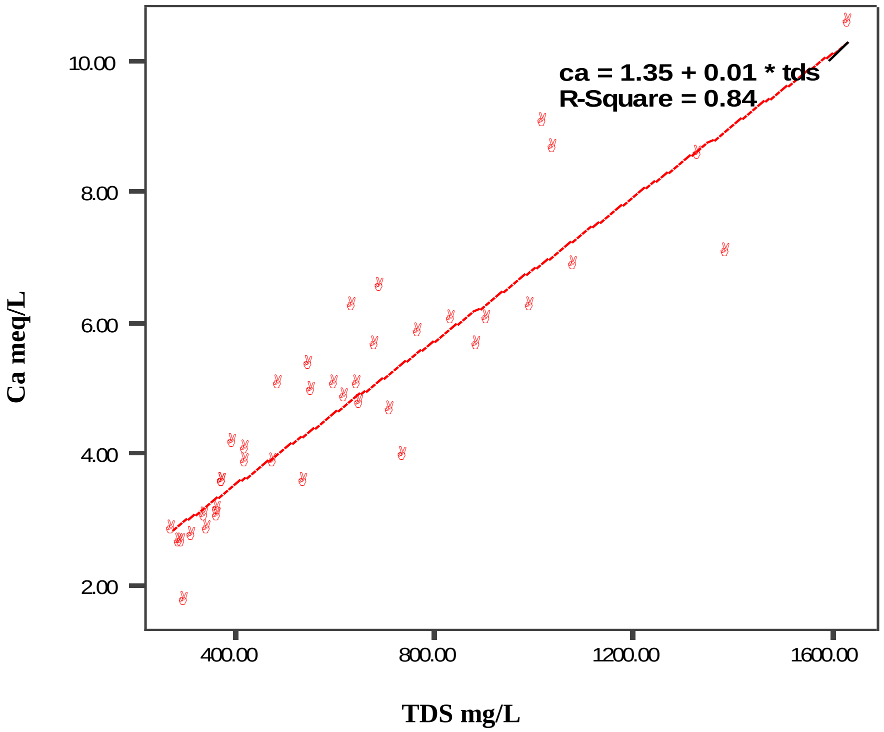


Fig. F: EC-SAR classification of the springs in the Deir Samit group.

Appendix 4.3: The strength of the relation between the different studied variables based on Spearman correlation coefficients.

Variable	EC	T ºC	pH	Ca	Mg	Na	K	Cl	SO_4	NO_3	HCO_3	TDS	SAR	Total hardness	SI-calcite	SI-aragonite	SI-dolomite	SI-gypsum	SI-anhydrite	Na/Cl	Ca/HCO_3	Ca/Mg	Ca/SO_4	TDS/EC
EC	1.000																							
T ºC	-.177	1.000																						
pH	-.454	-.053	1.000																					
Ca	.855	-.146	-.382	1.000																				
Mg	.829	-.155	-.446	.617	1.000																			
Na	.924	-.159	-.430	.750	.673	1.000																		
K	.317	-.017	.012	.363	.273	.244	1.000																	
Cl	.914	-.116	-.501	.697	.796	.895	.312	1.000																
SO_4	.660	-.205	-.116	.767	.567	.514	.303	.497	1.000															
NO_3	.324	-.269	.281	.583	.048	.343	.320	.146	.615	1.000														
HCO_3	.687	-.010	-.698	.457	.753	.594	.111	.655	.187	-.347	1.000													
TDS	.955	-.229	-.344	.915	.740	.903	.411	.858	.746	.562	.513	1.000												
SAR	.528	-.096	.059	.271	.276	.633	.080	.532	.137	.145	.306	.498	1.000											
Total hardness	.928	-.162	-.444	.917	.876	.784	.353	.811	.764	.388	.642	.924	.293	1.000										
SI-calcite	.001	-.067	.813	.082	-.013	-.087	.220	-.163	.206	.379	-.253	.079	.201	.053	1.000									
SI-aragonite	-.002	-.063	.816	.079	-.017	-.090	.219	-.165	.205	.379	-.257	.076	.201	.050	1.000	1.000								
SI-dolomite	.020	-.019	.767	.011	.121	-.085	.196	-.113	.154	.239	-.138	.058	.216	.078	.965	.965	1.000							
SI-gypsum	.666	-.210	-.238	.853	.499	.506	.321	.475	.930	.604	.230	.747	.062	.778	.138	.136	.041	1.000						
SI-anhydrite	.354	-.263	-.010	.560	.175	.264	.195	.082	.695	.552	.004	.426	-.024	.440	.221	.221	.105	.731	1.000					
Na/Cl	-.357	.052	.151	-.240	-.463	-.288	-.183	-.540	-.095	.007	-.231	-.327	-.141	-.375	.045	.044	-.054	-.061	.167	1.000				
Ca/HCO_3	.289	-.188	.251	.561	-.056	.347	.273	.153	.552	.938	-.408	.513	.147	.320	.290	.291	.125	.566	.501	.044	1.000			
Ca/Mg	-.059	-.035	.070	.253	-.505	.051	.105	-.128	.156	.464	-.383	.085	-.019	-.100	-.001	.000	-.254	.319	.367	.373	.591	1.000		
Ca/SO_4	-.033	.128	-.316	-.110	-.064	.104	-.127	.053	-.619	-.318	.292	-.103	.067	-.111	-.311	-.311	-.259	-.541	-.432	-.177	-.265	-.132	1.000	
TDS/EC	.076	-.217	.220	.356	-.069	.153	.396	.043	.449	.761	-.348	.341	.040	.192	.234	.233	.100	.457	.372	.007	.685	.507	-.311	1.000

Appendix (4.4): Figures for the relationships between the variables of the classes.



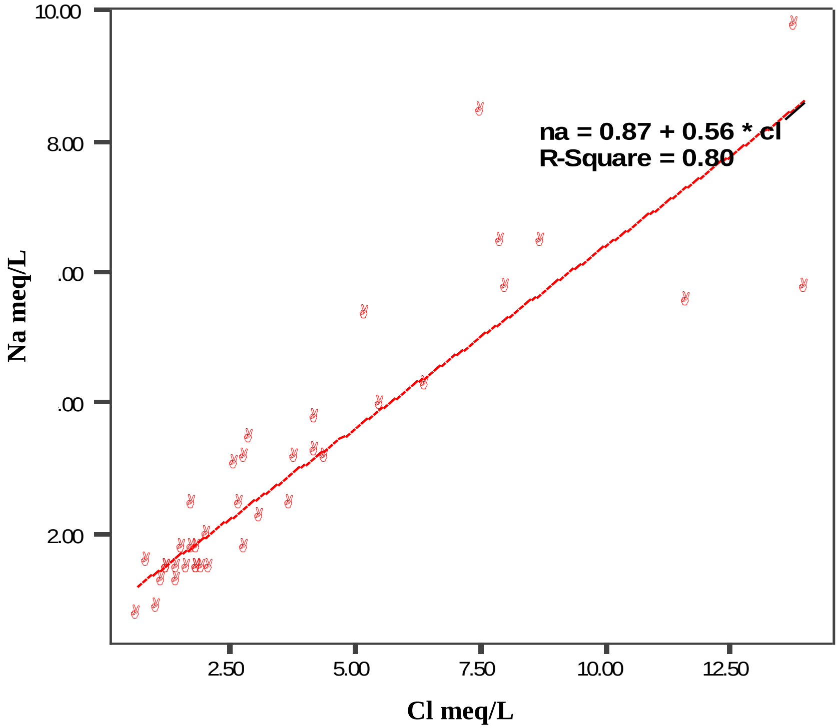


Fig. A: Relationship between TDS and Ca in class (I).
of very high significant relationship.

Fig. B: Relationship between Cl and Na in class (II)
of high significant relationship.

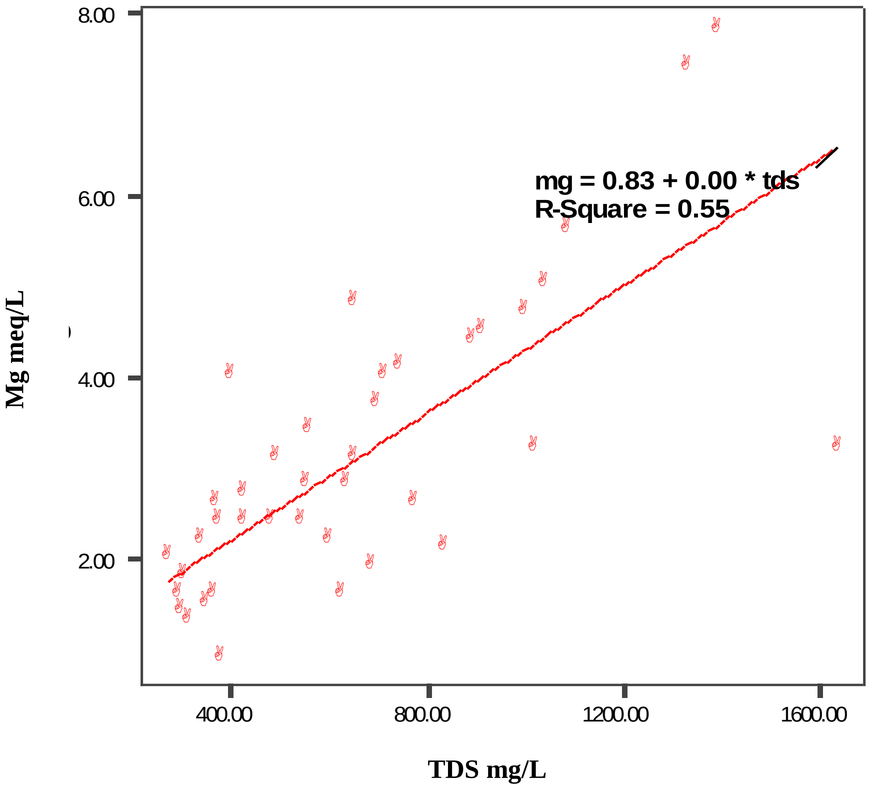


Fig. C: Relationship between TDS and Mg in class (III).
of good relationship.

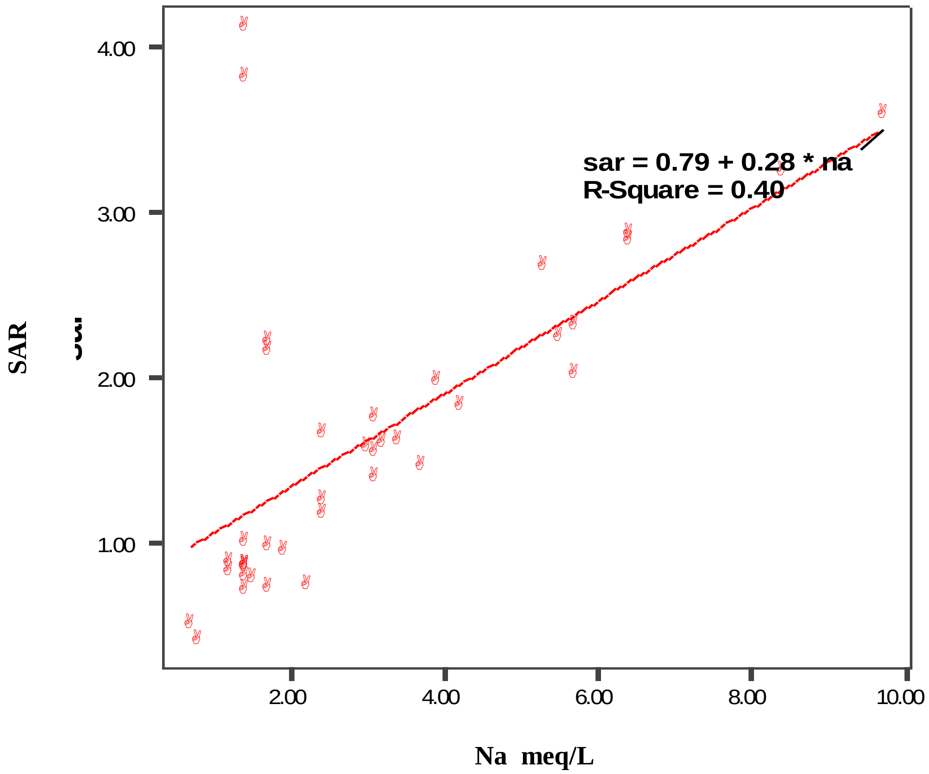


Fig. D: Relationship between Na and SAR in class (IV).
of medium relationship.

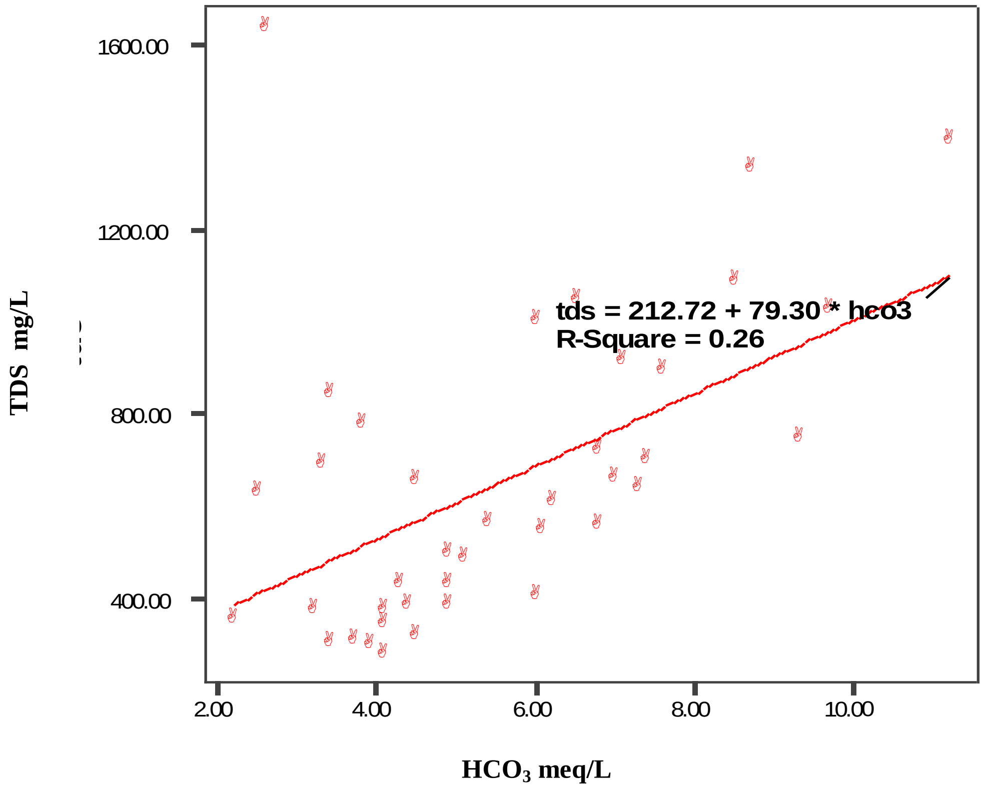


Fig. E: Relationship between TDS and HCO_3^{-1} in class (V) of acceptable relationship.

Appendix (4.5): Figures represents the percentage of the anions and cations for the clusters.

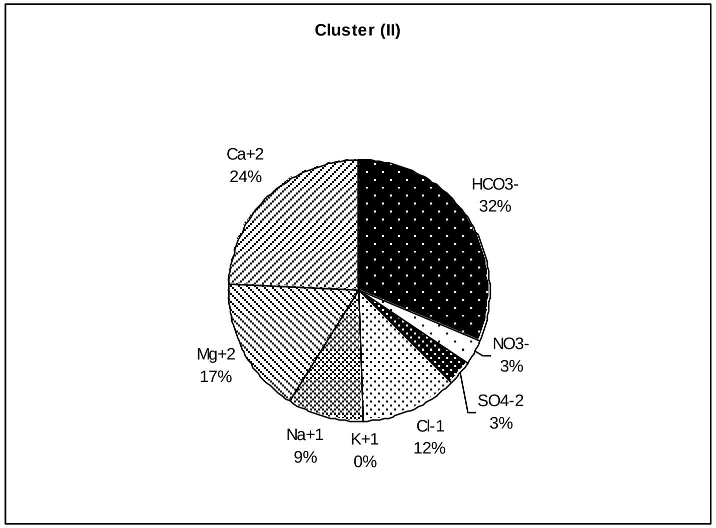


Fig. A: The presentation percentage graph of the cluster (II).

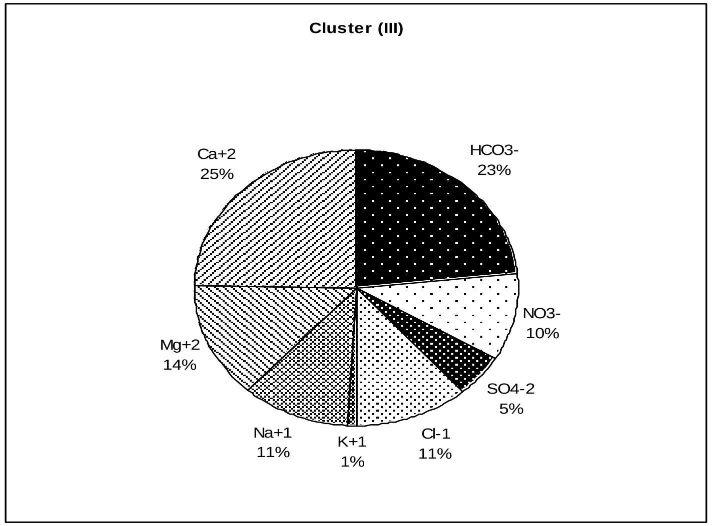


Fig. B: The presentation percentage graph of the cluster (III).

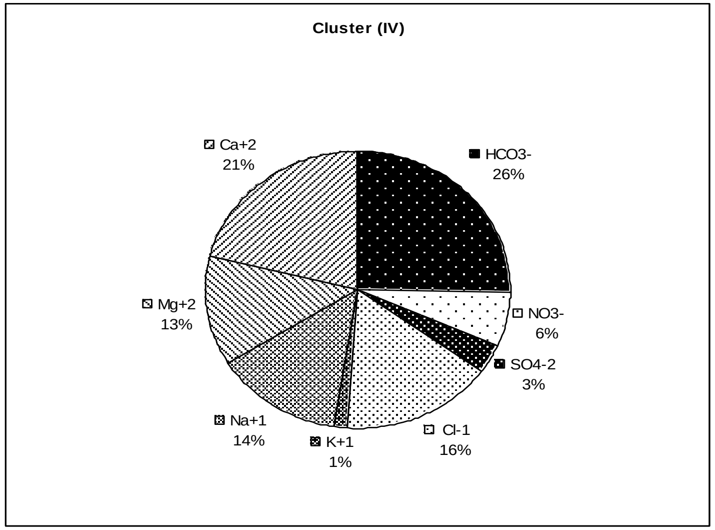


Fig. C: The presentation percentage graph of the cluster (IV).

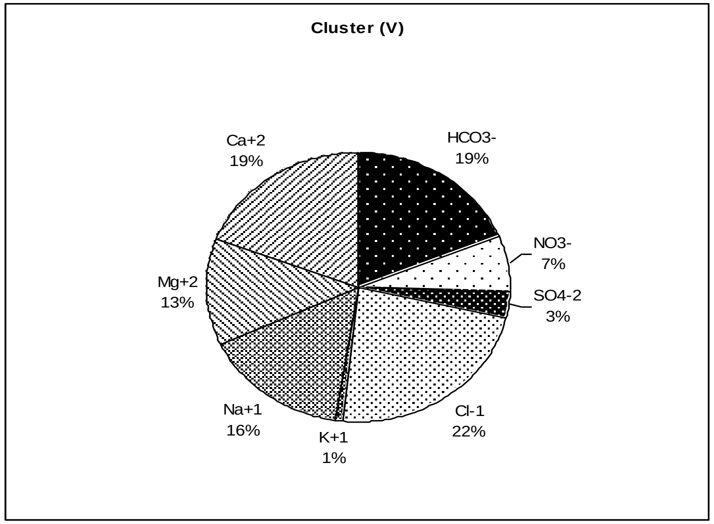


Fig. D: The presentation percentage graph of the cluster (V).

Appendix (4.6): Schoeller diagrams for the clusters (II – V).

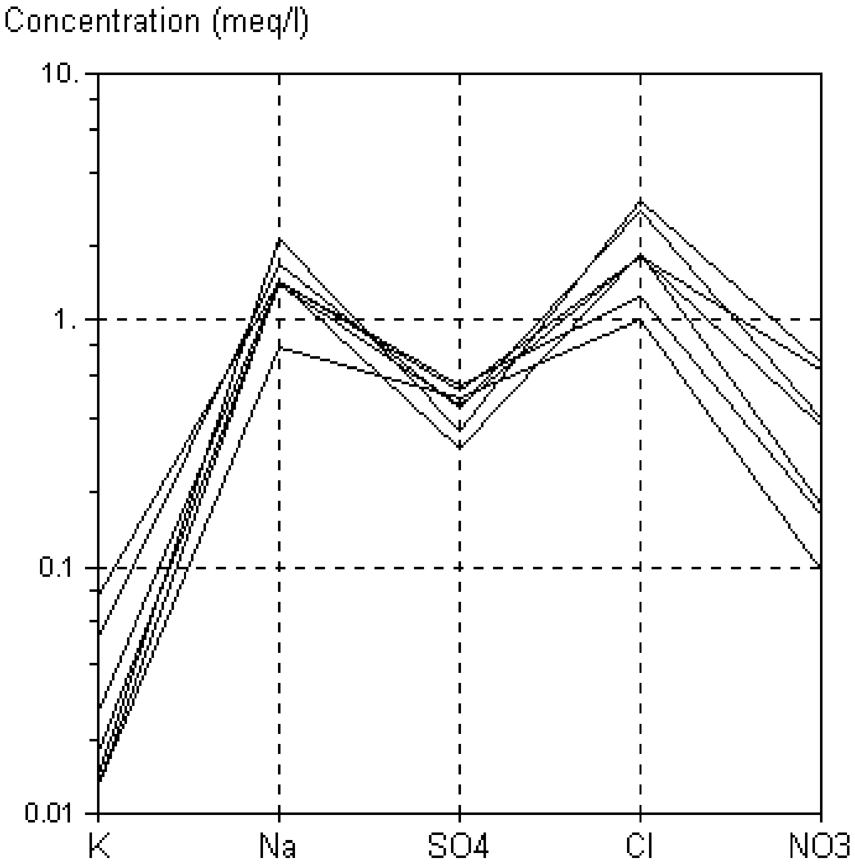


Fig. A: Schoeller diagram plot for the samples of cluster (II).

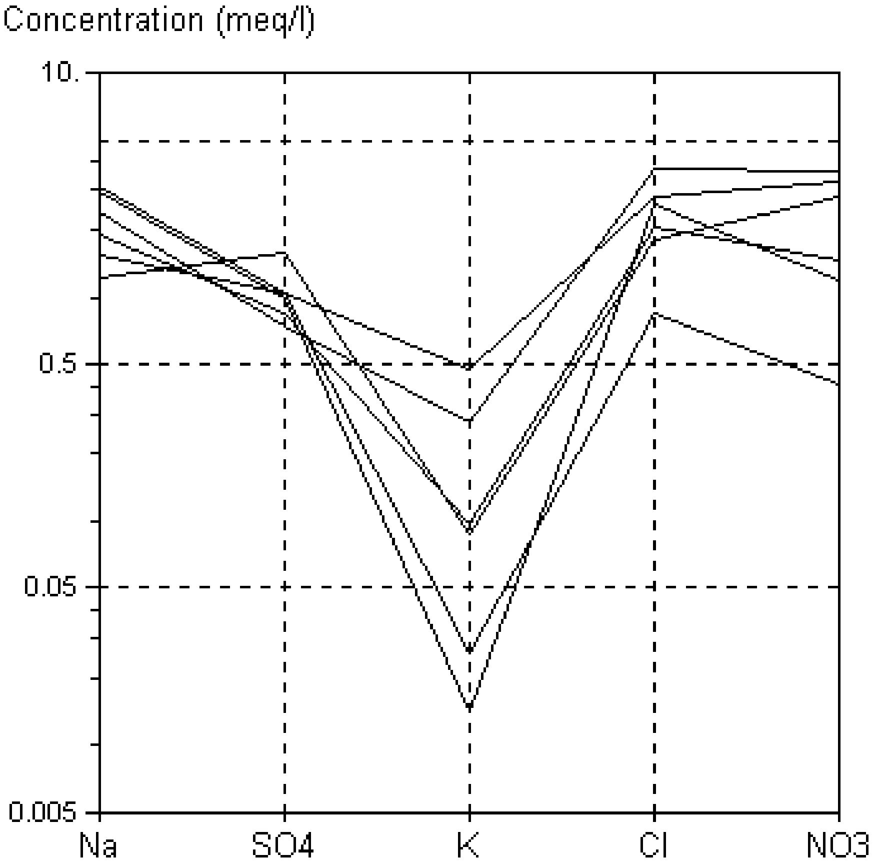


Fig. B: Schoeller diagram plot for the samples of cluster (III).

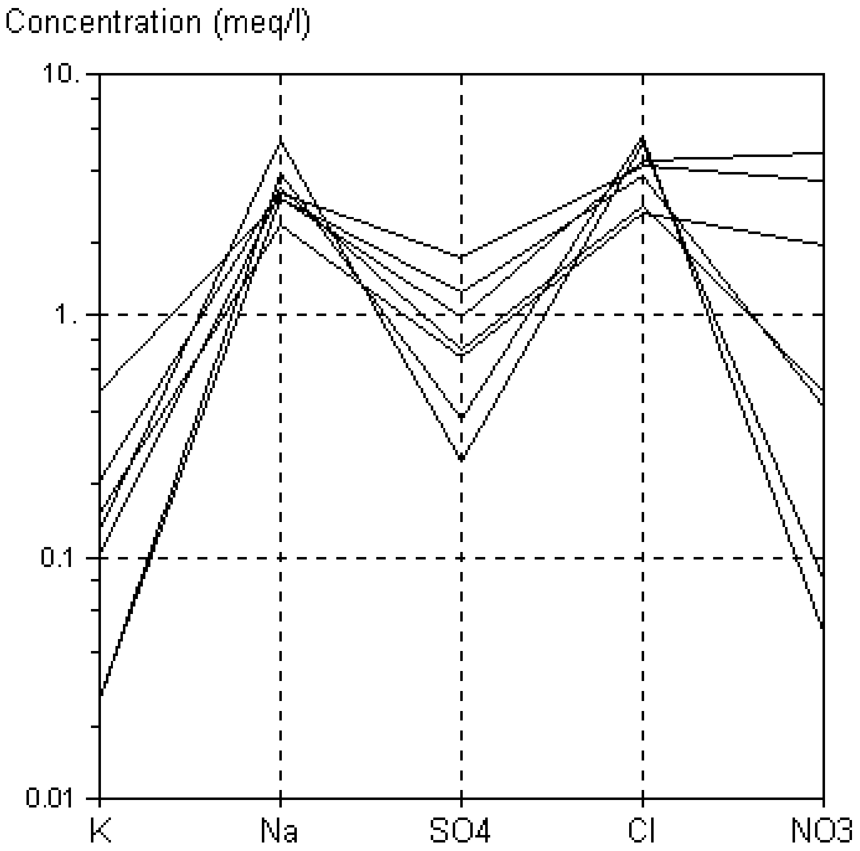


Fig. C: Schoeller diagram plot for the samples of cluster (IV).

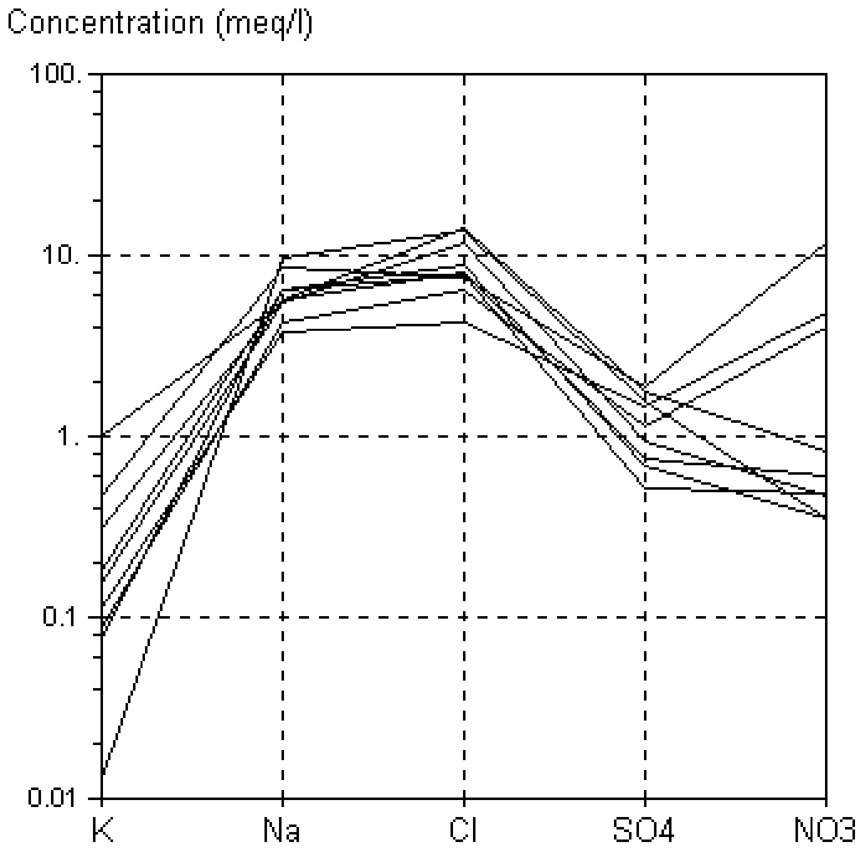


Fig. D: Schoeller diagram plot for the samples of cluster (V).

Appendix (5.1): Durov diagrams for the different groups of the study area.

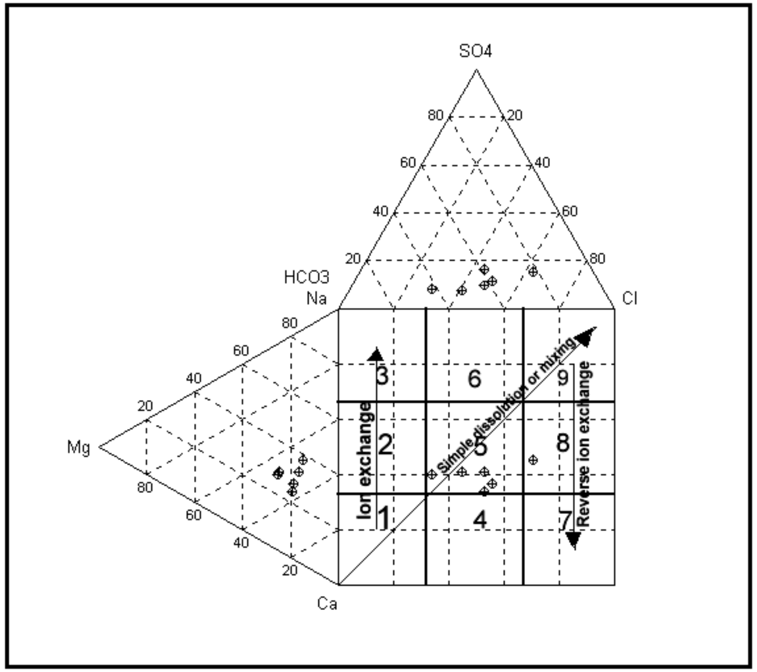


Fig. A: Plot of the springs of the Yatta group in the Hebron district.

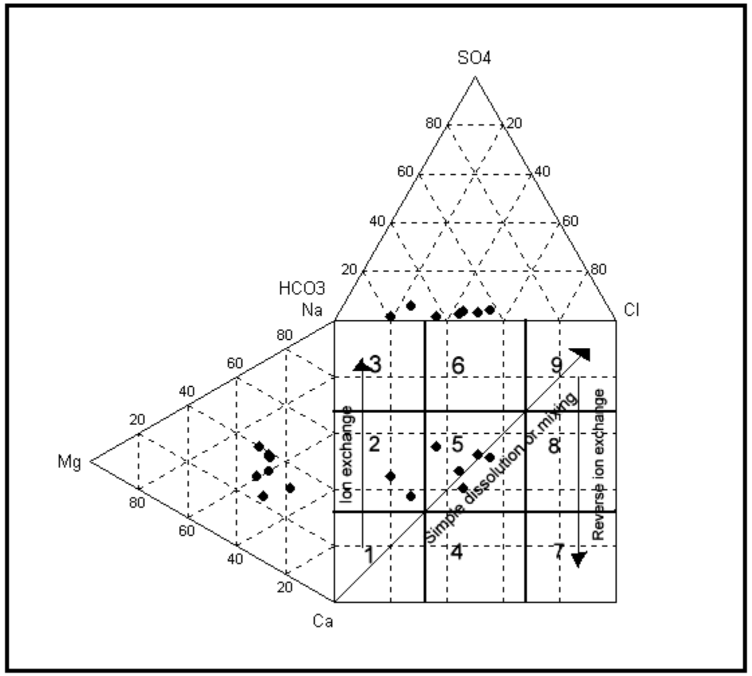


Fig. B: Plot of the springs of the Idna group in the Hebron district.

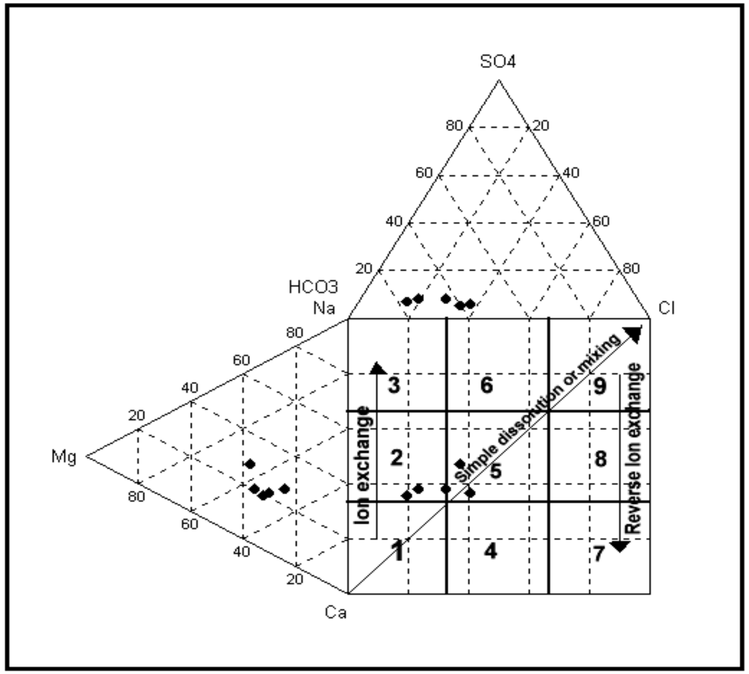


Fig. C: Plot of the springs of the Beit Kahil group in the Hebron district.

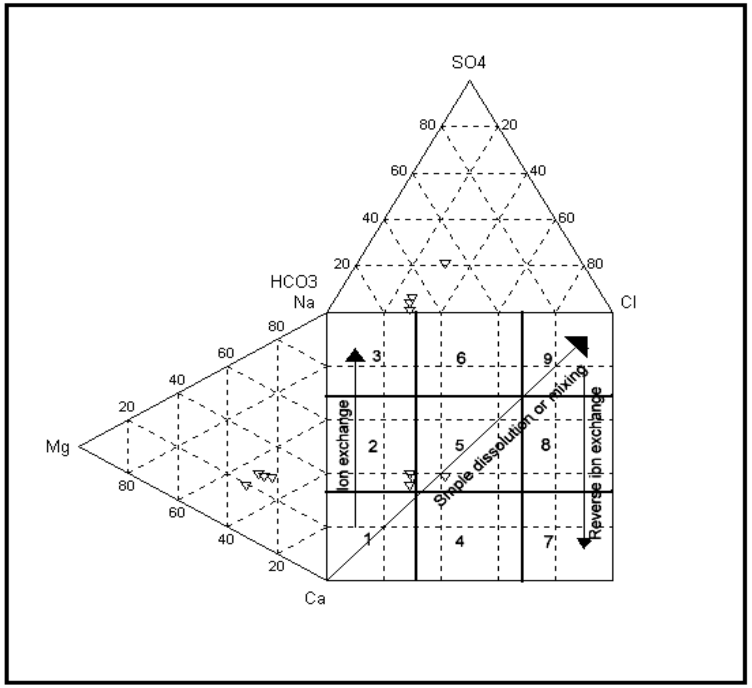


Fig. D: Plot of the springs of the Hebron city group in the Hebron district.

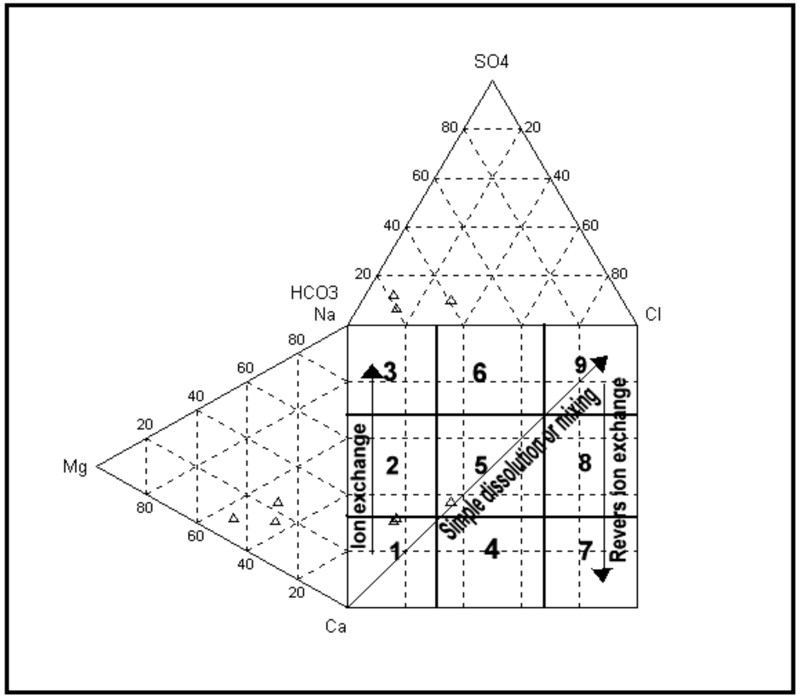


Fig. E: Plot of the springs of the Halhul group in the Hebron district.

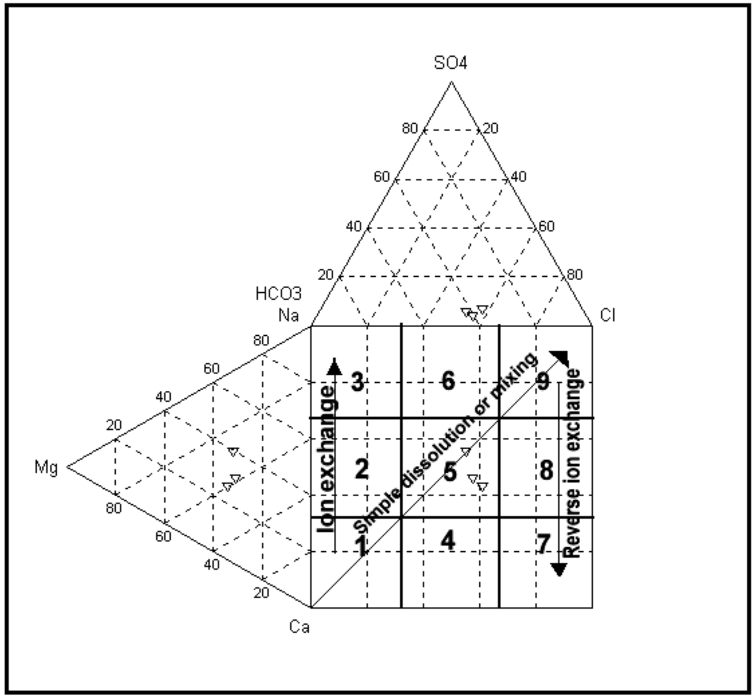


Fig. F: Plot of the springs of the Deir Samit group in the Hebron district.