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Quantifying Recharge Rate and its Mechanisms in Wadi Al-Ghar Catchment Area

By:
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Thesis Approval

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Jerusalem-Palestine
2011

The Right To Water Is a Human Right

The UN Committee on Economic, Social and Cultural Rights has noted:

‘The human right to water is indispensable for leading a life in human dignity. It is a prerequisite for the realization of other human rights’.

Dedication

I dedicate this to my beloved Family and Friends for their support and never-ending love.

I would like also to dedicate this thesis to all the professors in the department of Earth and Environmental sciences in Al Quds University who taught me for the last six years, and to anyone who has ever taught me throughout my life.

Declaration:

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

Signed: [signature]

Shadha Sami Musallam

Date: 25/4/2012

Abstract:

Groundwater is the primary source of water supply used in the West Bank. For proper water management and water banking, chloride mass balance method, bromide chloride molar ratio in addition to the stable isotopes tritium, deuterium and oxygen-18 have been used in Quantification of the recharge volume and mechanism in Wadi Ghar-situated in the south eastern part of the West Bank.

The precipitation volume over Wadi Ghar varies between 600mm in the upper section and decreases to 200mm in the end section. The precipitation volume over the catchment was estimated to be 94×10^6 m^3/year. However, depending on the 5 main geologic formations existing in the catchment of, Upper and Lower Cinemania, Turonian, Albian and Sinonian (chalk formation with minimum infiltration rate - equal to zero) age, the recharge rate for Wadi Ghar was calculated as between 70 and 180 mm/year, with a total average replenishment volume of 20.6×10^6 m^3/year. Thus the recharge of the Ghar catchment is about 22% of annual rainfall revealing replenishment potential within the estimated replenishment volumes of previous studies for the same area.

The isotopic signatures of ^{18}O between -7‰ and -5‰ and ^{2}H between -25‰ and -35‰ in groundwater demonstrate that water infiltrating the karstic carbonate Eastern Aquifer is from precipitation falling over the upper half of the catchment. The ^{3}H results also indicate that the water in the upper aquifer system is modern (fast replenishment). As for the water in the lower aquifer was considered to be sub-modern. The Cl/Br molar ratios of groundwater with an average value of 200 for Upper aquifer water and a value of about 680 for Lower aquifer water fortify the claim of water mixing between the modern and sub-modern water aged of both aquifers happening in the lower half subsurface of the catchment.

الملخص:

المياه الجوفية هي المصدر الرئيسي للمياه المستضفة الغربية. لكـــي يـــتم إدارة الميـــاه الصالحة للشرب بطريقة فعالة واستخدامها فيما بعد، تم استخدام طريقة التوزن الشامل للكلوريـــد، والنسبة اية بين البروميد والكلوريد، بالإضافة إلى نظائر مستقرة مثل الديوتيريوم والتريتيـــوم والأكسجين- 18 من أجل تقدير كميات وآليات شحن الخزان الجوفي في وادي الغار الذي يقع في الجزء الجنوبي الشرقي من الضفة الغربية.

كمية هطول الأمطار في وادي الغار تتراوح ما بين 600 ملم في الجزء العلوي وتقل إلى 200 ملم ي الجزء السفلي من المقطع. ويقدر حجم هطـــول الأمطـــار علـــى طـــول المســـاحة ب 94 × 10^6 م^3/سنة. ولكن، واعتمادا على التكوينات الجيولوجية الرئيسية الخمسة الموجـــودة فـــي منطقـــة ا الممتدة من عمر السينوماني الأعلى والأسفل والتوروني والألبي والســـيوني (أي تكـــوين الطباشير مع معدل تغذية ذو حد أدنى يساوي صفر)، تم احتساب معدل الترشـــيح (infiltration rate) لواد الغار على اساس 70 - 180 ملم/ سنويا بمتوسط حجم التغذية 20.6 × 10^6 م^3/ســنة. وبالتالي فان تغذية الخزان الوفية في وادي الغار يساوي حوالي 22٪ من الأمطار السنوية وهـــذا متوافق مع تقديردراسات سابقة.

ان تركيز نظائر ^{18}O يتراوح ما بين -5% و -7% و ^2H ما بـــين -25 %و −35% للميـــاه الجوفية مما يدل على أن المياه الجوفية تتغذى من مياه الأمطار الساقطة في الجزء العلـــوي مـــن الواد. وتشير نتائج ^3H أيضا الى أن الميه الجوفية في الخزان الجوفي العلوي هي حديثة مقارنـــه اه الجوفية في الخزان الجوفي السفلي الذي يمكن اعتباره بأنه من شـــبه الحديثـــة. ان النســـب المولية لتركيز الكلوريد/البروميد في المياه الجوفية والتي يبلغ متوسط ما قيمته في الخزان المـــائي العلوي 200 وحوالي 680 للخزان السفلي يدعم الادعاء بأن هناك خلط بين المياه الحديثة و المياه شبه الحديثة في طبقات الجوفية من الجزء السفلي من الخزان الجبلي.

Acknowledgment

I hereby give great recognition and acknowledgment to the generous funding through the research project (Sustainable Management of Water Resources (Quantity and Quality) in the Dead Sea Area (SUMAR) funded by the German General Ministry of Education, Science, Research and Technology (BMBF).

In addition, much gratitude is dedicated to my Professor and supervisor Dr. Amer Marei for giving me this opportunity in higher education. Nevertheless, I am much obligated to Dr. Saed Khayat as well, for believing in me.

I would like to add a special tribute to Hussam Utair, my coworker and comrade in research for helping me with all the field work and GIS mapping. Moreover, I would like to send my most appreciation to Muhamad Sbeh, who has helped me with many precious advices and GIS mapping.

To all the employees of *The Water and Environment Research lab* I give much praise, for all there endless support and help, especially Manal Al Khateeb, for her immense cooperation and management of all administrative and financial work during these past years.

I also would like to acknowledge the Palestinian Water Authority [PWA] for providing important resource data for this study and agreeing to use their PWA Wells as secure and safe locations for the manual rain gauge installation. Furthermore, lots of gratitude and many Regards to the Palestinian Meteorological Department [PMD] for providing, with great easiness and cooperation, very valuable and accurate meteorological data essential for this research.

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Table of Abbreviations

Abbreviation	Full Name
T	Tritium
(D) or (^2H)	Deuterium
^{18}O	Oxygen -18
abs	Above sea level
bsl	Below sea level
bgs	Below ground surface
mbgs	Meters below ground surface
CMB	Chlorine Mass Balance
GMWL	Global Meteoric Water Line
MWL	Meteoric Water Line
RMWL	Regional meteoric water line
LMWL	Local meteoric water line
MCM	Million Cubic Meters
wl	Water level
sw	Surface water
DS	Dead Sea
WB	West Bank
L/c/d	Liters per capita per day
GIS	Geographical Information System
WHO	World Health Organization
PWA	Palestinian Water Authority
PMD	Palestinian Meteorological Department
PCBS	Palestinian Central Bureau of Statistics
PHG	Palestinian Hydrology Group
oPt	occupied Palestinian territory
NGO	Non-governmental Organization
IAEA	International Atomic Energy Agency
UFZ	The Helmholtz Centre for Environmental Research
BMBF	Bundesministerium für Bildung und Forschung
SUMAR	Sustainable Management of Water Resources Quantity and Quality in the Dead Sea Area.

Chapter 1

1. Introduction:

“Water is life” this proverb has been used for many centauries all over the world. It is known that without water, no form of life can exist. That is why water is an essential assent and the utmost important natural resource for the Palestinian people.

To the contrary of people’s common knowledge, the West Bank in general is not considered to be a water-poor region, since the fresh groundwater resources are estimated to be approximately 669 MCM/yr and runoff water of about 215MCM (PWA, 2010).

However, Palestinians have been constantly denied their rights to use their own water resources since the Israeli occupation of the West Bank in 1967. The Palestinians use 11% only of their country’s share, while Israel uses 89%. Not only Palestinians are denied there water rights and prevented to access their own surface or groundwater resources, but also currently more than 87% of the annual safe yield of the Palestinian water from the West Bank’s Aquifer systems is used by Israel to meet 25% of Israel’s water needs (Isaac, 2009).

The average daily Palestinian consumption of water is 60L/c/d (Issaq, 2009) and 65 L/c/d (PWA, 2010) while the Israeli consumption of water is about 280 L/c/d (NAD - PLO, 2011) and 350 L/c/d (PHG, 2008/09). On the other hand the world health organization (WHO) recommends 100 L/capita/ day for healthy life standard. And thus, it is clear that we consume even less water that of the world’s standard.

In 2009 the abstraction of 94 MCM was done, out of which 50 MCM are used for agriculture irrigating around 90,000 dunums of land while 44 MCM are for domestic and industrial use. An additional 54 MCM was purchased from the Israeli National Water Company (Mekorot) a significant percentage of this volume is extracted from wells related to Mekorot company in the West Bank. Hence, the total water quantities utilized by Palestinians are calculated at 148 MCM. Moreover, water losses in the West Bank exceed 35%. thus the real net amount used is about 98MCM. Over the whole WB some of the most water-deficit areas are in the rural south and south-west region of the Hebron governorate; it has very limited amounts of water (Isaac, 2009). The Governorate of Hebron gets a total water supply of 16.7 MCM/yr for domestic purposes through a number of sources, including groundwater wells, springs and the purchased also water from Mekorot. The Governorate’s current total need of domestic water is around 31.2 MCM/yr, meaning that there is a water deficit of about 14.5 MCM/yr (PWA, 2009).

Hebron governorate is located to the south of the West Bank and has an area of about 1043 km², making 18% of the WB area (PWA, 2009). Moreover, It has the highest number of population compared to other governorates, the number of population reached 572,000 person in 2008 (PCBS, 2008). Between the years 2007/08 about 260 to 285 Km^2 of irrigated (3%) and rain-fed (97%) cultivated crops were planted, covering about 26% of the governorates area. it also has the largest pasture area within the whole West Bank (PCBS, 2008).

The number of communities situated in Hebron Governorate is 92. These 90 communities depend on water collected in cisterns during winter, and on purchasing water by tankers from springs, wells and filling points in the area (PWA, 2009). The population use of domestic water in Hebron governorate amounts to 58 L/capita/day which is exceeded by 5 times for Israeli settlers (Isaaq - ARIJ, 2009 – Map 5). There are around 17 Israeli settlements between urban and rural, within this governorate (PCBS, 2009). Figure (1.1) shows a clearer section of Hebron Governorate and the consumption of litters per capita per day of some major communities.

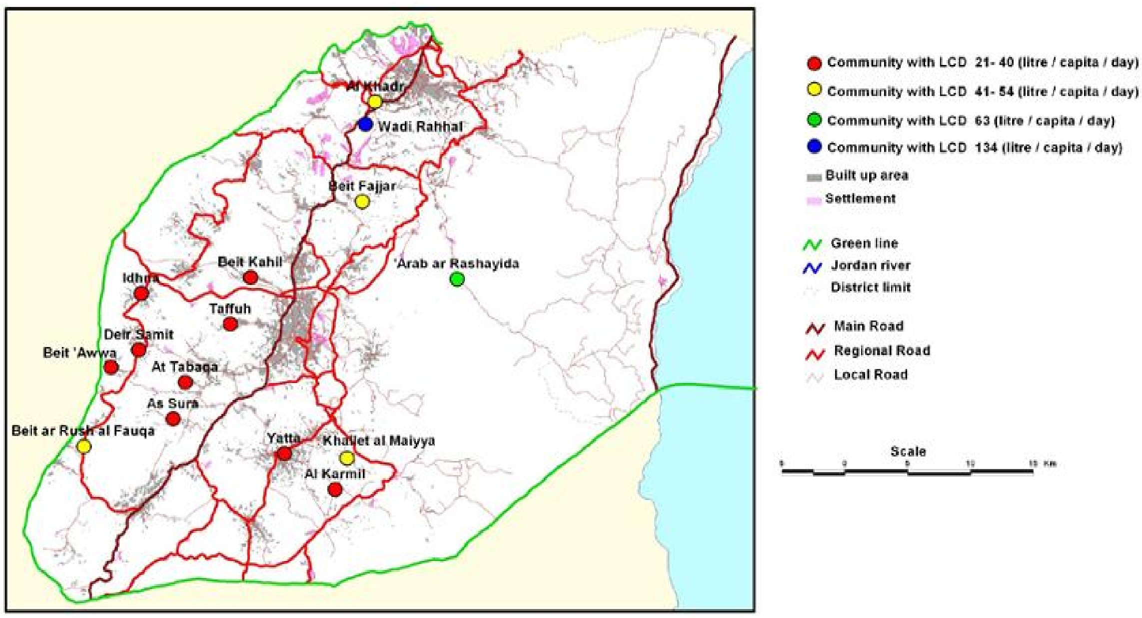


Figure (1.1): Hebron Governorate and liters per capita of water consumption per day (PHG, 2008/09).

The study area (Wadi Ghar) is located within the eastern part of Hebron Governorate depends heavily on water extracted from the PWA deep wells in Wadi Ghar to cover its domestic water needs. In general PWA deep wells located in this area taped 150-250 m^3/hr, that's about 1.2 - 2.2 MCM/a.

Chloride mass balance is an excellent technique to quantify the infiltrated water to the aquifer while on the other hand the chloride bromide molar ratio as well as stable isotopes ^{18}O and D will be used to identify the water origin, movement and residence time.

1.2 Problem Statement:

Hebron governorate scores low on all levels since it is the most semi arid region. Many groundwater wells were drilled in and around the study area during the last 30 years, These wells are taping water from the carbonate aquifer system of Upper Cretaceous age. The production of these wells decrease during the last 10 years rapidly. Moreover, the Palestinian Water Authority (PWA) plane to drill additional wells in the area.

The difference between the static water level and dynamic water level ranges between100-200m. During the last 15 years more than 8 wells have been drilled in the area causing the fall in the water.

1.3 Justifications:

Hebron governorate is highly dependent partially on the groundwater wells located within the catchment area of Wadi Ghar. In addition it has many un-served localities relying on tankers that consequently lead to poor quality of water reaching the users and is within the worst scoring governorates of the access components. Due to the severe deficit in the water supply. (PHG, 2008/09).

1.4 Objectives

The overall objective of this study is to investigate the recharge mechanisms, and recharge zones of Upper and Lower aquifer systems using chemical (CMB-method) and natural isotopic signatures in order to sustain the groundwater resources in this sub-basin.

The aim of this research is to estimate the hydrogeological condition of the groundwater aquifer, in order to determine the quantity and the recharge zones.

1.5 Limitations (obstacles):

The movement restriction in the area of study is the first obstacle, and the limitation of hydrogeological data is the second one. In addition, the number of wells are not very abundant, thus making the sample collection from the study area hard. The available historical data is not detailed and precise making the assessment difficult.

Chapter 2

Geology and Hydrology

1. The Geology of the West Bank – General Overview:

The West Bank is a series of anticlines, synclines and monoclines, as in fig. (2.1), Hebron anticline is one of these anticlines with an anticlines axis that is inclined towards the northeast direction having an asymmetrical nature. The asymmetry is caused by the gentle dipping of its western flank towards the west (Mediterranean Sea). Furthermore, its eastern flank dips steeply towards the east (Jordan Valley), the steep slope is dissected by the Valley's steep fault and transverse fault (Rofe and Raffety, 1963).

The anticline structure which forms the hilly connection (backbone) of the West Bank corresponds in general with the water divided, and determines the natural replenishment or catchment area of the local groundwater basins.

The axis of the main anticline also determines the main watershed and divides the underground water flow firstly of the west towards the coastal plane, secondly to the east towards the Jordan valley/ Dead Sea and lastly to the northeast towards Marj Ibn Amer and the Beisan Valley. Consequently, the aquifer system of the West Bank can be divided into three main groundwater basins as in figure (2.2); Western Basin, Northeastern Basin and Eastern Basin. The Eastern Basin is the one feeding the researched study area Wadi Ghar (Millennium Engineering Group, 1999).

The West Bank has an average rainfall of 450 mm/yr. The area of the West Bank is 5,879 Km^2 and the annual total average precipitation volume per year is about 2,600 MCM. Around 680 MCM of the 2,600 MCM is estimated to infiltrate the thin soil replenishing the aquifer systems. The remaining 1920 MCM of water ends as surface runoff or is lost through evapotranspiration (WRAP, 1994).

Data indicates that inside the West Bank, the total abstracted water by the Palestinians from 235 wells have dropped to approximately 42 MCM in 2009, while 56.9 MCM/ yr is abstracted from 40 deep illegal settler wells drilled by the Israeli Occupation after 1967 (PWA, 2009).

There are three major basins in the West Bank, Northeastern, Western and Eastern basin. Each one of these basins is divided into sub-basins as shown in figure (2.2), where water movement flow in each basin is displayed.

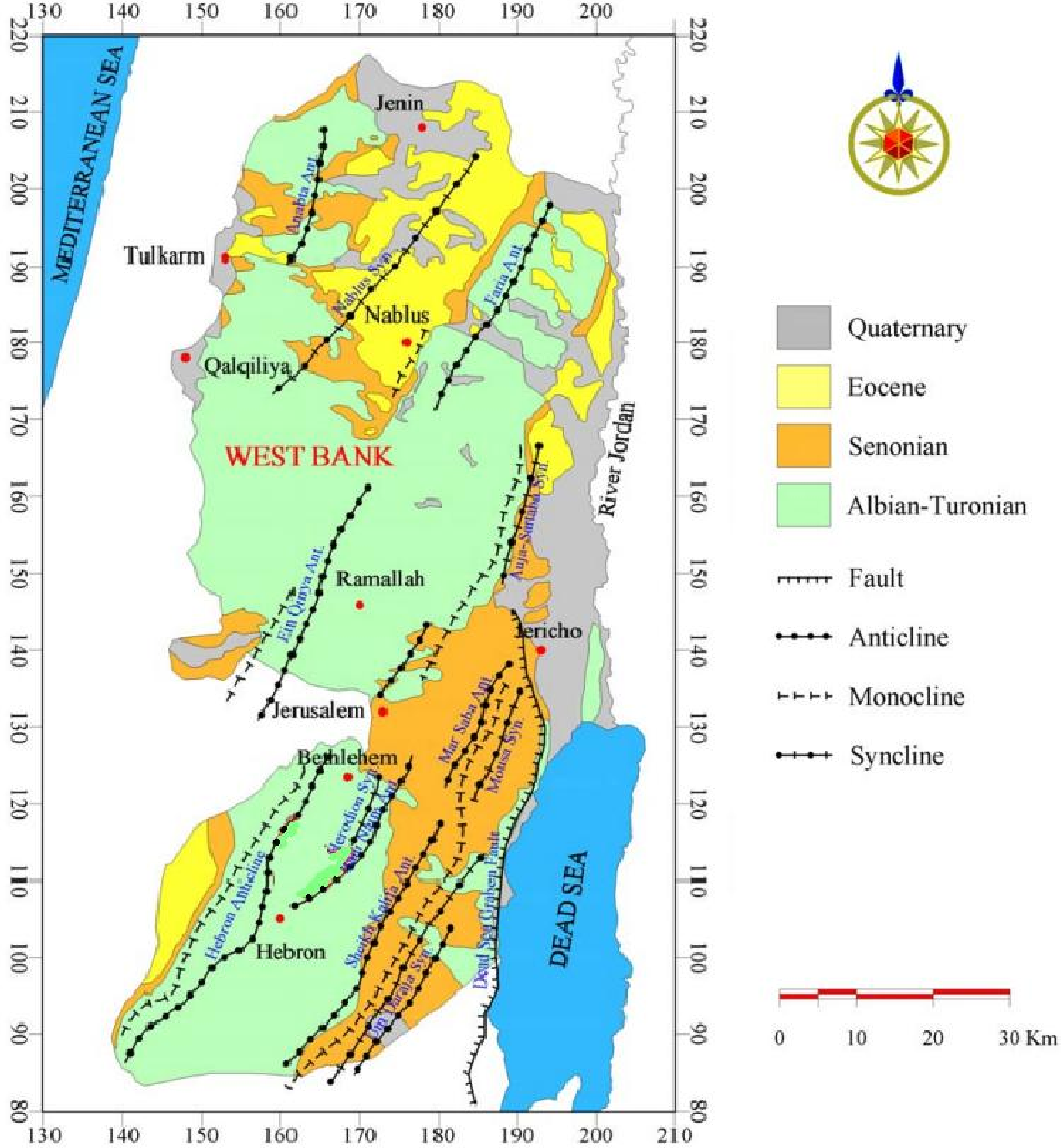


Figure (2.1): General geological and structural map of the West Bank [modified after (Geologic structure-Rofe & Raffety, 1963), (design and graphics – Qannam 2003)].

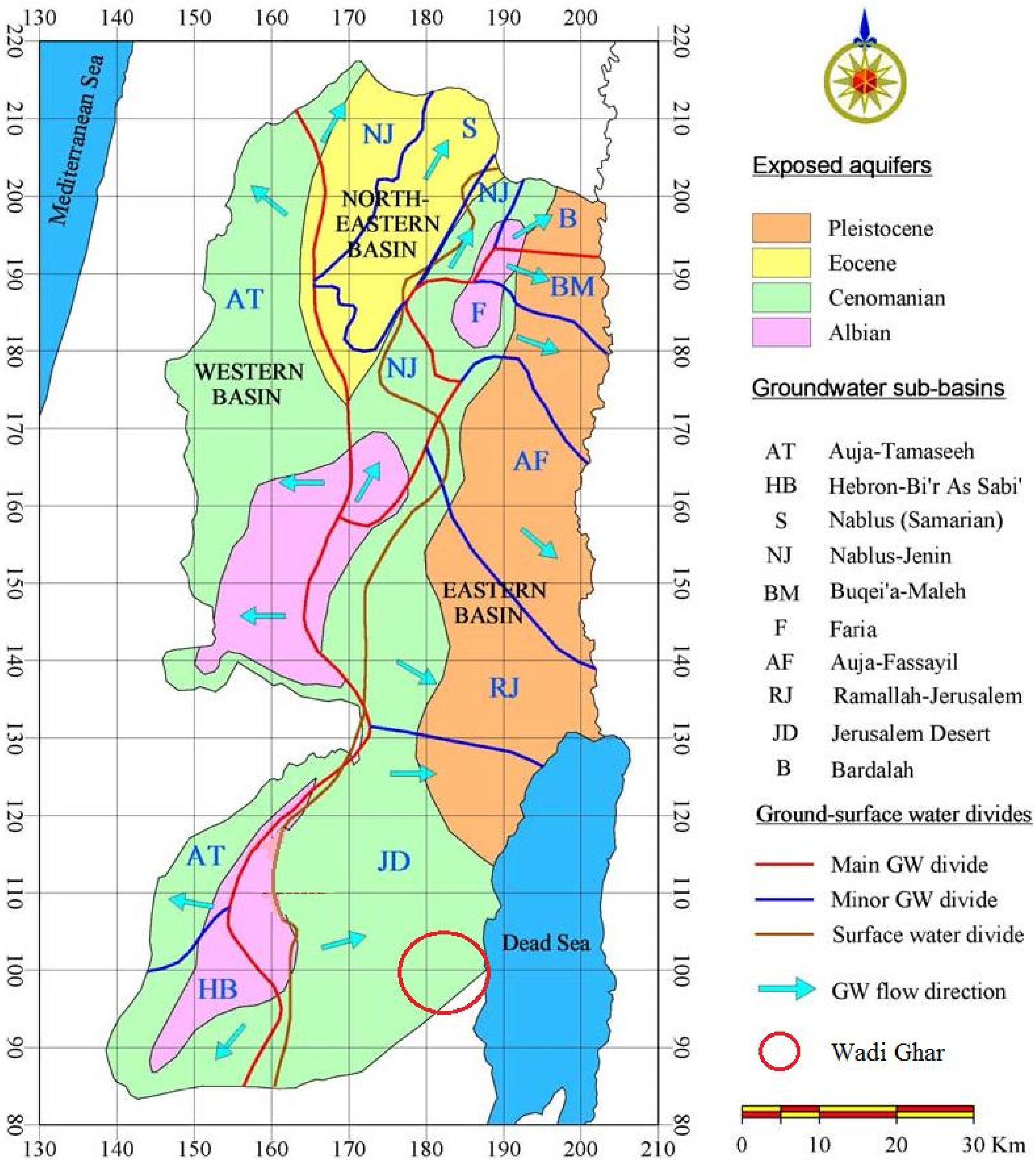


Figure (2.2): Groundwater basins and exposed aquifers in the West Bank / Palestine [modified after ARIJ 1995, Husary et al. 1996] (Qannam 2003)

2. Hydrological Overview

The groundwater flow direction in the Eastern Basin is primarily from the recharge area in the west, near the topographic surface water divide where aquifer formation out crop and receive about 600 mm/year rainfall to the discharge area in the east where many springs drain water along the shoreline of the Dead Sea. (Millennium Engineering Group, 1999).

The aquifer systems rely on recharge from rainfall. Thus, the aquifers outcrops are mainly along the Ramallah-Hebron Anticline where the highest rainfall occurs. Average rainfall on the highlands ranges from 500 to 700 mm/year. In the last ten years, rainfall dropped significantly, total average annual rainfall fluctuats between 20 to 30 % less than the annual avarage. As a result significant drop in the water table was noticed in the field wells. (Froukh, 2007)

The Eastern Basin lies almost entirely in the West Bank and is considered the second largest aquifer system there. By 2004, Israel had managed to install over 32 deep wells in the Eastern Aquifer. This Aquifer almost fully resides within the West Bank, yet Israel currently utilizes over 70% of its water (PHG, 2008/09).

Throughout the years the amount of water abstracted from the Easter Basin has been increasing, in the early 70's around 20 MCM of water was abstracted and in 1997 it reached about 65 MCM (Millennium Engineering Group, 1999). The volume gradually began to rise during the following years to reach about 160 MCM in 2009. Estimates of the safe yield of this basin vary around 172 MCM/yr but it has not been proven yet. The high increment in water abstraction from the aquifer was due to the many wells drilled and the intensification of abstraction of the older wells by Israel, to provide more water for settlers in the southern West Bank and meet there high demand of water consumption (khayat, 2005).

The major structural features of the Eastern Basin are the main faults forming the Jordan Rifts striking northeast- southwest. The geologic formations are mainly consist of limestone, dolomite, and marl of Upper Cretaceous age. These layers are forming the Upper and Lower aquifer systems, that separate through marl layers of Yatta formation, which acts in this area as aquiclude. On the other hand, a series of chalk sequence of Senonian to Paleogene ages, that consists mainly of thick chalk and chalky limestone units that compose the impervious cover of the upper aquifer system (Rofe and Raffety, 1963).

The hydrological system of the Eastern Basin is made of 2 primary aquifers; the Upper Aquifer and the Lower Aquifer.

1. Upper Aquifer: it is composed of the Turonian to Upper Cenomanian strata confined, at the top, by the Senonian chalk and chert layers of Abu Dees formation and at the bottom, confined by the impervious marls and marly limestone of the Yatta formation.
2. Lower Aquifer: it is composed of the lower Cenomanian and Albian strata. At the top, it is confined by the impervious to semi- permeable marls and marly limestone of the Yatta formation and at the bottom; it is confined by the glauconitic marls [comprising dark grey marl with abundant glauconite grains and sporadic phosphatic clasts] of the Qattana formation.

Table (2.1), shows the Formations distribution according to era, lithology and thickness. In addition, table (2.1) indicates the name of the formation in Arabic (Palestinian) terminology as well as the Israeli formation terminology for the same layer and group.

Table (2.1):Generalized stratigraphic column of the West Bank [modified after Braun & Hirsch, 1994; Millennium Engineering Group et al., 2000; Guttman, 2000; Guttman & Zuckerman, 1995; Bartov et al., 1988) (Qannam, 2003)

Geological Time Scale				Group		Formation		Lithology	Thickness (m)	Hydrostatigraphy
Era	System		Epoch	Palestinian	Israeli	Palestinian	Israeli			
CENOZOIC	Quaternary		Holocene	Recent	Kurkar	Alluvium	Alluvium	Marl, alluvium, gravel	Variable	Aquifer
						Gravel	River gravel			Aquifer
			Pleistocene	Lisan	Dead Sea	Lisan	Lisan	Thinly laminated marl with gypsum bands	200+	
	Tertiary	Neogene	Pliocene-Miocene	Beida, Jenin Sub Series	Saqia	Beida	Bit Nir and Ziglag	conglomerate	0-200	Aquifer
		Paleogene	Eocene	Belqa	Avidat	Reef nummulitic limestone	Zor'a	Reef limestone, bedded limestone, chalk with limestone undifferentiated	100-500	Aquifer in limestone and aquiclude in chalk
			Paleocene		Mount Scopus	Nummulitic limestone	Taqiya	Marl, chalk and clay		Aquiclude
MESOZOIC	Cretaceous	Senonian	Mastrichtian			Khan Al Ahmar and Zerqa	Ghareb	Yellowish chalk		Aquiclude
			Campanian			Amman and Abu Dis	Mishash	Chalk with back chert		Aquiclude
			Santonian				Menuha	Chalk		Aquiclude
			Turonian	Ajlun	Judea	Jerusalem	Bina	Limestone and dolomite (karstic).	90-120	Aquifer
			Cenomanian			Bethlehem	Weradim	Hard gray porous dolomite	90-100	Aquifer
							Kfar Shaul	Chalky limestone, chalk and marl	30-40	Aquitard
						Hebron	Aminadav	Karstic limestone and dolomite	110-140	Aquifer
						Yatta	Moza	Marl, clay and marly limestone	10-20	Aquiclude
							Beit Meir	Limestone, chalky limestone and dolomite	120-140	Aquifer
								Limestone inter -bedded with marl		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 and marly limestone	120-180	Aquifer
				Kurnub		Kobar	Qatana	Marl and clay	50	Aquitard
							Ein Qinyia	Marl and marly limestone	60-70	Aquitard
							Tammun	Caly and marl	80-150	Aquitard
			Aptian				Ein Al Asad	Limestone		Aquifer
					Kurnub		Nabi Said	Limestone		Aquifer
			Neocomian			Ramali	Hatira	Sandstone	150	Aquifer
	Jurassic		Callovian-Bajocian	Zerqa	'Arad	Upper Malih	Upper Malih	Marl interbedded with chalky limestone	190	Aquitard
						Lower Malih	Lower Malih	Dolomitic limestone, jointed and karstic	55	Aquifer

In Wadi Ghar, the oldest formation crop out at the axis of the anticline, whereas the younger Paleogene series (Senonian- Abu Dees) covers the flanks of the anticline in the southern and central part of the study area. Furthermore, the formation of the Upper and Lower Cretaceous are thick alternating sequences of limestone, dolomitic limestone, marls and marly limestone which make the aquifer system. On the other hand, a series of Senonian sequence of the Paleogene, consists mainly of thick chalk, chalky limestone with chert bands that compose the impervious cover of the aquifer system are found. The study area has various geologic formations as shown in figure (2.3). The main dominant formations are as follows as described by Rofe and Raffety in the hydrogeological survey they made of Palestine in 1969.

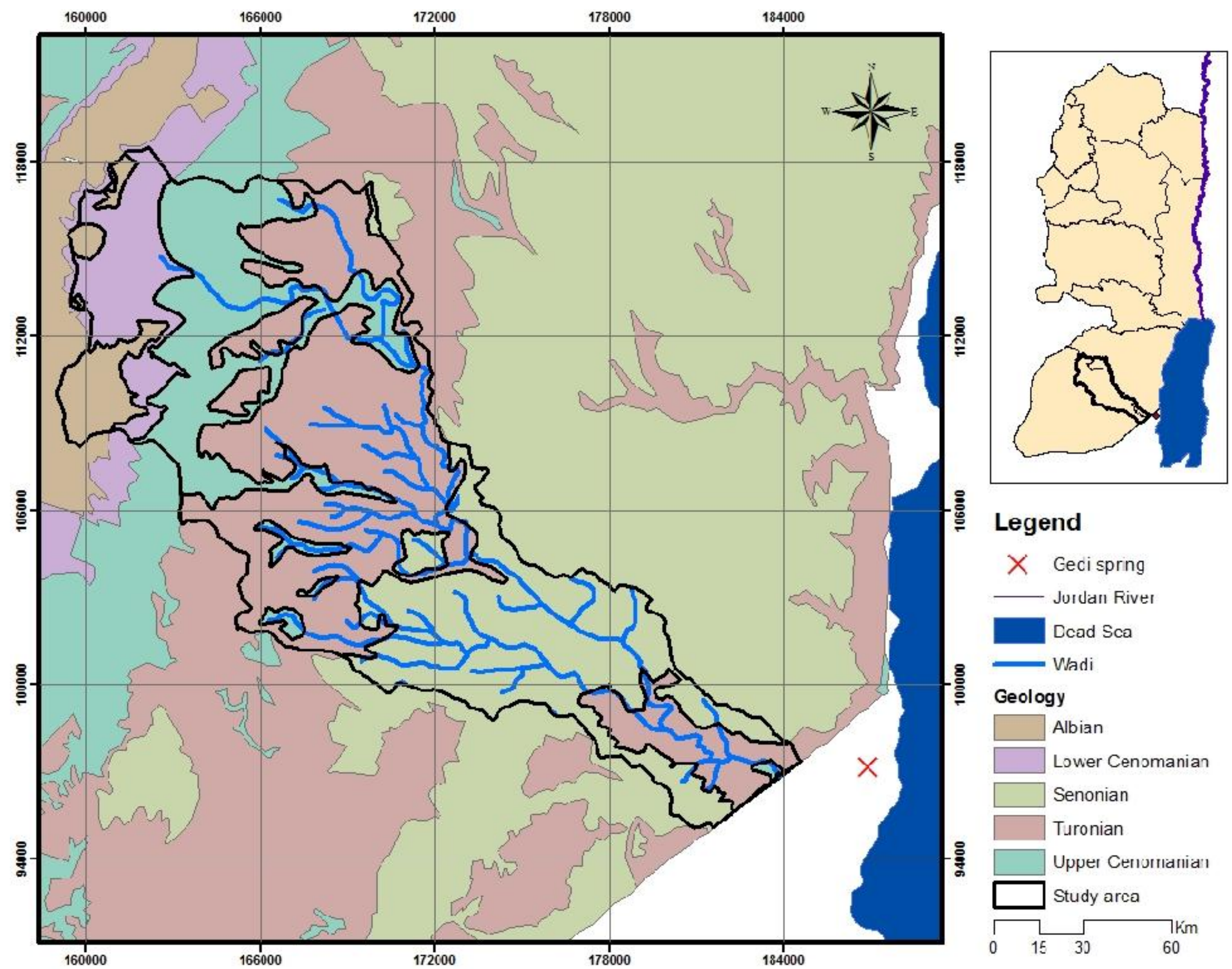


Figure (2.3): Geologic Formations and Ghar Wadi tributaries covering the area of Wadi Ghar surface catchment.

- **Abu Dees Formation (Senonian Age):** It is approximately 200 to 450 m thick. It is composed of massive chalk hard and bedded in its lower part in addition to fragmented, soft and unbedded in its upper part. In addition to chalk, chert is also found. The chalk is usually white but in some areas dark colored due to the presence of bituminous materials. The formation is occasionally phosphatic with a distinctive twin band of chert beds. In general chalk often appears to be fractured, sometimes nodular at its base, and occasionally brecciated and re-cemented. This layer may seem like a fracture flow aquifer but because of its clayey nature it is considered as an aquiclude. Abu Dees Formation covers the middle to lower section, about 58.7 Km^2, of the surface catchment area of Wadi Ghar.

- **Jerusalem Formation (Turonian Age):** This formation underlies the Abu Deis formation and is approximately 70 to 130 m thick. Its lithology is characterized by karstified limestone and dolomite with marl and clay, mainly near the bottom. In addition, occasionally occurrence of chalk is evident on the top of this formation. This layer is also locally cliff forming, frequently with thin partings and porcellanous and laminated. It is a pink color at its surface and cream brown throughout. Red nodules are present at its top and turn to lenticular in its lower part. This formation covers the middle part of the catchment of Wadi Ghar with an area of 94.3 Km^2.

- **Bethlehem Formations (Upper Cenomanian Age):** The Bethlehem formation is 30 to 115 m thick and underlies the Jerusalem formation. Its mainly made-up of limestone, chalky limestone and mottled red & cream marl at the top, and two marl bands near the base, that act as a confining aquiclude for the Hebron Formation beneath. Another part is made-up of hard brown weathered dolomite with some limestone. Bethlehem Formation is frequently highly jointed and fractured making this formation a good aquifer.

- **Hebron Formations (Upper Cenomanian Age):** The second formation, Hebron formation is 105 to 260 m thick. It is of a dolomitic and calcitic composition and with a well-jointed karstic nature. Both Bethlahem and Hebron Formations cover an area of 43.5 Km^2 within the catchment and are visible around the upper section of Wadi Ghar.

- **Yatta Formation (Lower Cenomanian):** it is composed of limestone, chalky limestone, dolomite, marl and greenish clay at the bottom. This formation can be divided into 3 sub- unit.
  - The upper unit is 5 to 15 m thick. It is made of a thin impervious layer of yellow creamy marls inter-bedded with thin laminated dark green to gray clays to creamy yellow marly limestone intercalation; this makes the upper sub unit of Yatta Formation act as an aquiclude, locally separating the Upper Aquifer from the Lower Aquifer.
  - The middle sub-unit of Yatta formation ranges between 40 to 50 m of thickness. It tends to be more calcareous, consisting of marly limestone inter bedded with highly fractured dolomitic limestone.

- The lower sub-unit is 50 to 70 m thick and is made of creamy, chalky marls and white crystalline limestone, which is found directly above the massive limestone at the top of the Upper Bet Kahel Formation. The composition of the middle and lower sub units of Yatta formation gives its properties as an aquifer, and could be considered as the production zones of the Lower Aquifer System.

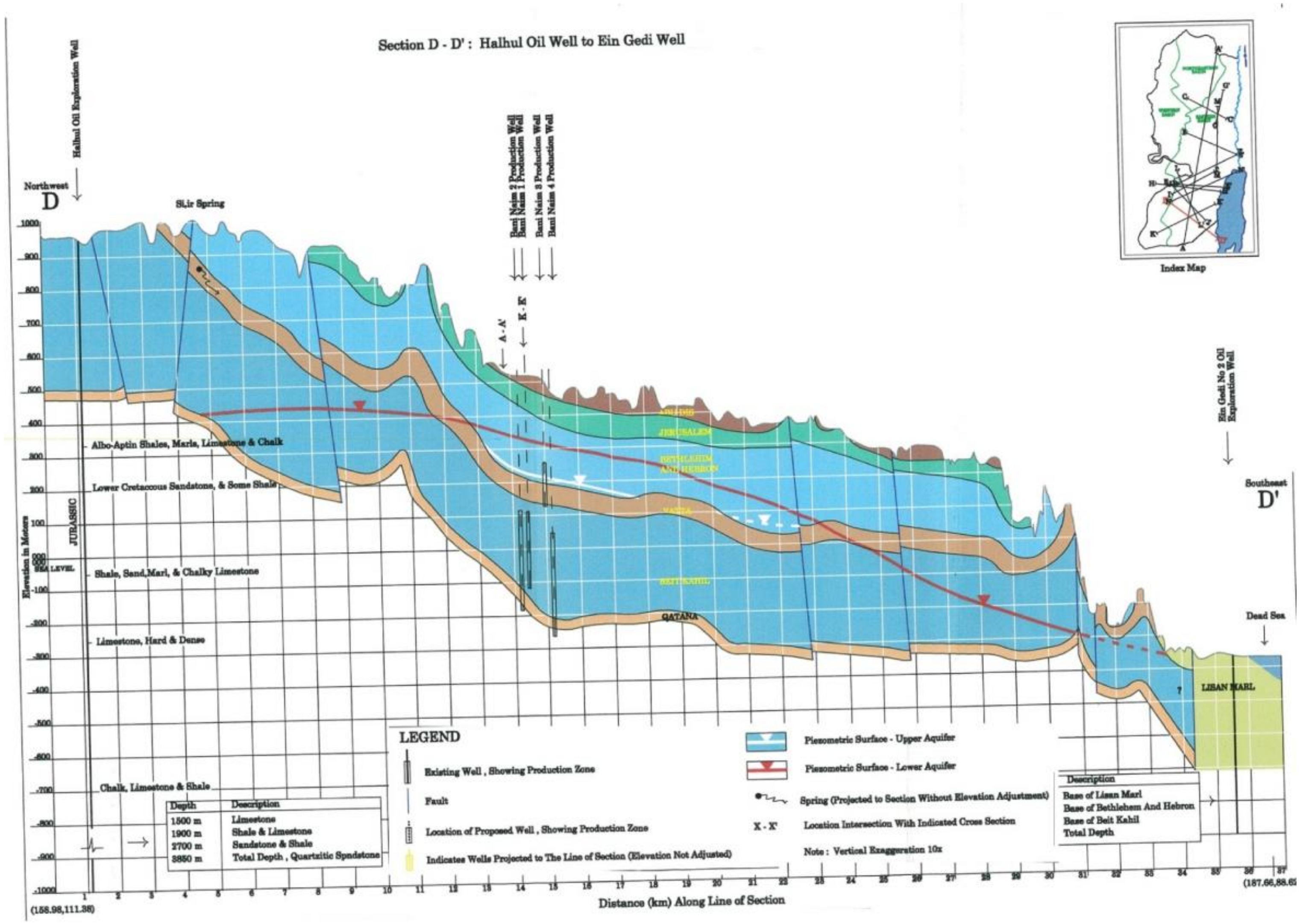
- **Upper Bet Kahel Formation (Albian):** Is ranging between 160 to 190m of thickness. The lower part of this formation is made-up of limestone with thin layers of porous dolomite interchanging with marly limestone and calcitic massive limestone near the base. Gray limestone layers alternating with layers of shale and marl, are typical for the lower part On the other hand, the upper part of the Lower Bet Kahel Formation, is made-up of gray to brown dolomite with clayey and marly limestone. The layers outcrops are characterized by stratification and extremely geometric jointing. Generally, the Lower Bet Kahel is considered to be a moderate to good aquifer, because of the numerous marly beds interaction diminishing its permeability forming a buffer between the upper and the lower zones of the formation. Bet Kahel formation covers only about 20 km^2 of the 225km^2 of the catchments area and is situated in the most upper part of the mountains with the highest elevation.

The Hebron, Bethlehem and Bet Kahel Formations are considered to be good aquifers; the composition provides good infiltration since they are made of calcite, dolomite and limestone. On the other hand, the Abu Dees formation covers 59 of 225 Km^2 (about 25% of the catchments area) and has low infiltration capability due to the major rock constitution, chalk, thus forming an impermeable barrier for infiltration.

The Geological Cross Sections shown in figures (2.4) (a), (b) and (c) are very significant in developing an overview of the hydro-stratigraphy related to Wadi Ghar. These cross-sections are essential to evaluate the characteristics of the groundwater movement and aquifer recharge. It is fundamental to understand the lithology of the aquifer under Wadi Ghar in order to do a solid assessment and a proper conceptualization of the hydrogeology of the study area

Figure (2.4.a) shows a geological cross section of the different Formations from Halhul to the Dead Sea. The central part of the section - between 13 and 23 km- shows that the water table of the lower aquifer is actually higher than the water table of the upper aquifer residing at around 400m asl while the upper aquifer's water table is at 200 m asl. While this is a clear proof of water mixing between upper and lower aquifer, the mixing happen within the Formations of Hebron and Bethlehem which are manly composed of limestone, dolomite and marl.

However, to the North D of section D-D' it is clear that the water table of the lower aquifer is in Beit Kahel Formation, and the actually feeding area of the lower aquifer are about the first 4 km of the upper northern D section. Moreover, the major area feeding the upper aquifer falls over a distance of 10 km including Bethlehem, Hebron and Jerusalem Formations.



Figure(2.4.a): geologic cross-section in the Eastern Aquifer section-1, *from Halhul oil well to Ein Gedi well.* (Millennium Engineering Group, 1999 – chapter 4 / section D-D')

As noted, the study area has eight major faults that dislocate and shift the geologic formations continuity. The Ghar area is crossed by 3 major geological structures that can be accounted for; First, a monocline at the upper part of the catchment [mainly cuts through Cenomanian aged Formations]. Second, a Syncline (Um Daraja) that traverses through the middle section of the catchment and third, an anticline (Sheikh Khalifa) that crosses the lower part of the catchment [mainly across Senonian aged formation]. The faults role in water mixing is noticeable since it lacerate vertically through the Cretaceous limestone, marl and Dolomite, causing the water from the lower aquifer to rise along the dolomitic layers into the upper aquifer. Moreover, the karstic nature of limestone encourages this claim, since water can move more rapidly between the aquifers.

Section J-J' cuts through parallel to the upper north eastern part of wadi Ghar catchment. Underneath *Bet Fajar- Bet Sahur syncline* about 12 km from the north section J, it can be observed that the upper aquifer water table residing in Hebron and Bethlehem formation, is above the lower aquifer water table residing mostly in Bet Kahel formation. However, moving about 7 km to the south section J', the water table of the lower aquifer rises and surpasses the upper aquifer table with an approximate distance of 100m for a distance of 7 km and then falling back to bet Kahel formation. This implies water mixing in the southern area of the section within the Hebron and Bethlehem formation.

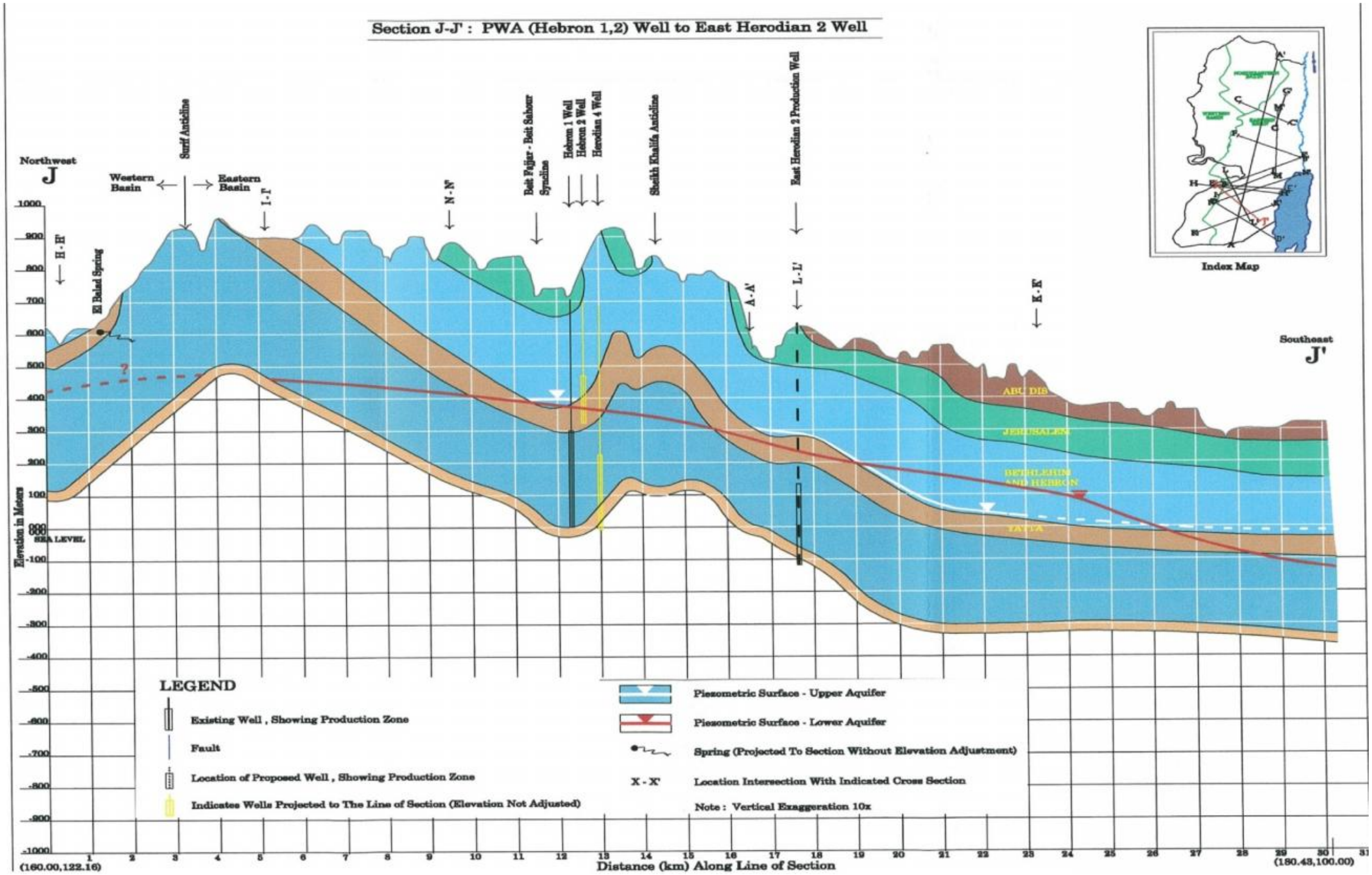
Furthermore, it can be observed from the section that all the Herodian wells (1, 2, 3, 4) abstract water from the lower aquifer before the mixing happens.

The cross section K-K' shows the surface water divide between the eastern and western basin. From the formations overlay it can be deduced that the catchment feeding the upper aquifer happen between 8km and 26km with Jerusalem formation covering the surface area. Since Jerusalem formation is characterized with solid compact lime stone, multiple karsts can be found, thus infiltrating the water to the upper aquifer relatively fast.

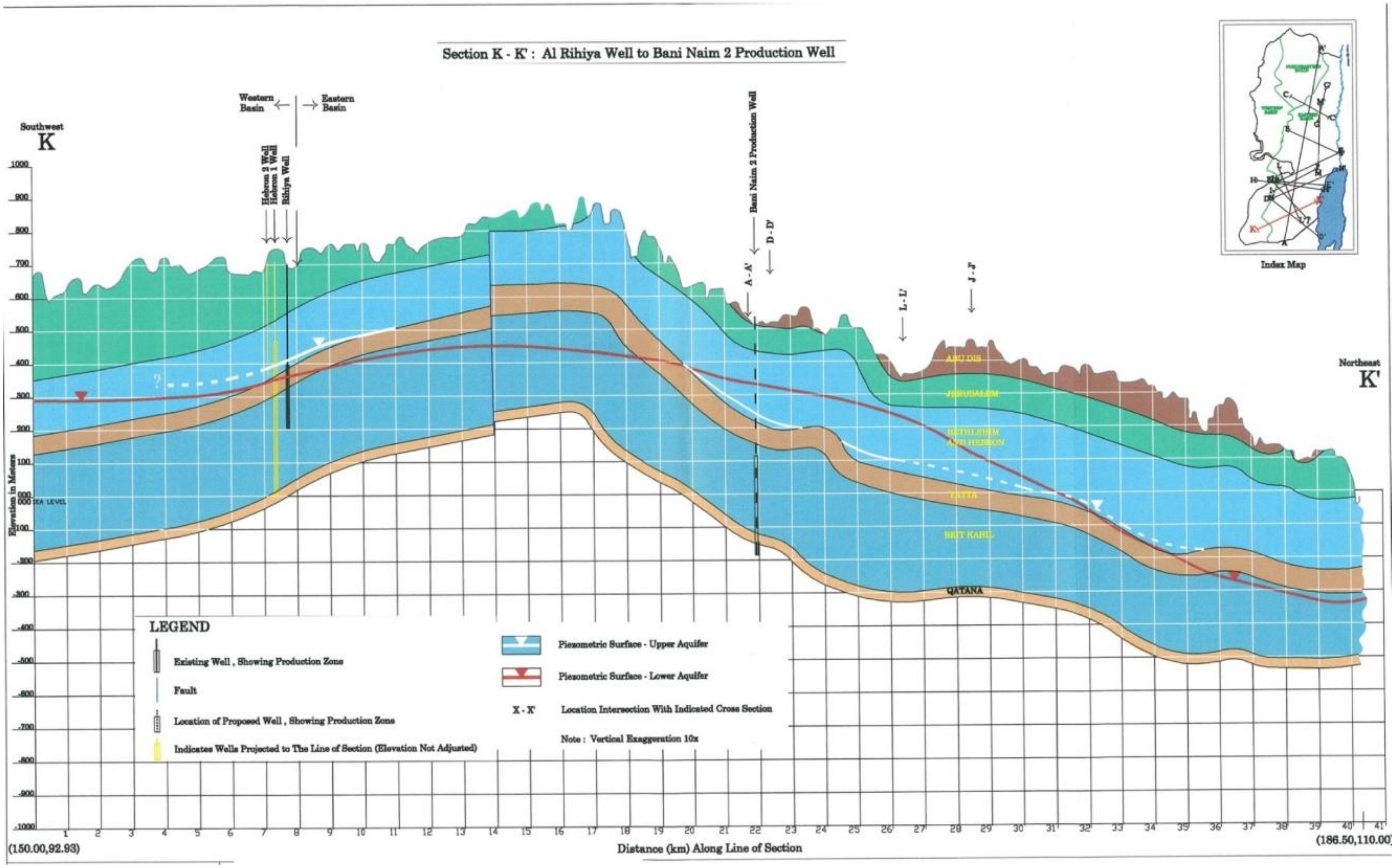
In addition towards the northeast part of the section the lower aquifer water table starts to rise above the upper aquifer water table causing mixing between the two aquifers water, but since the inter section of the water tables happens for a relative short distance the amount of water mixed is somewhat small compared to the total volume of water in both aquifers.

Lothologic data of well bores was drawn using the "Win Log" software in order to have a more detailed insight of the strata around the area of Wadi Ghar as in figure (4.a) and (4.b) – Appendix A -1.

The raw data of the layers description and depths where taken from the PWA - CH2MHILL, 2003 reports of Izzariya 1a production well, Aroub 1a monitoring well, Aroub 1b monitoring well and Bani Naim 2 (BN2 Monitoring well). The locations of the wells are shown in figure (1.4) – Appendix A -1.



Figure(2.4.b): geologic cross-section in the Eastern Aquifer section-2, *from JWC 4 production well to Ras El Wad monitoring well.* (Millennium Engineering Group, 1999 – chapter 4 / section JJ')



Figure(2.4.c): geologic cross-section in the Eastern Aquifer section-2, *from Al Rehiyeh well to BN2 production well.* (Millennium Engineering Group, 1999 – chapter 4 / section KK')

The Hebron Governorate situated to the south of the West Bank has an average monthly rainfall of 580 mm/yr as Figure (2.5) shows, of an average maximum of 140 mm in February and a minimum during the months of June to August. Precipitation in the year 2009 was higher than average in February by about 50mm, but on the other hand it was less than average in November and December by more than 70mm thus falling bellow the average yearly precipitation and considered as a "dry year" for 2009.

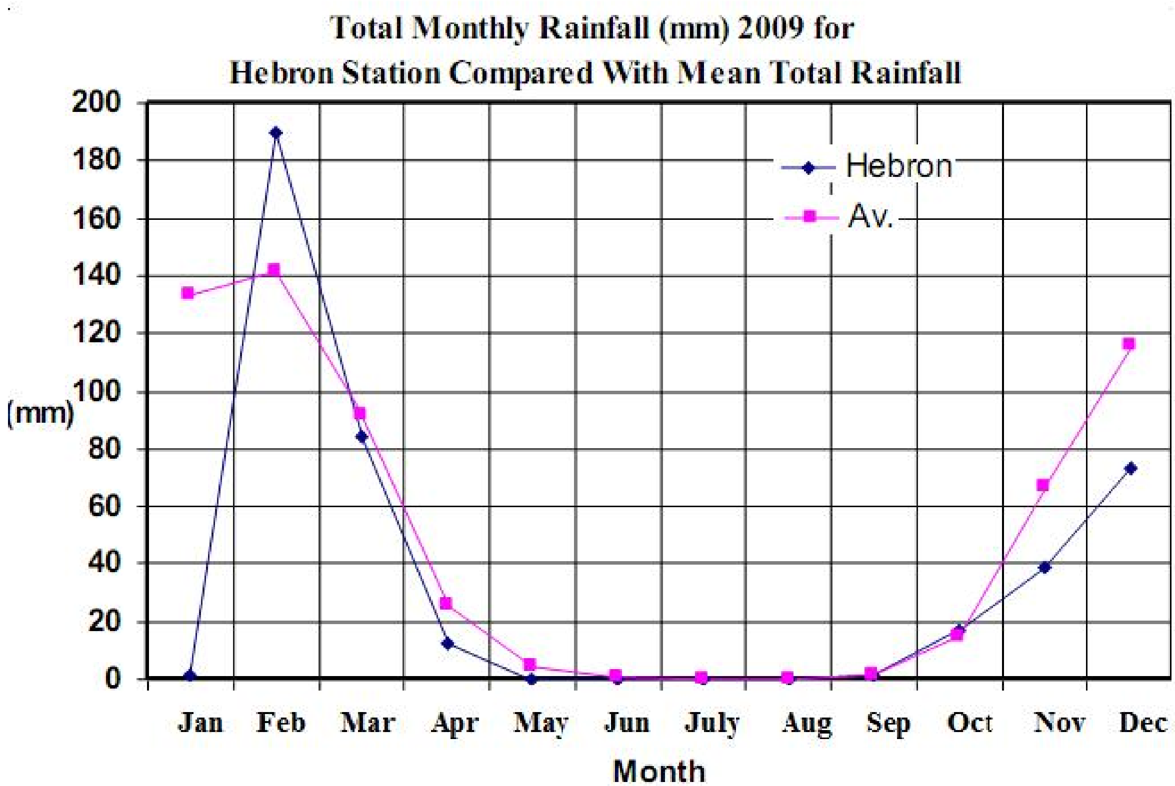


Figure (2.5): monthly Rainfall for 2009/10 in Hebron station in comparison with mean average of monthly precipitation in Hebron (PMD, 2010).

i. Evaporation and Evapotranspiration

According to the Rofe & Raffety study during the early 1960's the evaporation in Al Arubb (a refugee camp included in the catchment area) has the dated evaporation as in figure (2.6.a). Through many years, since early 1970's, a large amount of rainfall data has been collected in the Hebron region from rain gauges located in Al Arrub station or in the Hebron Station. Figure (2.6.a) shows the mean precipitation volume over the Hebron area each month of the year. It can be deduced that most of the precipitation of rainfall occurs from the months of December to February and March with a peak value in February. Nevertheless, a significant amount of rainfall happens prior and after that period; meaning November and May.

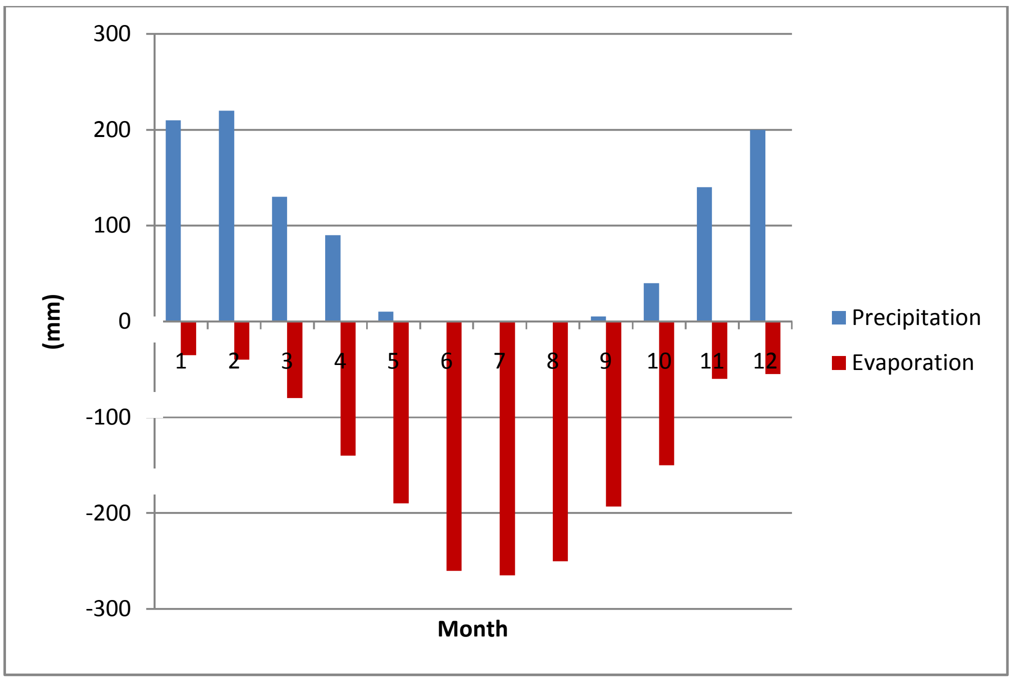


Figure (2.6.a): The potential evaporation in (mm) per month over the different months of the year [modified after Rofe & Raffety, 1963 and PMD 2010].

Observing figure (2.6.a), a precipitation- evaporation water balance can be estimated as in figure (2.6.b). The graph shows that in the rainy season the total amount of water from precipitation will amount to over 600 mm during one year, while the evaporation amounts to around 1300 mm during the year with a peak potential evaporation from June to August with values above 200 mm. this means that usually the amount of potential evaporation exceeds precipitation causing a deficit in the area.

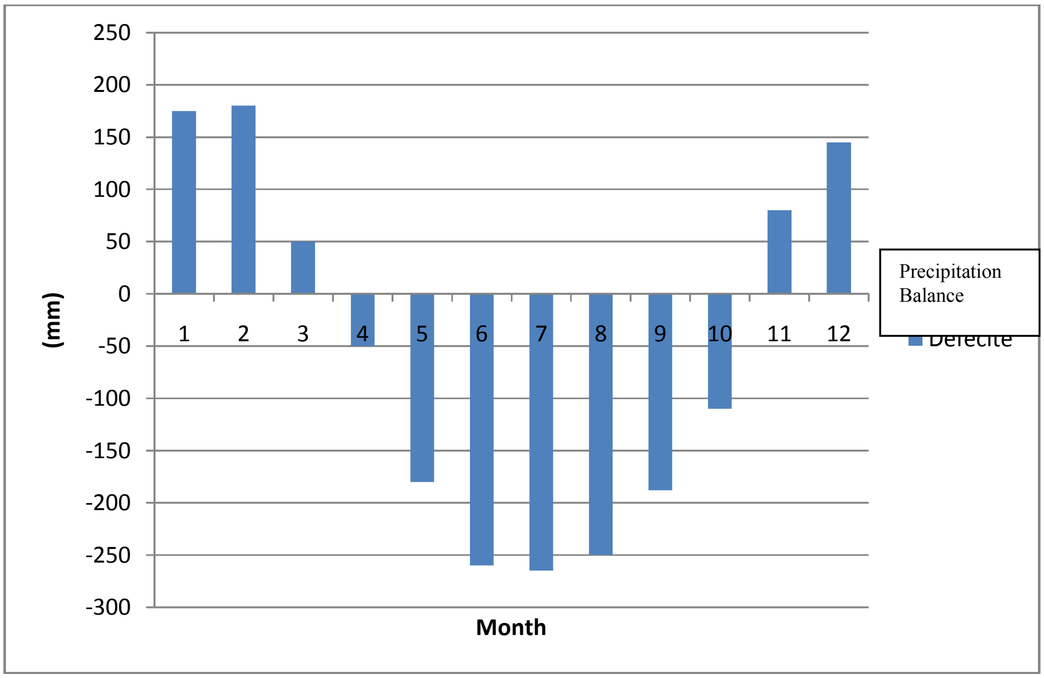


Figure (2.6.b): The precipitation - Evaporation water balance estimated in (mm) per month over the different months of the year.

ii. Aridity:

Qannam (2003), mentioned in his PhD thesis that the aridity index can be classified as in table (2.2). Furthermore, the aridity equation to calculate the study area's aridity involves the calculation of mean annual precipitation of the area and the mean air temperature. Since all the data needed to calculate the equation is available, the aridity index of Hebron will be calculated in the ***Results and Discussion*** - Chapter 4.

Table (2.2): Aridity indices of the different climatic regions given by Pahari and Murai in 1995.

Index		Class	
De Martonne	***Muria and Honda***		
≤ 5	≤ 5	Arid	Desert
5 - 10	5 - 10	Semi arid	Semi desert
10 -20	10 - 30	Semi-humid	Grass land
20 - 40	> 30	Humid	Forest
> 40	-	Wet	Tropical forest

The aridity index is identified as:

$$X = P / (10 + T)$$

Where;

P: is the mean annual precipitation (mm)
T: mean annual air temperature (C°), [where the annual air temperature equals the sum of monthly average temperature divided by 12].

iii. Springs Hydrogeology:

There are 22 springs that discharge around 217020 m^3/yr of water within Wadi Ghar catchment area. The average discharge of the springs is about 5 L/s. Flow of 0.36 m^3/h is the average of 113 spring with an average annual flow of 50 MCM. Most of the springs have the same average discharge/ hour. None of the above spring exceeds the discharge of 0.2 m^3/h and the majority of the springs covering the whole catchment area are restricted into three major places; Al-Arrub, Bet Ummar and Halhul. This fact is linked to the geologic distribution of the different formations covering the study area.

Table (2.3): Springs location and discharge volume around catchment area (AQU GIS database; PHG, 2005).

Spring ID	Name	Locality	Discharge (m^3/h)	Discharge (m^3/yr)	Formation
BB/060	Qusbar	Halhul	0.208	1825	Bet Kahel
BB/061	Al Aiwinat	Halhul	0.145	1277	Bet Kahel
BB/062	Al Teenah	Halhul	0.125	1095	Bet Kahel
BB/063	Zabud	Halhul	0.25	2190	Bet Kahel
BB/064	Isa	Halhul	0.0002	2	Bet Kahel
BB/065	Um Jubar	Halhul	1.375	12045	Bet Kahel
-	Therweh	Halhul	0.0107	94	Bet Kahel
CB/051	Sa'eer	Sa'eler	0.0687	70579	Bethlehem
CB/048	Beer Ayad	Al Arrub	2.7	23725	Bethlehem
CB/047B	Al Bus	Al Arrub	0.625	5475	Bethlehem
CB/047A	Beer El Buss	Al Arrub	1.5	13140	Bethlehem
CB/042	Beer 'Id	Al Arrub	*	*	Bethlehem
CB/043	Beer Hamad	Al Arrub	*	*	Bethlehem
CB/044	Al Marj	Al Arrub	2.125	18615	Bethlehem
CB/045	Harshah	Al Arrub	7.1	62780	Bethlehem
CB/046	Barradah	Al Arrub	0.2210	1936	Bethlehem
CB/040	Mareena	Beit Ummar	0.125	1095	Bethlehem
CB/041	Kufeen	Beit Ummar	*	*	Bethlehem
BB/051	Muqattam	Beit Ummar	0.125	1095	Bethlehem
BB/052	Karih	Beit Ummar	0.0014	12	Bethlehem
BB/053	Jadur	Beit Ummar	0.0043	38	Bethlehem
BB/054	Jenan	Beit Ummar	0.0002	2	Bethlehem

iv. Wells Hydrogeology:

The abstraction from the Eastern Aquifer began in the 1960's firstly in 2 wells drilled through the Upper Aquifer in Ramallah and Bethlehem area. The average annual abstraction at that time was around 1.5 MCM/ year. Since then almost 66 wells have been drilled in both the Upper and Lower aquifer and the abstraction reached 50 MCM/year within 50 years. In the mid 1970's water meters were installed and since then records of water abstraction were recorded but unfortunately prior to that abstraction rates can only be estimated.(PHG, 2008/9)

Most of the water consumed is provided not only by the natural springs in the eastern aquifer but also from the drilled wells. Figure (2.7) shows the wells distribution over the Hebron Governorate and in table (2.4), different wells drilled in the catchment are displayed in accordance to their depth and formation covering their location.

As shown in the table (2.4) most of the wells are found in Turonian and Cenomanian formations. The majority of wells used for domestic use are penetrating the Cenomanian aquifer. It can be observed that most of the domestic wells are from the Upper Aquifer while the agricultural wells are deeper and penetrate the Lower Aquifer.

Table (2.4): Wells location, Depth and aquifer, within Wadi Ghar catchment area (AQU GIS database).

Well ID	Wells Name	Governorate	Well Depth (m)	Water Use	Formation	Aquifer
16-10/002	Bani Nuem B1	Hebron	750	*	UBK/LBK	Lower Aquifer
16-10/001	Bani Nuem A1	Hebron	480	*	UBK/LBK	Lower Aquifer
17-10/001	Eastern Herodion 2	Hebron	731	*	UBK/LBK	Lower Aquifer
16-11/010	PWA 1	Hebron	601	Domestic	UBK/LBK	Lower Aquifer
16-11/001	PWA 11	Hebron	851	No pumping	UBK/LBK	Lower Aquifer
16-11/008	Hebron Municipality 1	Hebron	704	Agricultural	UBK/LBK	Lower Aquifer
16-11/009	Hebron Municipality 2	Hebron	350	Agricultural	Bet/Heb	Upper Aquifer
16-11/006	Herodion 4	Hebron	691	Domestic	UBK/LBK	Lower Aquifer
16-11/007	Herodion 5	Hebron	350	Domestic	Bet/Heb	Upper Aquifer
16-11/005	Al Arrub AS	Hebron	-	Agricultural	Heb	Perched
16-11/004	Al Arrub Nursery	Hebron	-	Agricultural	Heb	Perched
16-11/001	Bet Fajar	Hebron	237	Domestic	Bet/Heb	Upper Aquifer
16-11/001A	Bet Fajar 2	Hebron	305	Domestic	Jer/Bet/Heb	Upper Aquifer
16-11/002	Bet Fajar 3	Bethlehem	305	No pumping	Jer	Upper Aquifer

*UBK: Upper Bet Kahel, LBK: lower Bet Kahel, Bet: Bethlehem, Heb: Hebron, Jer: Jericho.

Figure (2.7) shows the wells and springs distributed along the upper part of the catchments Turonian, Lower and Upper Cenomanian aged formations. While on the Senonian there are no springs or wells drilled.

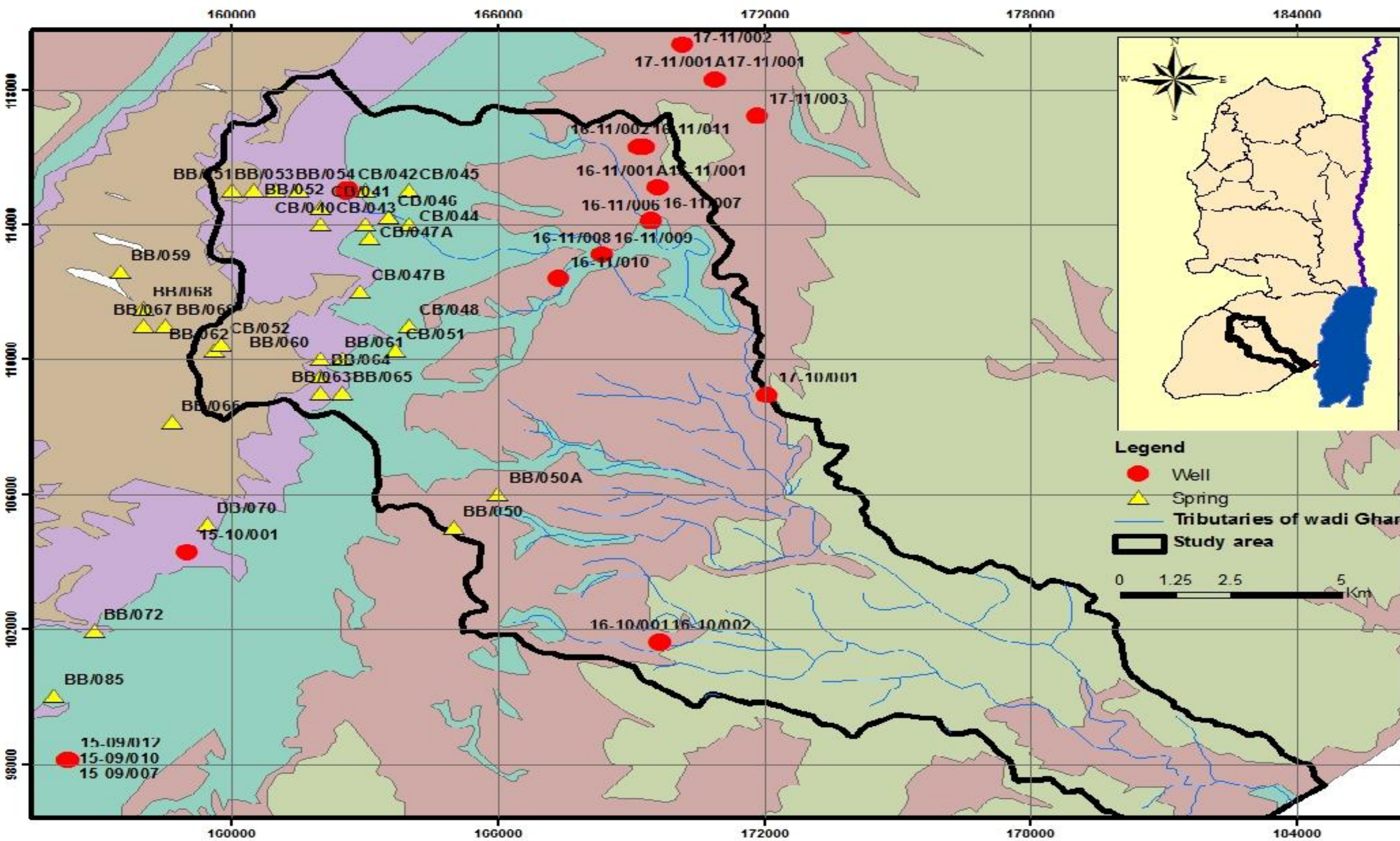


Figure (2.7): Wells and springs distribution overlaying the geological formations of Wadi Ghar.

Chapter 3

Previous studies

The following studies will focus on the techniques used in this study, applied in places all over the world.

1. Chloride Mass Balance (CMB)

D.L. Rudolph and others (2005) State that Chloride and environmental stable isotopes ^{18}O and ^{2}H have proven to be useful for quantifying infiltration due to their non-reactive behavior. They further add that the distribution of these tracers throughout the flow system can indicate the degree of interaction between surface water and shallow and deep groundwater, if each water source has a distinct concentration of tracers.

Stephan Moysey and others (2003) made a research in the USA about the $^{36}Cl/Cl$ ratio. They claimed that the main source of it in meteoric groundwater at the continental scale is the fallout of stable chloride from the atmosphere, which is mainly derived from oceanic sources. Atmospheric circulation transports marine chloride to the continental interior, where distance from the coast, topography and wind patterns defines the chloride distribution.

B. S. Sukhija and others (2003) studied the piston flow vs. preferential flow. What's interesting about this paper is the reference to the chloride technique concept. According to the researchers the environmental chloride technique provides information about the process of groundwater recharge rates by the environmental chloride profile method, based on the mass balance of chloride. Where in the total input of chloride through precipitation for a set of years is compared with the total soil chloride in the profile. Such a relation provides the long term piston flow recharge rate. The relation between input chloride and that in groundwater (chloride ration method) provides total recharge (piston flow + preferencial flow) to the aquifer because the preferencial flow component that bypasses the unsaturated zone is accounted for in the groundwater. The researchers also add that the assumptions in the chloride techniques are that the rainfall is the only source of input chloride (no other source or sink for chloride), steady state conditions exist in the profile/matrix and the area is flat with no lateral flow of groundwater to the sampling point. The paper further adds some information from study in comparison of chloride concentrations of groundwater and that in the soil profile elucidated piston flow or preferential flow.

2. Chloride/ Bromide Ratio

David F. Rugh. Thomas J. Burbey (2007) made a study on recharge using KBr and KCl salts as tracers. The study showed that only a small amount of Cl or Br where adsorbed to the soil. In the study only about 0.265% of Cl was released from the soil while 4.6% of the Br was adsorbed to the soil. The highest Br^- adsorption occurs at clay soil according to this study.

Jennifer L. Druhan and others (2007) study in Texas, USA found that the Br/Cl ratio in their study area is 4.600. This number comes due to, the exclusion of bromide during halite precipitation subsequent dissolution of halite results in aqueous Cl/Br ratio on the order of 1,000-10,000 and higher. The study states that high Br and low Cl/Br ratio are found in a variety of surface sources such as fallout from vegetation fires, leaching of chemical fertilizers, and decomposition of organic matter and oxidation of ethylline dibromide (a gasoline additive).

Chloride and Bromide have similar chemical characteristic. As a first approximation, both $Cl^-$and Br^- can be considered to be conservative in groundwater transport. However, this may not be strictly true, particularly for Br^-. Besides Bromide chloride ratio is not generally affected by changes in season (Neal & others, 2007).

Grant A. G. and others (2006) study in Canada, shows that Bromide, like Cl, increases in concentration with TDS. However, Br and Cl do not maintain a constant ratio in water with TDS greater than 2 g/L. In addition, it shows that the average Cl/Br ratio of sea water is 658 by molar ratio.

Sybille kilchmann and others (2004) made a study around the Alpine area. The study showed that the concentration of bromide in groundwater from carbonate aquifers is the highest compared to others but it was only surpassed by the molasse aquifer (this formation occurs along the Jura Mountains in western Switzerland and consists of gypsum bearing sandstone and marls with intercalated dolomitic limestone layers).

Bromide has relatively minor contribution to the composition of water, it's concentration in water depends primarily on the geochemistry of the materials in which water has come into contact. Most episodes of freshwater contamination leading to increased salinity probably occurres with contaminant increase of bromide. However, localized area, intensive application of brominates pesticides, e. g., the soil fumigant 'methyl bromide', can produce a major contribution to bromide levels. Not to mention leaching of greenhouse soil fluids after methyl bromide fumigation results in releasing elevated inorganic Bromine to the shallow ground-water concentration. As a result, the hydrolysis of methyl bromide in the soil gives a high Br/Cl ratio (Vengosh, 2002).

Extensive application of methyl-bromide as a pesticide in agricultural areas can affect the Cl/Br ratio in agriculture return flows. Although most of the applied methyl bromide (70 to

90 %) volatilizes to the atmosphere, the residual methyl bromide remaining in the soil degrades by methylation of organic matter and by hydrolysis, which releases Br to the soil fluids and the underlying aquifers.

Bromine in nature is one of the key halogens occurring mainly in the inorganic form of bromide. Although it is the 46th most abundant element in the crust of the earth, bromine is found predominantly as bromide in seawater and in brines (Neal & others, 2007). Natural bromine in water is most commonly in the form of the negative monovalent ion, bromide (Br-) (Davis, 1998b). The chemical characteristic of bromide is quite similar to Cl^-. Because of the chemical characteristic of the two elements, they provide complementary and commonly overlapping geochemical information. The ratio of Chloride to Bromide have been extensively used to detect the origin of the dissolved salts in ground water and brines since both from the stable anions of Cl^- and Br^- in water and are usually not affected by water rock interaction (Davis, 1998). Bromide ions generally appear in a constant ratio with chloride ions (Bathurst, 1980).

A large portion of [Cl^-] and [Br^-] in potable groundwater originates from:

a. Atmospherically transported material which falls as both wet precipitation and dry fallout
b. Dissolution of evaporates
c. Extrusion of brine from compacting clays
d. Diffusion of ions out of saline fluid inclusions and micro-pores
e. Expulsion of water through re-crystallization of minerals
f. Intrusion of sea water into coastal aquifers.

After a study done in Japan, it was concluded that Soil moisture content was the most important factor affecting bromide dissolution into the soil, which increased markedly under flooded condition (Neal & others, 2007).

Differences in preferential flow of water and Br were attributed to soil horizon thickness, soil texture and structure, macro-porosity, and slope gradient. Preferential; flow of water and Br under variably saturated conditions was found to be highly variable within a given soil profile and that differences between the distribution and magnitude of preferential flow occurred across topographic positions (Strock & others, 2001).

The ratios of Chloride to Bromide have been extensively used to detect the origin of the dissolved salts in groundwater (Davis, 1998). Br/ Cl mass ration in the Dead Sea is 10.45.

3. Stable Isotopes (^{18}O, ^{2}H)

A trusted natural geologic record of events is located in Greenland. Snow has fallen regularly and consecutively, for more than hundred thousand years there, without ever melting again. This has created a virtually unbroken sequence of layers that can be analyzed. The most renowned record of data was a result of the "North Greenland Ice Core Project" whose latest core published in 2004, is more than 3 km long and covers the last 123,000 years (J. Savino & M. Jones, 2008).

J. Long & others (2007) studied the Rapid Greek in south Dakota, USA. The isotope ^{18}O in the southern part of the study area have values heavier than -12‰, which generally represents stream flow and areal outcrop recharge occurring south of rapid creek. Values lighter that -12‰ generally represent stream flow and areal outcrop recharge occurring at the north of it. the study also suggested that the difference in isotopic signatures of sinking stream of the study area are the result of combination of altitude differences and the global area from which moist air travels to different sites.

Jennifer L. Druhan and others (2007) studied groundwater recharge and Salinization in Texas, USA. The study included an analysis of water sample collected above 200 m bellow ground surface, the isotope ^{18}O data was plotted vs. the GMWL line, the deviation was very pronounced and from that deviation the water was thought to be of brakish or salty in nature below 320 m fresh water was observed. The ^{18}O value didn't decrease with depth suggesting non-uniform mixing.

Ozyurt & Bayari (2007) have done a research in Turkey. The study included a graph that showed the correlation between ^{3}H, ^{18}O and Temperature. It is well observed in the graph that when the water temperature drops drastically below zero to around -20C^{o} the concentration of ^{3}H and ^{18}O in the water degrees drastically too and when the water temperature rises again the concentration of those to isotopes increases also. The study also states that ^{18}O increases in discharged water when there is more rainfall water mixing than snow.

Yuhong Liu and others (2007) completed a study in China. They claimed that if the temporal variability of isotopic composition in surface water was insignificant, indicating that water source supply of this surface water was, on the whole, stable. The study also emphasized the importance of stage melting of snow in isotopes fractionation. The longer melted snow contained more fractionated isotopes. The overlapping of isotopes analysis between the classier water on an altitude of 4,800 m (asl) and the groundwater was high indicating that the source of the groundwater in that particular study area derived from the glaciers. Fractionation always occurs during evaporation and may contribute to the variation of D and ^{18}O in surface water. Altitude is an important factor related to the isotopic fractionation in areas with large topographical range.

Charideh and Rahman (2006) made a study about the karst aquifer and submarine springs in Syria. The study states that the groundwater of major karst systems and submarine springs in the coastal limestone of Syria has been investigated using isotopic techniques.

Cuneyt Dilsiz (2006) conducted a study in Turkey about the relationship between isotopes and water temperature. The study showed that cold springs had less concentration of d and ^{18}O than that of the thermal springs. The main observation of the study was that the absences of the evaporation effect on the isotopic composition, meaning that the recharge of the reservoir is quite rapid and that the infiltrating water doesn't reside for a long time in the soil horizon.

I. B. Goni made a study in (2005) about tracing stable isotopes in Chad region. In the study he mentioned that a previous study made by Clark and Fritz (1997) have observed many deep artesian groundwater from arid regions that are characterized by depletion in ^{18}O and ^{2}H with respect to modern water.

Glynn & Plummer (2005) made a study about understanding groundwater systems. The paper discusses problems of research in hydrochemistry (1) obtaining representative information from groundwater systems. (2) Using groundwater tracers to understand groundwater flow and reactive processes. (3) Obtaining groundwater system age for various time scales. It also emphasizes the fact that isotopic data are useful in identifying sources of recharge to groundwater system and in tracing groundwater flow. According to the study ^{2}H and^{18}O have helped refine estimates of recharge and flow time scales, interpret the origin and mode of aquifer recharge, provide temporal and special information to aid the calibration of ground water flow models. Inert tracers can also provide direct information on the ground water origins, flow direction and residence time.

Stable Isotopes [^{18}O, ^{2}H] and Tritium ^{3}H – As Tracers in the oPT have a local meteoric water line (LMWL), based on analyses of surface water samples from the recharge area of Jerusalem and Ramallah mountains (Abu Dees Meteorological Station) which was done by the UFZ Isotopic Hydrogeology Department in cooperation with Al-Quds University (Khayat, 2005):
Gave the following equation: **$\delta\ ^{2}H = 8\ \delta\ ^{18}O + 19.5‰$ SMOW**

W. Bajjali (2004) made a study in Jordan near the Dead Sea. He studied the relation between ^{18}O and ^{2}H in that area. The result of the correlation was the linear equation [D = 8 ^{18}O + 10 ppm]. The deuterium excess parameter is defined in the study as [d = D – 8 * ^{18}O]. The precipitation throughout the eastern Mediterranean have shown a different correlation between the ^{18}O and ^{2}H, namely d~ 22‰. The Eastern Meteoric Water Line (EMWL) defers from the GMWL by strong deuterium excess due to strong primary evaporation. However, In a study about recharge areas in the Sultanate of Oman, M. Matter and others (2005), stated that the MWL established for southwestern Israel are $^{2}H = 5.8^{18}O + 8.6$.

If the isotopic data fits nicely with the regional meteoric water line (RMWL) then it evidently implies that groundwater is recharged by the recent atmosphere precipitation (Li, Zhang and Hou, 2007) the displacement of the data line from RMWL signifies that the water from a shallow aquifer had undergone evaporation during the recharge process. This was also confirmed by (A. Guendouz and others, 2005) where they made a full hydrochemical and isotopic research in Algeria. The result of the data analysis of the isotopes that were plotted against the GMWL was located below the line, evidencing an evaporated feature. The overall isotopic signature of these waters corresponds to that of rainfall which has undergone evaporative enrichment before or during infiltration through the Aeolian deposit.

J. Perrin and others (2003) made a study in Swiss Jura. The study involved the investigation of a karst aquifer. In the research they claimed that the inputs are dependent on the actual infiltration. Since evapotranspiration acts in a completely different manner depending on the areas vegetations cover (agriculture, forest, and desert). This process can increase the concentration of ions, influence the temperature of infiltrated water, or even change isotopic ratios.

J.Y.chen and others (2002), made a study in china where they discovered that isotopes separated in well water according to weight. The peculiar thing though, was that the heavier isotopes like ^{18}O was found in the upper younger layer (about 24 years old) while the lighter isotope D was found in the lower older strata of the water (more than 6000 years old). Primarily the heavy isotopes come from cotemporary rainfall and lighter isotopes come from ancient rainfall or other sources.

Ondra Sracek and Rigardo Hirata (2002) made a study on stable isotopes in Brazil. They suggested that a trend toward negative values down gradient of ^{18}O implies a probable recharge under colder climatic conditions. On the other hand, the study discussed the truthfulness of this information since in the tropical regions depleted ^{2}H and ^{18}O have been found, thus they do not necessarily indicate a cold climate. Lastly they added that other means of tracing where necessary to authenticate the values of ^{2}H and ^{18}O in tropical areas.

Alan E. Fryar and others (2001) stated that the differential enrichment of ^{2}H relative to ^{18}O during evaporation typically causes plots of ^{2}H versus ^{18}O to have smaller slopes than the GMWL; transpiration is non-fractionating. The researchers add that the isotopic fractionation increases with surface water residence time.

In a study made by Yechieli in (2000), there were some data collected from two different wells located near the southern part of the western side of the Dead Sea. From each well multiple samples of water were taken at different depth and Isotopes analysis of ^{18}O and ^{3}H were made. The first well (510) has been sampled from the depth of 9 to 30 m. on the average the fractionation of the ^{18}O increases with depth to change from -5.3 to -0.18 at 15m depth and then it becomes 3.29 at a depth of 30 m. While the tritium changes from 0.9 TU at 9 m to 6.3TU at a depth of 30m. The second well (501) shows similar results as well.

The isotope-ratio mass spectrometer (IRMS) has been used for the analysis of the stable isotopes in this study. It allows the precise measurement of mixtures of stable isotopes. The analysis of stable isotopes is normally concerned with measuring isotopic variations arising from mass-dependent isotopic fractionation in natural systems.

Stable isotopes can be used to determine the distribution of water and recharge rate and mechanism if the isotopic modifications of soil moisture are examined, as it infiltrates through the unsaturated zone to the aquifer (Selaolo, 1998).

Climatic variation causes water level and isotope concentration to vary over the yearly cycle (D. A. Reynolds, 2006). Climatic fluctuation can be established using the oxygen isotopes method. The methods concept release in comparing the relative abundance of ^{16}O and ^{18}O isotopes in air bubbles trapped in the Snow or ice. The abundance depends on the temperature of the cloud from which the snow has fallen long ago (J. Savino & M. Jones, 2008). Stable isotopes ^{2}H and ^{18}O composition of precipitation undergoes variation due to latitude, altitude, amount of rainfall, temperature, ect. (B. S. Sukhija and others, 2005)

Distinctive warm and cold periods called "Oxygen Isotope Stages" (OIS) have been established. In figure (3.1) the variation of oxygen in relation to cold and warm periods can be observed. The figure portrays the change in ^{18}O for the last 500 Myr.

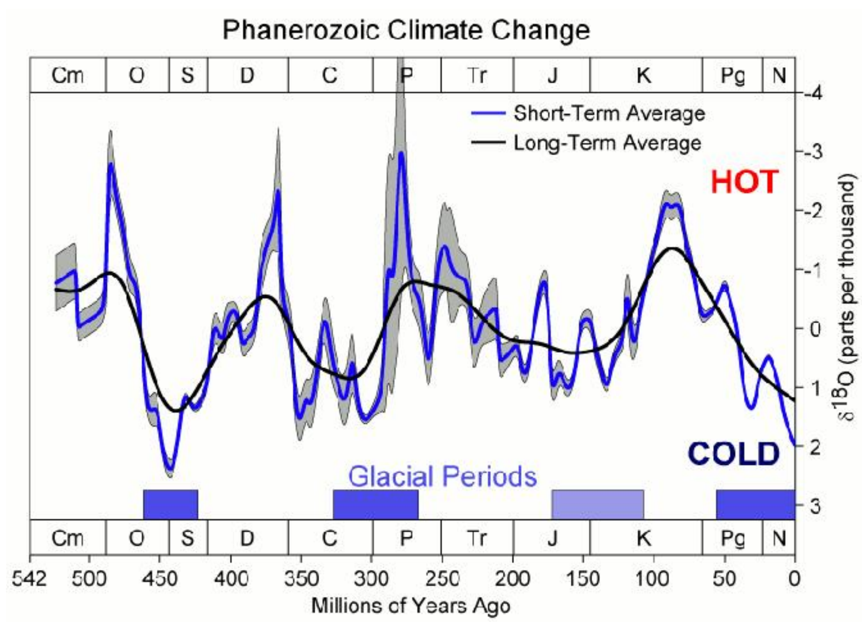


Figure (3.1): Effect of Phanerozoic climatic change on ^{18}O fractionation (Wikipedia the free encyclopedia – Oxygen & printable).

Figure (3.2), shows the ^{18}O and Temperature correlation in precipitation. Empirical observations do show that mean annual $d^{18}O$ values and mean annual temperatures are strongly correlated in the spatial domain.

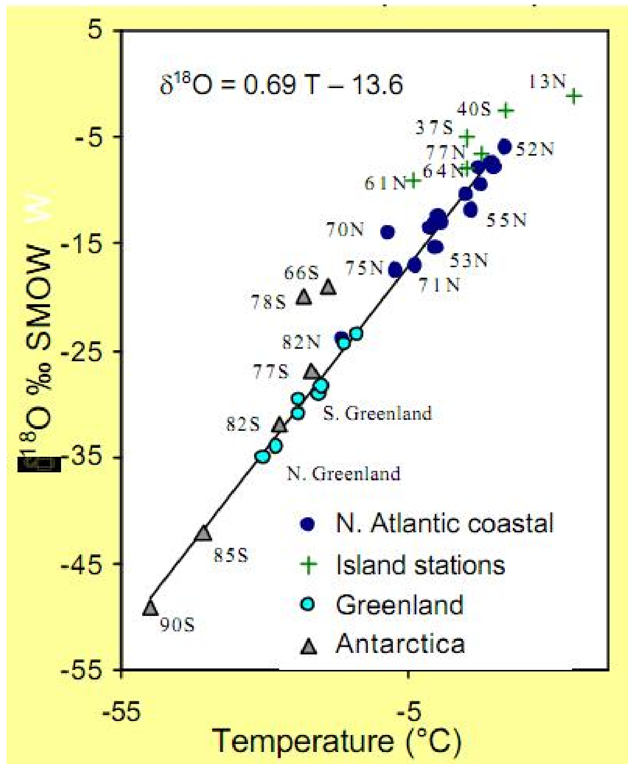


Figure (3.2): Shows the ^{18}O and Temperature correlation, in precipitation (Dansgaard, 1964)

Oxygen-18 stable isotope is used to identify the recharge process and mixing of groundwater from deferent sources. Surface water contains a distinct composition of stable isotopes due to enrichment caused by evaporation. Therefore, ^{18}O makes it possible to distinguish between evaporated water and water directly recharge from precipitation (B. S. Sukhija and others, 2005).

Isotope fractionation happens when the water molecules with deferent masses exhibit differing vapor pressure so that during a change of phase evaporation, condensation and sublimation, enrichment of heavier isotopes in the more volatile phase takes place. In some places, the higher temperature and low precipitation during the early rainfall of summer result in the enriched heavy isotopes content, and depleted heavy isotopes content of heavy rainfall during subsequent months of the summer (B. S. Sukhija and others, 2005). This case is particularly well observed in India where heavy rainfall season (monsoon) happens in summer.

Figure (3.3) shows the fractionation of ^{18}O in relation to altitude, for the Rainout and Rayleigh distillation.

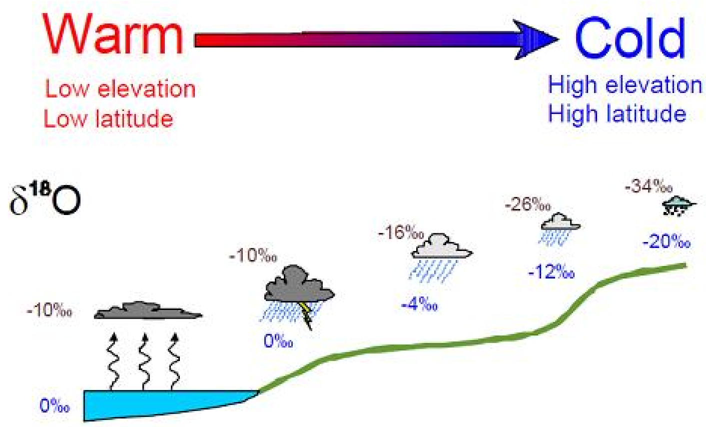


Figure (3.3): Fractionation of ^{18}O through altitude and temperature (Clark and Aravena)

The close relationship between deuterium and oxygen-18 in freshwaters, including precipitation, gives rise to the GMWL, the best-fit line (delta D = 8* delta ^{18}O +10) of all data points.

The concept of the deuterium excess (d) is defined as [d = delta D – 8 * delta ^{18}O]. This relationship is also well understood and can be reproduced by models based on the Raleigh approach. 'd' varies under non-equilibrium conditions, providing information not available from $d^{18}O$ or dD alone. 'd' mainly reflects kinetic fractionation occurring during non-equilibrium processes (such as evaporation above the ocean surface) due to the difference in diffusivity between heavy and light molecules. Generally thought that polar 'd' values contain information on meteorological conditions at evaporative source regions, such as sea surface temperature (SST) and humidity. Global mean d = 10‰ today, but large variability between different samples and environments (Dansgaard, 1964).

In addition to the phase changes under equilibrium conditions a kinetic effect results from a different diffusivity for the isotopically different water molecules in air. The higher diffusivity for $^{2}H^{1}H^{16}O$ as related to $^{1}H^{1}H^{18}O$ results in an additional separation, a higher deuterium excess.

Humidity relative to saturation at sea surface temperature and wind speed is the major controlling factors. Within-cloud processes do not modify significantly the excess as long as only the formation of precipitation is considered. The result is a clear seasonal response as the hemispheric GNIP data demonstrate.

The deuterium excess can be used to identify vapor source regions. Winter precipitation originating from the Mediterranean Sea is characterized by distinctly higher excess values, reflecting the specific source conditions during water vapor formation. Increased deuterium excess in precipitation can also arise from significant addition of re-evaporated moisture from continental basins to the water vapor travelling inland. If moisture from precipitation with an average excess of 10 ml is re-evaporated, the lighter $^{2}H^{1}H^{16}O$ molecule may again contribute preferentially to the isotopic composition of the water vapor and this, in turn, leads to an enhanced deuterium excess in precipitation (www. naweb.iaea.org).

The fractionation of ^{2}H versus ^{18}O relationship in precipitation can be used to unravel processes affecting rain water or soil moisture such as evaporation and mixing trends (Selaolo, 1998). Figure (3.4) shows the ^{2}H and ^{18}O trend line of annual and monthly precipitation.

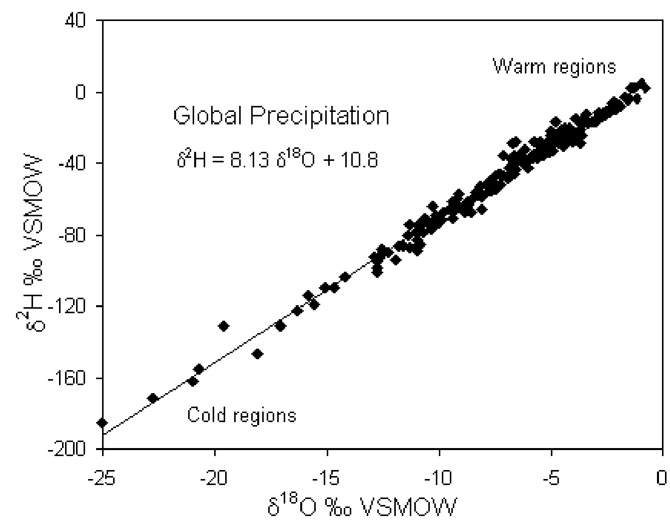


Figure (3.4): Global relationship between d^{18}O and d D in precipitation. Heavy dotting indicate the position of the GMWL [www.science.uottawa.caeihch2ch2.htm.gif]

In surface water body evaporates, enrichment of ^{2}H and ^{18}O will take place resulting in a ^{2}H-^{18}O slope between 4 and 6. Unsaturated, dry soil commonly shows a slope of 2 to 5 depending on the moisture content of the soil.

Furthermore a study in the early 80's suggested that it is unlikely that uptake of soil moisture by plants (transpiration) results in fractionation of ^{2}H and ^{18}O (Selaolo, 1998).

Selaolo in 1998, mentioned that the moisture fluxes below the root zone can be estimated from the displacement of ^{2}H isotopic values of soil moisture from the local meteoric water line. This technique enables estimates of the local recharge to be made particularly for low recharge conditions in semi-arid areas.

Chapter 4

Results and Discussion

The people settled in Wadi Ghar are some farmers in over 25 communities covering more than 17 Km^2 with a population of more than 65000 (PCBS, 2010). However, the residents in the lower section of the catchment are mainly Bedouins raising livestock. The main crops planted are grapes, olive trees and wheat; these are rain-fed crops that do not need irrigation and they are mainly distributed in the upper part to the middle of the catchment area.

The study area locates over the eastern slope, where water flow direction is towards the east due to the acute difference in slop (0.02). Since the slop is steep [1400m (elevation)/ 87000 m (distance)] it is natural that at some point there will be a natural discharge in form of springs in the Jordan valley/Dead Sea areas

The geologic structure of the area controls the groundwater flow direction, thus influencing to a certain extent the active supply of wells. Structural control elements serve to impede groundwater movement; this is the case of the Eastern Basin wherein most of the area, the non uniformity of the hydraulic gradient is caused by the head difference of 1400 m over a distance of more than 87 km between the basin's recharge area and the Dead Sea. Groundwater discharge happens in different ways; it occurs through pumping wells, spring flow and underflow to the Jordan Valley and the Dead Sea.

1. Surface Catchment Area of Wadi Ghar

Wadi Ghar is located to the southern middle part of the Hebron Governorate as shown in figure (4.1). Positioned over the Main Middle Mountains Chain of Palestine, with an area of 225 Km^2 and a length of 15 Km the difference in the elevation between the west highlands and Dead Sea level eastwards is more than 1100 m.

The surface catchment area has a fan – shape borders. The slope of the Wadi is considered to be steep about (0.02), changing from over 1000 m of altitude to - 400 m at its end point, the Dead Sea (calculated from the GIS database of AQU). The Wadi has very low to no vegetation coverage where mainly natural small spine- bushes cover the slopes; The soil covering the area is very dry and can be eroded easily since the area has a very limited vegetation cover as in Appendix A - (Figure 1).

Wadi Ghar is a rain-shadow desert which occupies the eastern slopes of Mountains. The mean annual rainfall decreases from about 600 mm in the western part to less than 200 mm in the east, this decrease in precipitation is accompanied by an average maximum temperature increase from 26 to 32 C^0 in August, and a minimum temperature in January (which is the coldest month) between 15 -12 C^0, respectively.

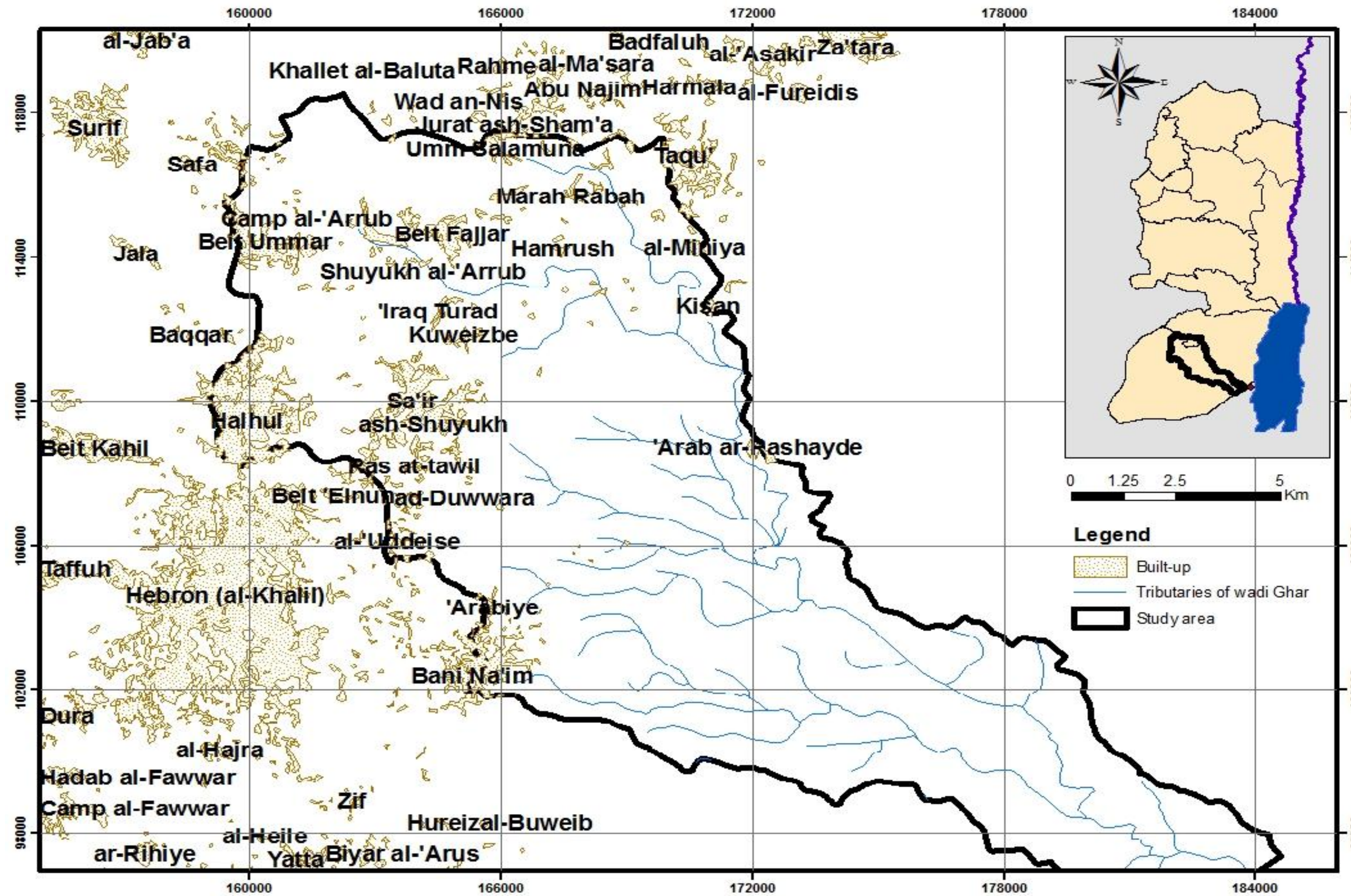


Figure (4.1): Surface catchment area of Wadi Ghar drainage system and major communities within.

2. Rainfall Collection

The rain gauges chosen were manual rain gauges. They are made of 150 cm hallow iron tube with a diameter of 7 cm. The head is a bullet-shaped piece of metal pierced in the middle holding a graduated glass tube of 300 ml. Figure (4.2) shows the rain gauge shape. The seven rain gauges where distributed in the catchment area according to figure (4.3).

The rain gauges are composed of three parts:

1- The first part is the bullet head. The head is pierced in the center to collect water. The top opening has a diameter of 2.9 cm and the bottom diameter is of 1.2 cm.

2- The second part is the 150 cm hollow tube holding the bullet head. The tube is filled with sand for support and stability.

3- The third component is the rainwater measuring tube attached to the bullet head. The tube is scaled until 300ml.

Figure (4.2): Manual rain gauge applied on the field within the catchment of Wadi Ghar

Using the manual rain gauge system, seven gauges were distributed over Wadi Ghar surface catchment as shown in figure (4.3). The gauges were distributed as equally as possible in the northern part of the catchment, but on the other hand they were lacking in the southern part of it, due to political restrictions.

Table (4.1): Rain Gauges station location coordinates and elevations.

No	Site Name	East	North	Elevation
1	PWA11	169190	116300	700
2	PWA1	167370	112390	700
3	Arab AlRashaeda	172070	108940	500
4	Bani_Naem 1	169660	101610	400
5	Shueikh Municipilaty	164179	109358	900
6	Beit Ommar	160312	114464	800
7	Halhul	159863	110134	1000

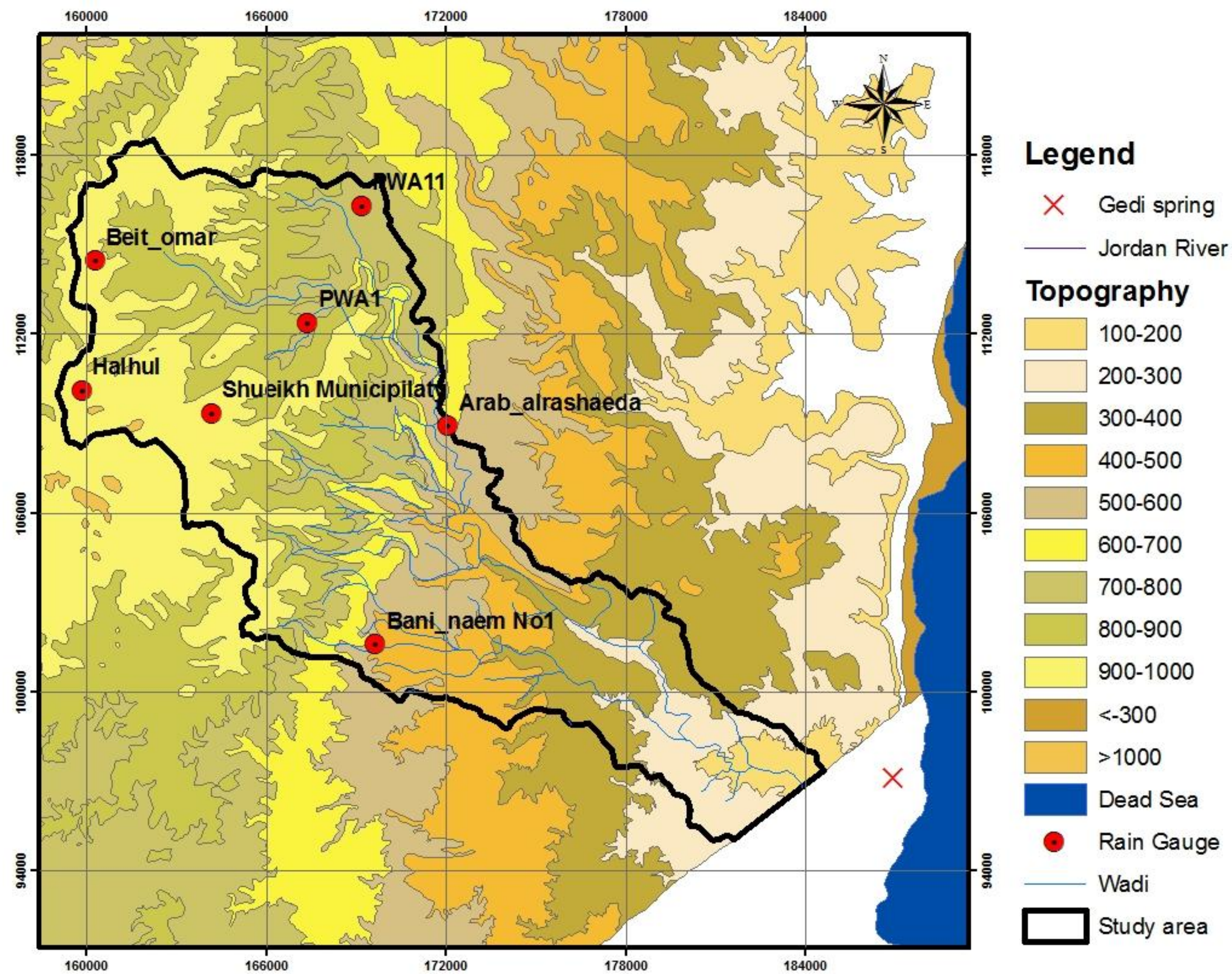


Figure (4.3): The distribution of rain-gauges over Wadi Ghar catchment area topography.

3. Rainfall Data:

The historical data of precipitation measurements of the Hebron Rain Gauge, located on 1005 m of altitude, has been brought together from the Millennium Engineering Group Report 1995 and Modified with recent data collected from the Palestinian Meteorological Department in Ramallah. The mean precipitation of the area is about 580 mm/yr.

Since the Hebron Governorate is located mostly on the upper side of the Mountains, with an elevation of 1000 m to 500 m as in Figure (4.3), the mean annual rainfall seems logical. The graph of the Precipitation measure in (mm) in Hebron station from 1970 to 2010, can be observed in figure (4.4).

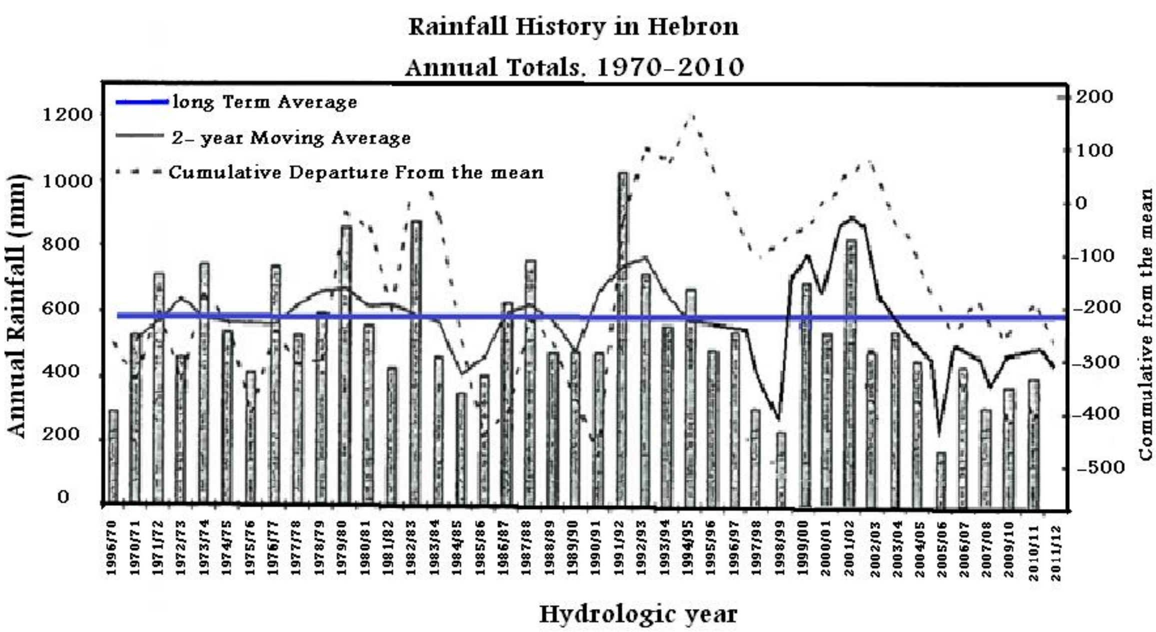


Figure (4.4): Complete rainfall history in Hebron from 1970 to 2010 [modified after Millennium Engineer Group, 1999 and the Palestinian Meteorological Department, 2011].

From the graph in figure (4.4) it can be observed that the absolute driest year in the last 40 years happened recently in the last 10 years laps, in 2006, where the precipitation amount was only 190 mm during the whole winter. On the other hand, the wettest year by far happened in 1992 with around 1020 mm of precipitation. The peculiar thing is that 1992 exceptionally high precipitation followed a dry period of 3 years, compensating for the deficit created by the dry years before and after it, thus keeping the average precipitation of its 10 years group close to the overall average of precipitation. In table (4.2), a more detailed precipitation description of the last 40 years is set in 10 years groups. The average of each group is calculated on its own, and the maximum along the minimum precipitation of each group is pointed out.

Table (4.2): Precipitation of the last 40 years divided in 10 year groups from 1969/70 to 2009/10.

GROUP 1		GROUP 2		GROUP 3		GROUP 4	
Year	**Precipitation (mm)**	**Year**	**Precipitation (mm)**	**Year**	**Precipitation (mm)**	**Year**	**Precipitation (mm)**
1970	***290***	1980	860	1990	470	2000	680
1971	510	1981	550	1991	465	2001	520
1972	700	1982	410	1992	***1020***	2002	***800***
1973	460	1983	***890***	1993	695	2003	465
1974	***740***	1984	425	1994	570	2004	525
1975	530	1985	***350***	1995	655	2005	460
1976	405	1986	400	1996	465	2006	***190***
1977	720	1987	620	1997	520	2007	430
1978	520	1988	750	1998	330	2008	300
1979	600	1989	465	1999	***250***	2009	400
Av.	**548**	**Av.**	**572**	**Av.**	**544**	**Av.**	**477**

From table (4.2), it is clear that the average precipitation for each 10 year group over the last 40 years falls around 550 mm. an exception is the last 10 years which fall below average by 60 to 70 mm. it can be concluded that 70's average is slightly below the total average, while the 80's -group 2- average is above the total average by a surplus of at least 20 mm. the following ten years (90's) slightly fall back in precipitation and create a deficit of about 5mm. However, the ten year lap creating the highest deficit in rainfall amounts of 70 mm is the 2000 to 2010 – group 4. Some scientist may attribute this decline in rainfall amounts to the worldwide climate change and global warming since other regions in the world have suffered from the same result.

Rainfall data was collected using the Manual rain gauges, Figure (4.2) and distributed throughout the catchment area as shown in figure (4.3). After each rainstorm the water conserved in the scale tube, inside the Gauge, was collected manually and the water sample conserved in 60 ml polyethylene Bottles for isotopes analysis. In table (4.3) the precipitation volume collected after the four major rainstorms occurred during that time, It can be observed, as in figure (4.5), in each specific rain gauge installed showing the distribution of rain over the rainy season in 2010/2011.

The data collected using this method, was demonstrated to be unsuccessful due to multiple reasons:

1. The location of rain gauges is very far apart, thus the collection of samples was inefficient in Time and Transportation Cost.
2. The collection of samples requires 1 to 2 days of collection after the rainfall event, leading to significant amounts of evaporation.
3. The Gauge structure is fragile, and the scale tube inside was broken multiple times in different locations since it was made of glass.
4. The rain precipitation during 2009/10 has been lower than average and so not much amount of sample was collected in the different rain gauges.

5. The study area has low number of residents – as in figure (4.1) – thus the position of the Gauges were not as ideal as desired, instead secure locations like PWA's Wells were chosen for safeguarding of the gauges.

Table (4.3): Rainfall data collected on the field from the Rain gauges in 2010/11.

Date	Rain Gauge Name	Precipitation (mm)
22/9/2010	Arab Rashaydeh	No data
22/9/2010	PWA 11	No data
22/9/2010	PWA 1	No data
22/9/2010	Al-Shiyukh	10
22/9/2010	Bani Nuem1	No data
22/9/2010	Halhul	No data
22/9/2010	Bet Ommar	15
***	***	***
13/2/2011	Arab Rashaydeh	41
13/2/2011	PWA 11	51
13/2/2011	PWA 1	60
13/2/2011	Al-Shiyukh	49
13/2/2011	Bani Nuem1	40
13/2/2011	Halhul	34
***	***	***
3/3/2011	Arab Rashaydeh	73.5
3/3/2011	PWA 11	110
3/3/2011	PWA 1	101
3/3/2011	Al-Shiyukh	97
3/3/2011	Bani Nuem1	58
3/3/2011	Halhul	53
3/3/2011	Bet Ommar	110
***	***	***
5/4/2011	Arab Rashaydeh	Broken
5/4/2011	PWA 11	0.5
5/4/2011	PWA 1	0.5
5/4/2011	Al-Shiyukh	0.5
5/4/2011	Bani Nuem1	0.5
5/4/2011	Halhul	Broken

Figure (4.5) shows the graph of Precipitation volume during rainy season of 2010-2011.

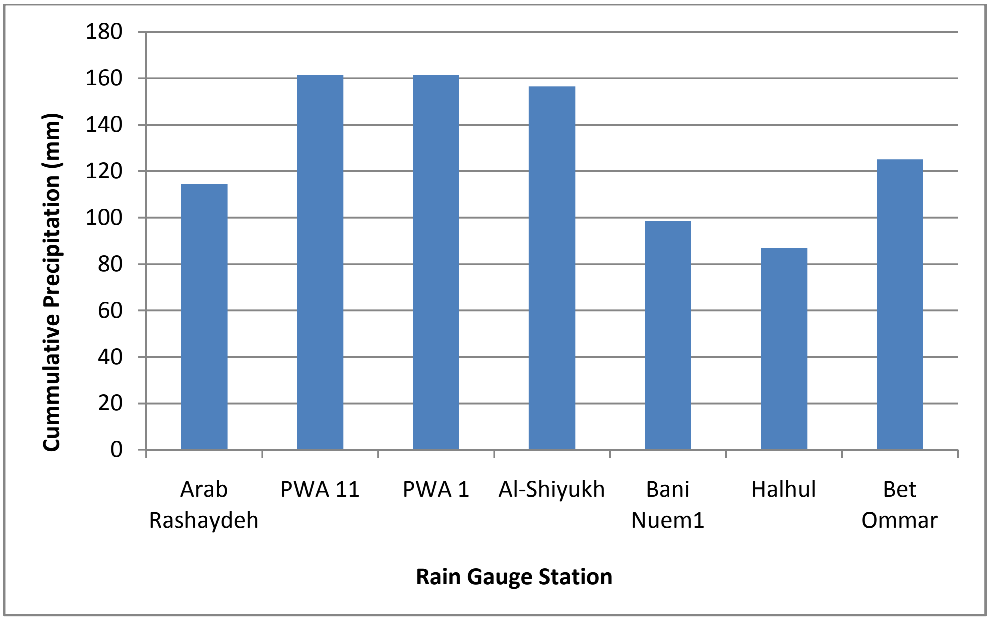


Figure (4.5) showes the cumulative presipitation of all the rainfall events collected during (2010/2011) in (mm) versus their Rain Guage station**.**

From figure (4.5), it can be observed that the higher cumulative rainfall events happen in the northwester part of the catchment over the area where PWA1, PWA11 and El-Shiyukh are located with a cumulative amount of 160mm for each one. While to the south western direction of the catchment the rainfall fall amounts are definitely lower falling below 100 mm.

Due to the multiple problems that arose from using the manual type of rain gauge, guaranteed data from the ***Palestinian Meteorological Department*** has been used for the calculations.

The rainy season started in December 2010 and lasted until April 2011. The rain storms where distant in occurrence but heavy in rainfall. The figure (4.6) shows the quantity of rainfall during the rainy months from September 2010 until April 2011.

The PMD data provides a detailed rainfall summery of the West Bank precipitation. Each rainfall is recorded separately and the collective rainfall volume is then given. Figure (4.6) shows the distribution of rainfall throughout the winter (rainy months) of 2010/2011.

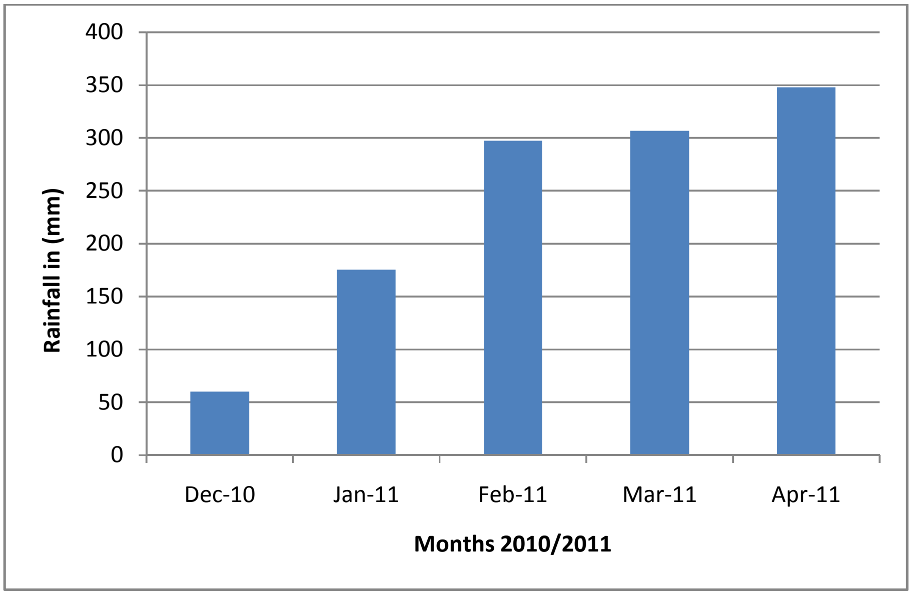


Figure (4.6): The amount of rainfall through the rainy season from December 2010 to April 2011 (cumulative for each month).

The values obtained by the PMD station in Hebron show that the actual cumulative amount of rainfall was at its lowest in December with less than 50mm and peaked in April with 350 mm, which is quit unusual since the highest rainfall in average happens in February. The total amount of rainfall that year is estimated to be 1180 mm which is almost the double of the average yearly precipitation making 2010 a 'wet year'.

Figure (4.7), was created using GIS program 9.3, at Al Quds University GIS laboratory. The figure represents the amount of precipitation over the surface catchment area of Wadi Ghar. From the figure it can be observed that the highest precipitation rate of about 550 mm happens in the highest point of the catchment with an altitude of 1000 m and degreases to 400 - 500 mm in the upper section. Whilst the middle section of the catchment has an average between 400 to 360 mm of precipitation and continues to decrease gradually toward the end reaching 320 mm. However the furthest end part of the catchment, the Dead Sea, has precipitation average of less than 120 mm.

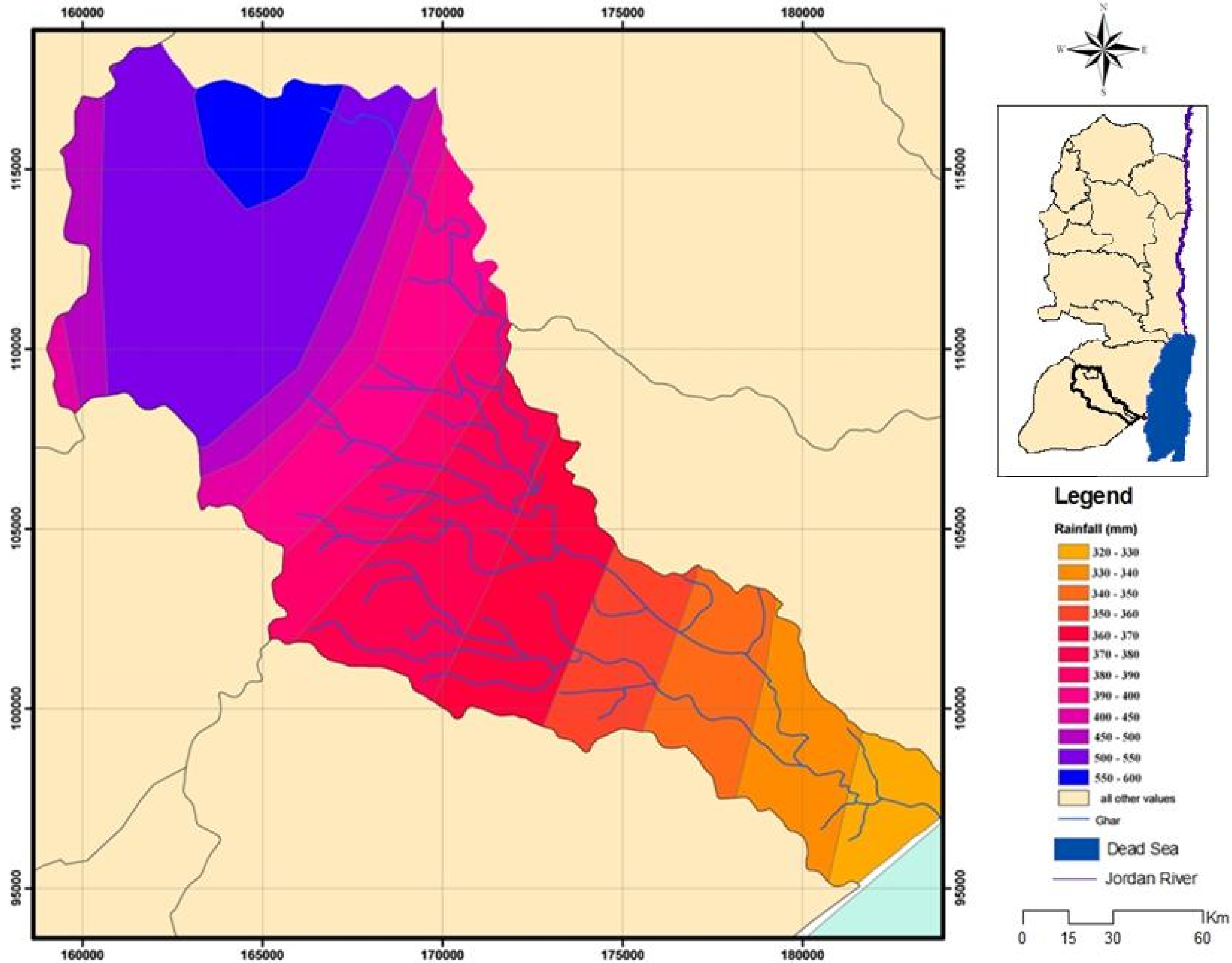


Figure (4.7): Simulated isohytal map of rainfall distribution over Wadi Ghar surface catchment area.

4. Isotopes Data:

There were two sampling campaign carried out during the study span. The first set of samples that were analyzed where taken from rainwater samples from the distributed rain gages across the study area. In addition, groundwater samples from wells around the area of Wadi Ghar were also collected for isotopes analysis of ^{2}H, ^{18}O and ^{3}H. Table (3.1) provides a list of the Rain gauges installed and there ^{18}O analysis.

Table (3.1): Shows the results of isotopes analysis for the first set of data collected.

Sample Name	East	North	Altitude (m)	d^{18}O (‰) average
Halhul rain gauge rain-water	159863	110134	1000	-6.8
PWA1 rain gauge rain-water	167370	112390	700	-5.2
PWA11 rain gauge rain-water	169190	116300	700	-5.5
Arab Rashaydeh rain gauge rainwater	172070	108940	500	-4.4
Bet Ommar rain gauge rainwater	160312	114464	800	-6
Bani Nuem rain gauge rainwater	169660	101610	450	-3.6

Figure (3.1) shows the relation between the isotopes result of ^{18}O analysis from the rainwater of the rain gauges distributed over the catchment area and the altitude on which the gauges have been installed.

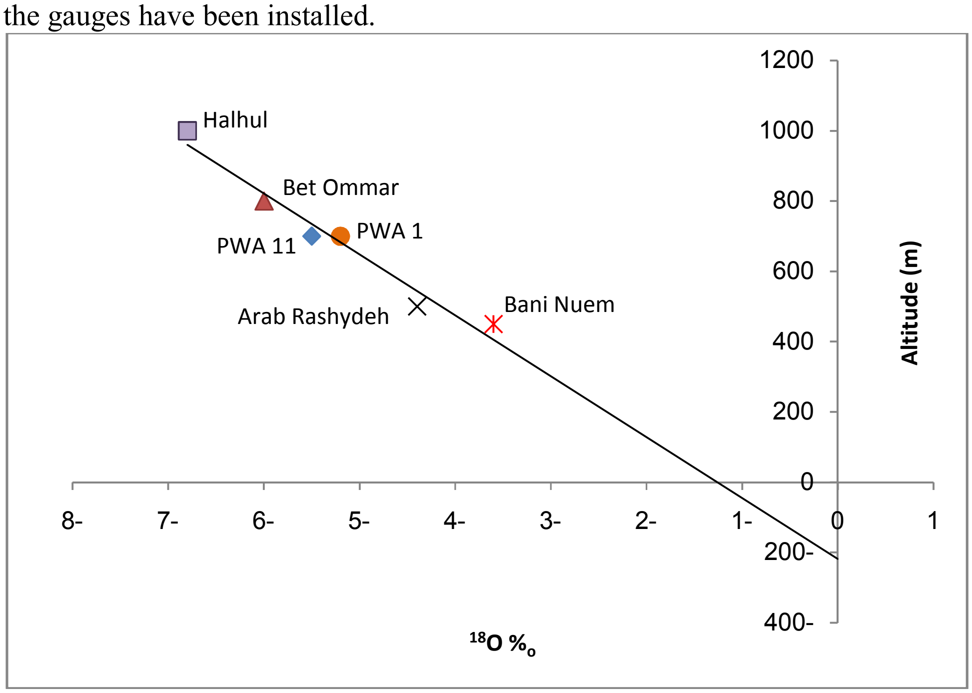


Figure (3.1): The correlation between $^{18}O‰$ of rainwater and altitude of installed Rain Gauge.

Yuhong Liu and others (2007) stated that higher altitudes correlated to lower values of both D and ^{18}O. This theory was also supported by a study made in Cyprus (Boronina A, 2005). Rainwater has lower values of D and ^{18}O because of its distance from the ocean and rain at higher elevation. Present day average precipitation value of -9‰ ^{18}O concentration is indicated in this study of Jennifer L. Druhan and others (2007), Texas. Such water may have infiltrated recently during winter front or a tropical depression.

The data plotted in figure (3.1) is distributed in accord to the theories mentioned in the previous studies, Where the higher the rain gauge, the lower the ^{18}O‰ in it. Halhul station which is the highest about 1000 m of altitude had the lowest ^{18}O of about -7 whereas Bani Nuem has the highest value of -3.6 over an elevation of around 450 m. The slope of the linear equation of the graph has been calculated to be 100 for the equation.

The isotopic data in Figure (3.2), show that ^{18}O increasing with decreasing altitude in Rainwater, Besides, the ^{18}O content in rain water is clustered around the -7 to -5‰ in the upper to the middle of the catchment, which is very close to the print found in water fallen at relatively moderate altitudes with short rainfall events that have an ^{18}O of -8.2‰ in general (Li, Zhang and Hou, 2007). Furthermore the evaporation rates of 50 - 200 mm/month and relative humidity of 75% causes a shift in values of ^{18}O by <1‰ (Alan E. Fryar and others 2001).

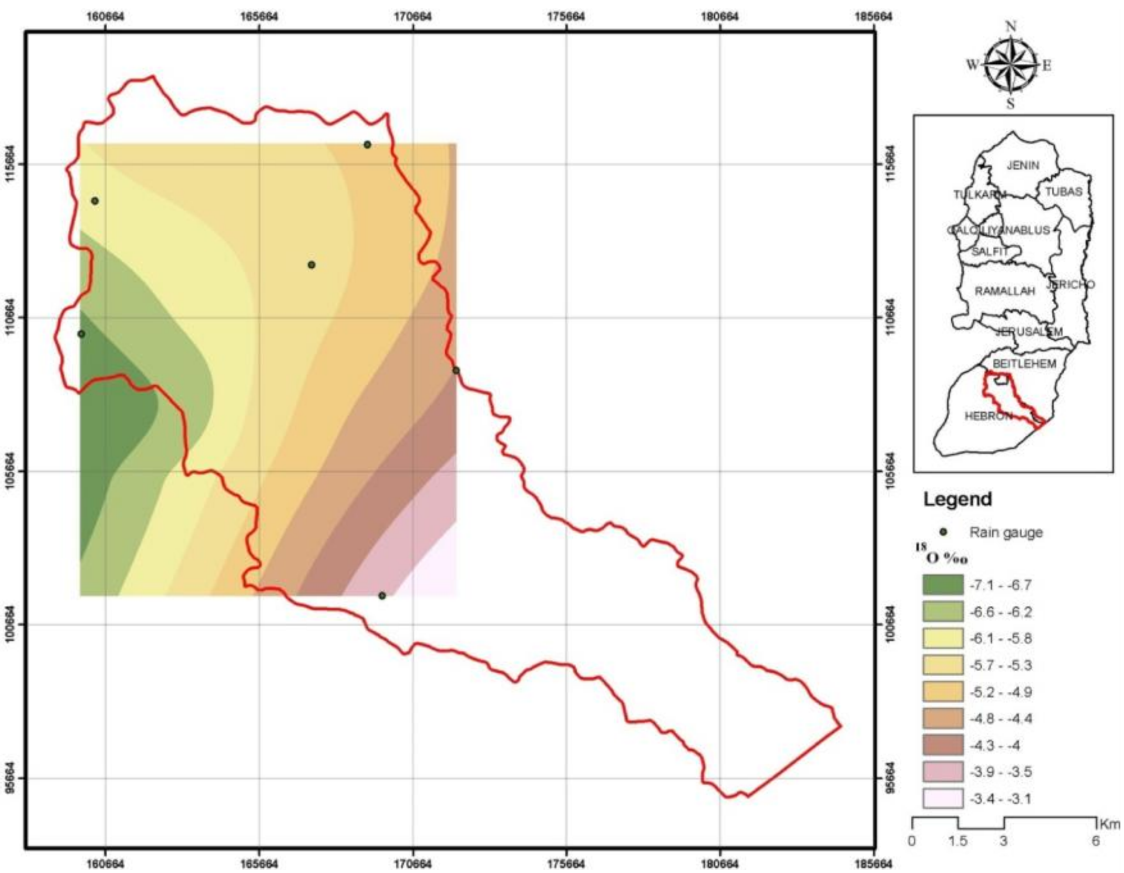


Figure (3.2): 18- oxygen distribution from rainfall over the catchment of Wadi Ghar.

Table (3.2) shows the isotopes values of the groundwater collected from wells around the study area. Samples were analyzed for ^{18}O and D, and the results were plotted including the rainwater analysis as shown in figure (3.3).

Table (3.2): Analysis results for isotopes of groundwater samples collected.

Well Name	Well Depth (mbgs)	EC (µS/cm)	TDS (mg/l)	^{18}O	^{2}H	d-excess
BN2 - PW	950	553	276.5	-5.3	-22.9	16
Bet Fajar well	237	-	-	-5.8	-26.9	19
Bet Fajjar	305	586	293	-6.0	-26.2	21
BN2	450	561	280.5	-5.9	-27.7	19
Rashadya	500	-	-	-5.8	-28.2	18
Herodion (1)	350	453	226.5	-5.9	-26.6	20
Herodion (2)	731	703.4	351.7	-6.2	-26.6	22
Herodion (3)	800	268.3	134.15	-6.2	-26.0	22
Herodion (4)	691	598	299	-6.1	-26.7	21
PWA 1	600	552	276	-6.2	-25.9	22
PWA 11	851	765.2	382.6	-6.1	-26.9	21
PWA3	741	-	-	-5.7	-22.9	23
Izzariya (1)	827	996	498	-5.9	-26.6	20
Izzariya (2)	793	793	396.5	-6.2	-26.6	22
Izzariya (3)	835	835	417.5	-5.8	-24.1	19
Al Fawar (1)	100	577.28	288.64	-5.9	-24.0	20
Hundaza	672	546	273	-6.1	-29.0	21
JWC 4	788	513	256.5	-6.2	-26.7	22
Al Rehea	495	409	204.5	-5.9	-23.8	20
Al Samoua	191	545	272.5	-5.6	-23.5	18

Figure (3.3) shows the plot between the linear relation of ^{18}O and ^{2}H in the analyzed samples in table (3.2) in addition to the results of ^{18}O Rainwater. On the other hand, Figure (3.4) shows the plot of ^{18}O and ^{2}H for groundwater samples only and its linear equation.

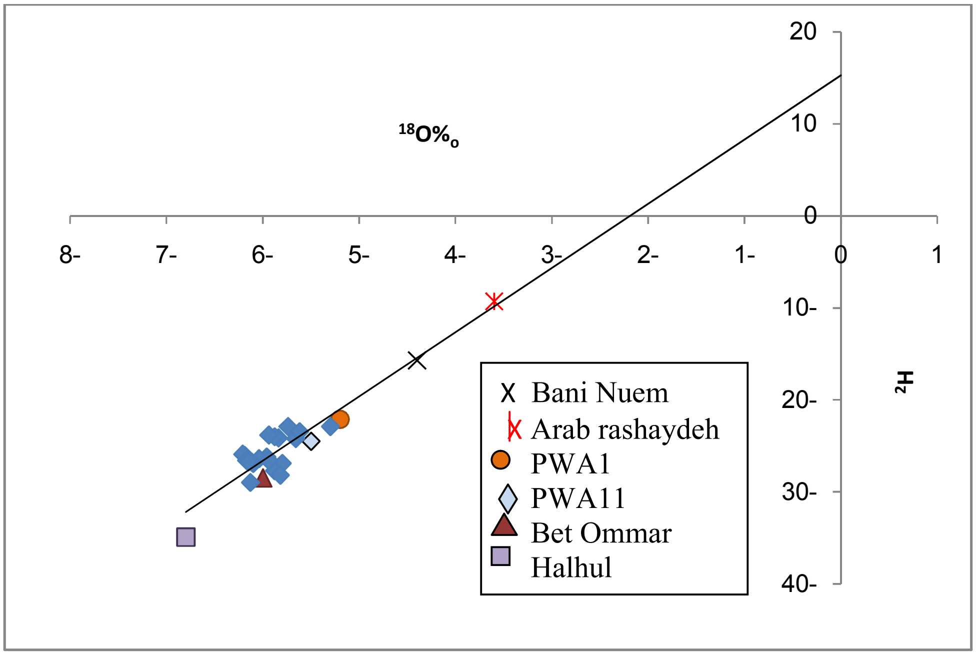


Figure (3.3): Plot of ^{18}O vs. ^{2}H for the groundwater and Rainwater

Jennifer L. Druhan and others (2007) studied on groundwater recharge and Salinization in Texas states that the deeper water with lighter ^{18}O and ^{2}H values is older than the shallow water associated with modern recharge.

Soil and subsurface water inherits the isotopic characteristics of the meteoric and surface water input, and change in isotopic composition occur as a result of recharge process and mixing with water of deferent composition. In a semi-arid zone (like Wadi Ghar study area), the water loss by evaporation gains its importance since that heavy isotopes content of groundwater gets enriched relative to that of precipitation (B. S. Sukhija and others, 2005).

According to Charideh and Rahman (2006), the ^{18}O values of groundwater range from -6.8 to -5.05%$_o$, while those for submarine springs vary from -6.34 to +1.08%$_o$ (Eastern Mediterranean seawater samples have a mean of + 1.7%$_o$). The study aquifer is Cenomanian Turonian which is similar to the aquifer in our study area. The same study also focuses on the variation of ^{18}O in rain water, at the beginning of the rainy season, October and November, and the end of the rainy season, March and April, which are characterized by relatively lighter rainfall with enriched ^{18}O values and exhibits 'amount effect' (a process whereby the isotopic composition of samples from lighter rainfall is more enriched than that of samples collected from heavy rainfall). This was proven by the fact that most isotopically depleted rainfall samples in the study were those collected during the major rainy season (December, January, and February). This result is very close to the results obtained in this study for rainfall, where the rainy season is also from November to April with major heavy precipitation in December, January and February.

Charideh and Rahman (2006) researchers further add that the relatively high deuterium excess "d", (d = $^{2}H - 8 * {}^{18}O$) is a typical property of Mediterranean precipitation, where the value of ^{2}H excess are significantly higher than 10‰. It also shows the equation representing the coastal meteoric water line in Syria given as: D = 6.00 ^{18}O + 4.6. The study shows that the altitude effect on fractionation is -0.23‰ per 100 m. In addition, the observed relatively enriched composition of the coastal aquifer (upper cretaceous suggests a much lower mean elevation of recharged zone). A graph in the study shows that there is a positive relation between the ^{18}O and the Cl concentration in the sampled water. Since wadi Al Ghar is not very far from the Mediterranean and is very close to the Dead Sea (about 15Km from the upper point) the Cl relation to the isotopes value can be considered as relevant.

Daniel H. and others (2006) made a study in Kras region (Italy/ Slovania). In this study analysis of ^{18}O was made on a certain well 1-4 times a day for 5 weeks. A graph in that study showed that when the rainfall increased about 20 mm the ^{18}O increased about 1‰. The same correlation has been made with an increase in rainfall of 60 -70 mm, with an ^{18}O increase of 1.2‰ which is not much deferent from the previous increase. On the other hand, the ^{2}H increased as far as 8‰ for the same amount of rainfall. This asserts that there is a strong correlation between the amount of rainfall and enrichment of groundwater with ^{18}O and ^{2}H. The isotopes will deplete with intensity of rainfall because the evaporation decreases.

Figure (3.4) shows the relation between ^{18}O and ^{2}H in groundwater only. The importance of this graph in comparison to Figure (3.3), derives from calculating the linear equation of the points.

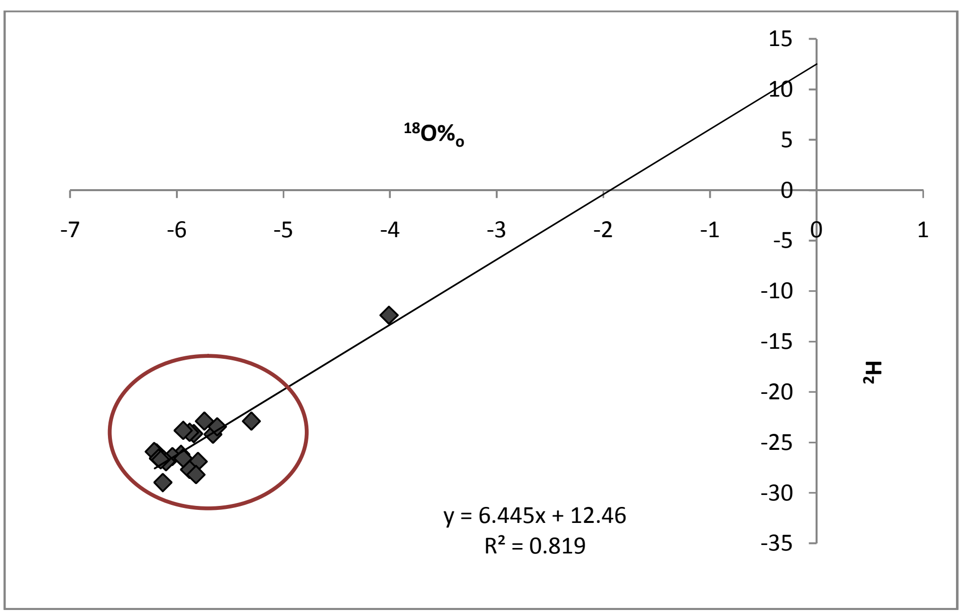


Figure (3.4): Plot of ^{18}O vs.^{2}H for the groundwater sampled from wells

Xianquan Li, Li Zhang and Xinwei Hou (2007) conducted a study in China. The analysis of the groundwater samples showed that the most depleted water in that area about -11.5‰ indicated the largest rainfall event in region and/or groundwater infiltration at higher elevation. The most enriched water with ^{18}O was about -8.2‰ indicating a lower elevation and/ or short rainfall events.

Accordingly the results of B. Yehdegho and P. Reichl (2002) conducted in Simmering Massif, Austria, show a considerable difference in the ^{18}O content that was observed in the carbonate spring of the study area. The value ranged from -11.49 to -10.39‰ because of karticity rapid infiltration. Furthermore, the study added that a ^{2}H signature of -49‰ and an ^{18}O signature of -7.3‰ represent relatively modern recharge conditions (Ondra Sracek and Rigardo Hirata, 2002).

None of the samples either from rainwater Figure (3.3) or groundwater figure (3.4), have an ^{18}O signature close to 1.7‰ which is the characteristic of water originating from the sea. Furthermore, this implies that the rainfall has crossed a relatively long distance from the Mediterranean Sea before precipitating on the Hebron-Jerusalem Mountains in addition to the 'shadow of rain' position of the al Ghar catchment. In addition precipitation happens mostly through the cold winter months of December through February, and it has been proved –in previous studies- that the relation between ^{18}O and D concentration in relation to temperature is inverse. Thus, the relatively low concentration of these two isotopes is also due to the cold temperature during rainfall precipitation in winter and also the high intensity through short periods of time precipitation.

The groundwater in figure (3.4) shows that the water samples have a value of ^{18}O mainly between -5 and -6.5‰, this value indicates that water resides in a karst aquifer with a main rock formation of limestone.

According to Charideh and Rahman (2006) the enrichment of ^{18}O and the percentage of freshness of water has a negative linear relation, meaning that the more the water is enriched with ^{18}O the less it is fresh. The higher the ^{18}O value the less fresh is the water, thus comparing the groundwater ^{18}O values of -5 to -6.5‰ with the Dead Sea ^{18}O value of 4‰ it can be supposed -with a high degree of confidence- that the water has a fresh character rather than a saline or brackish one.

From figure (3.4) the slope value of the linear line correlation is 6.5. water infiltrating dry soil and penetrating to the below aquifer has a slope of 4 to 5 when ^{18}O values are plotted against D values. The slight deference between this study result (6.5) and the correlated values implies a precipitation infiltration through dry to semi dry soil, since both values are so close. This can indicate that there is no direct contact with the aquifers water and the Dead Sea water.

J. Perrin and others (2003) made a study in Swiss Jura Evapotranspiration can cause ^{18}O enrichment of around 1.2‰ in rain compared to the water collected from the lysimeter in the study area. When the data of ^{18}O has low temporal variability it indicates that the water circulates slowly in the unsaturated zone. ^{18}O is also the only non-reactive parameter with an evenly distributed input.

However, it can be noticed that the largest portion of the groundwater ^{18}O values fall under the same signature of rainfall collected from Halhul, PWA1, PWA11 and Bet Omar between -7 and -5 as in figure (3.5). This indicates that most of the infiltration of rainfall to the underlying aquifer happens in the upper part of the catchment area as in the upper part of the mountains.

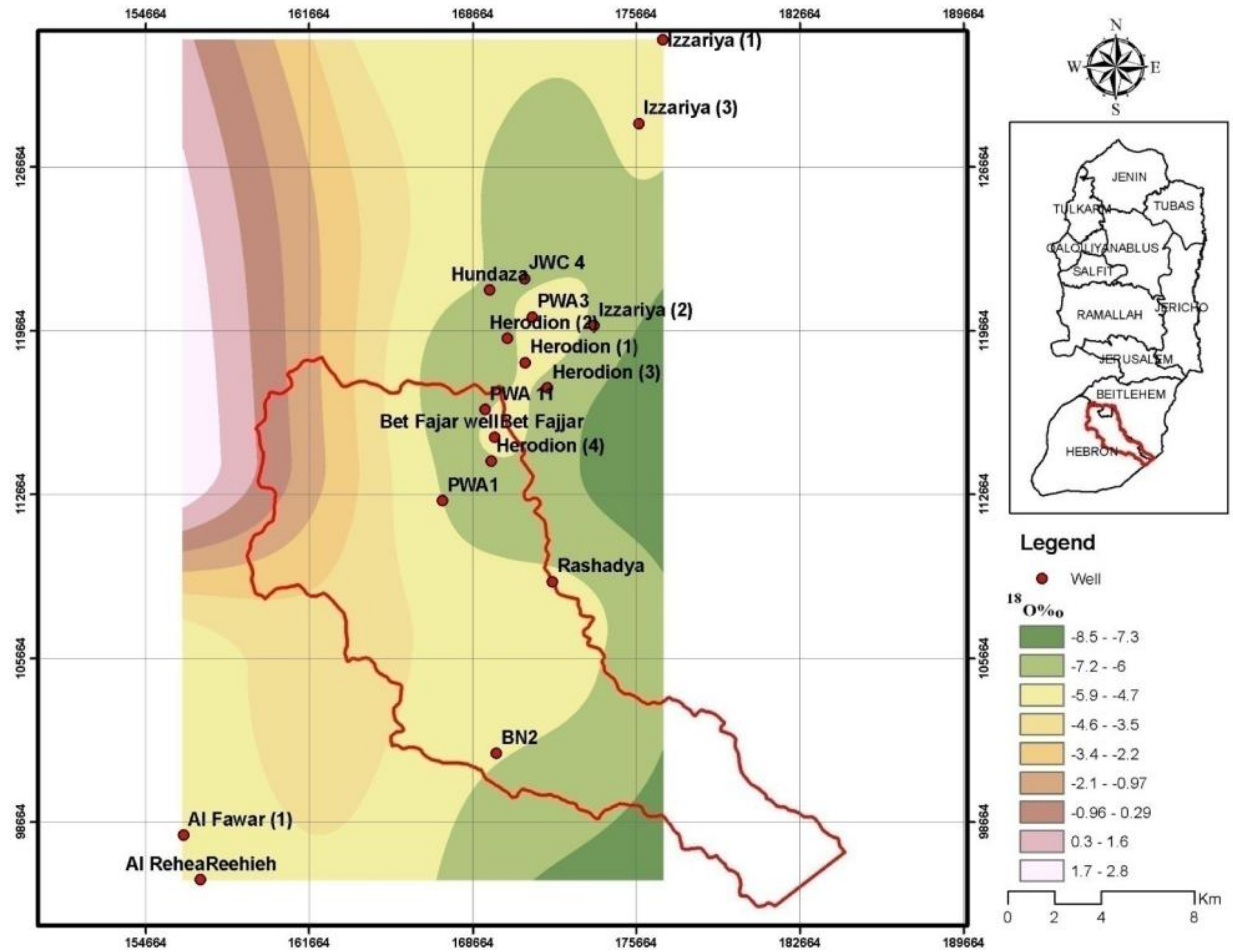


Figure (3.5): 18- oxygen distribution from groundwater over the catchment of Wadi Ghar and surrounding area.

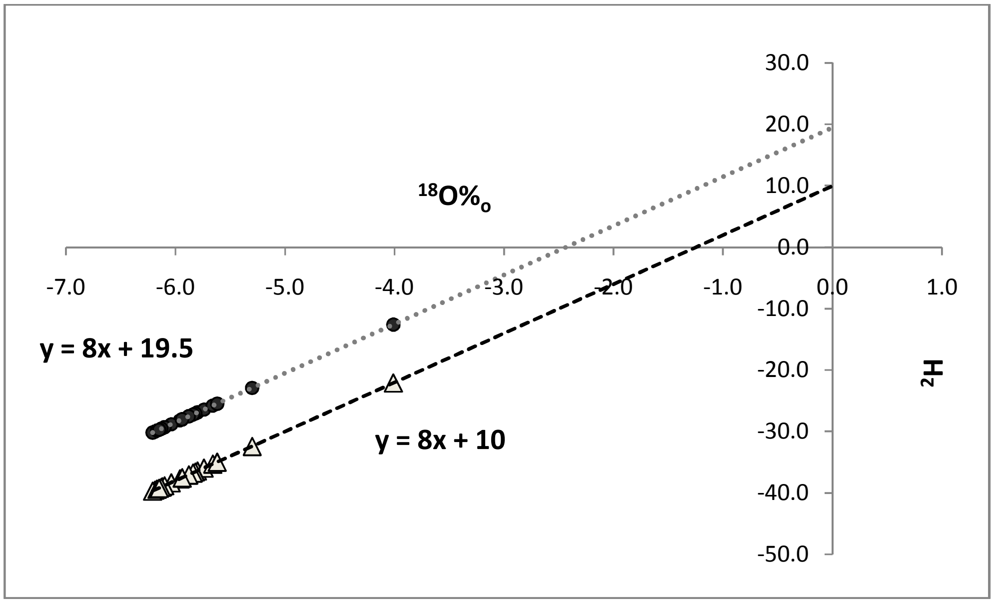


Figure (3.6): GMWL [in triangular markers] vs. RMWL [in round markers] graph and there respective linear equations of the data obtained from the isotope analysis in Wadi al Ghar.

The X factor of the linear equation in the plot of figure (3.4) is about 6. This number indicates that evaporation may have happened to the water since the X factor of rainwater's linear equation is usually 8. The 2 units of displacement between eight and six support the opinion of longer residence time in percolation of the water infiltrating through the strata to reach the aquifer. This theory is further sustained by the graph of the GMWL versus the RMWL in figure (3.6). It is clear that the RMWL is displaced further than the GMWL. The displacement in a perfect parallel trend signifies the occurrence of evaporation in the shallow aquifer during recharge process.

The water age is categorized with isotopes prints, thus, the modern water is characterized by an ^{18}O signature of -7.3%$_o$, the groundwater ^{18}O%$_o$ beneath Wadi Ghar is mostly enriched with -5 to -6.5%$_o$ meaning that the water is somehow sub-modern (over 60 to 100 years). Likewise, the D signature of modern water is -49%$_o$ and the groundwater sampled has a D value of -24 to -28%$_o$ fortifying the previous deduction of sub-modern water.

A study made by Grant A. G. and others (2006) in Canada summarizes the following relation between TDS, isotopes and water type. 1) A poorly characterized high TDS, high ^{18}O water which represent basin brine. 2) Low TDS, high ^{18}O water consistent with modern recharge. And 3) low to intermediate TDS water with low ^{18}O values related to sub-glacial recharge.

In Figure (3.7) a plot between the TDS and ^{18}O of the groundwater is plotted. Most of the points concentration is on medium TDS (between 400 and 600 mg/l) and an ^{18}O value of -5.9 to -6.2 which is considered relatively enriched. Thus in referring to (Grant, 2006) the closest result is modern recharge with low TDS and High ^{18}O, but since this study's results are both medium then the groundwater can be described as sub-modern with a slight mixing of modern water.

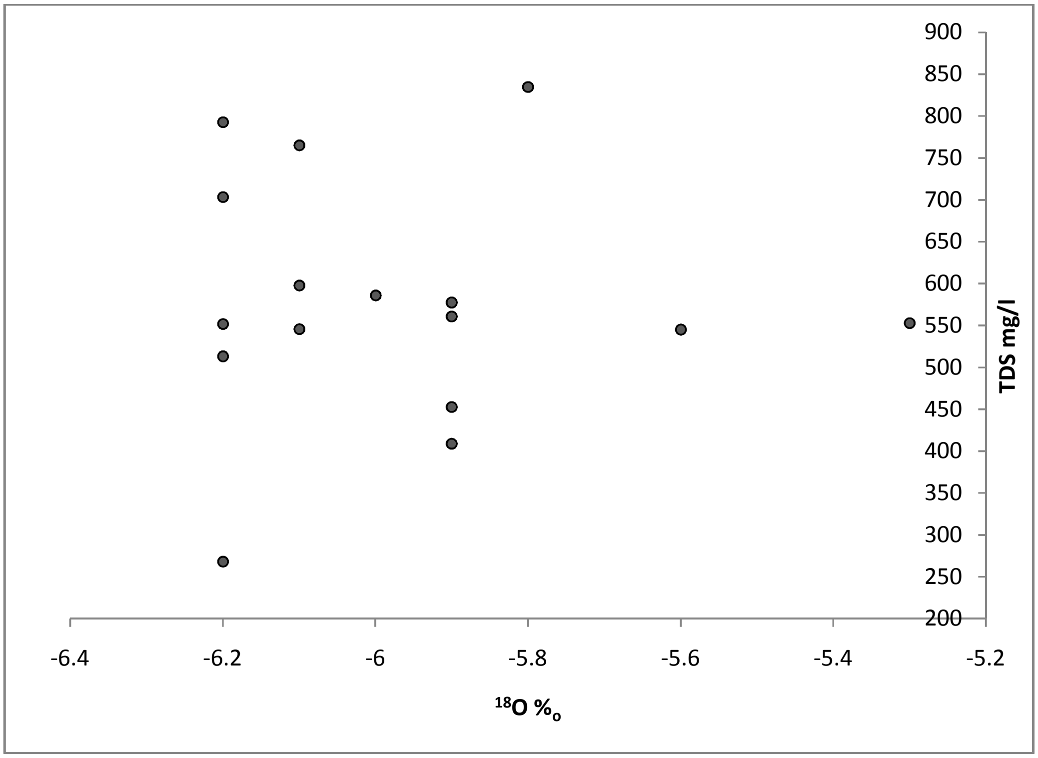


Figure (3.7): Relation between TDS and ^{18}O concentration in groundwater in catchment and surrounding area.

This graph also confirms that the recharge happens in the higher part of the catchment since the isotopic signature of ^{18}O in the groundwater still falls under the rainfall values of PWA1, PWA11, Halhul and Bet Omar as in figure (3.5).

5. Tritium data

According to (Kendal and Fritz) the distribution of tritium results is separated accordingly to table (4.1).

Table (4.1): Classification of Tritium age in relation to its concentration in TU.

TU	Age
< 0.8	Sub-modern (prior to 1950's)
0.8 - 4	Mix of sub-modern and modern
5 - 15	Modern (<5 to 10 years)
15 - 30	Some tritium bombs
>30	Recharge in the 1960's to 1970's
>50	Recharge in the 1960's- Tritium Bomb testing

In table (4.2), samples of rainfall, surface water and ground water were collected and analyzed. The sample collection reached the Dead Sea and surrounding springs.

Table (4.2): analysis of tritium samples collected from wells in Wadi Ghar catchment area.

Sample Name	Well Depth (m)	TU	Error TU	Aquifer	Sample Name	Well Depth (m)	TU	Error TU	Aquifer
BN2	600	**0.02**	0.01	Lower aquifer	Izzariya-1	750	**0.03**	0.01	Lower aquifer
Hebron Mt. - Reehieh wells	*	**0.01**	0.01	Upper aquifer	EG 20 En Gedi saline	55m	**1.00**	0.03	Shallow aquifer
Hebron Mt. - Fawwar	80	**3.56**	0.08	Upper aquifer	En Gedi 22	28m	**0.98**	0.03	Shallow aquifer
Hebron Mt. - Fawwar	80	**3.54**	0.08	Upper aquifer	En Gedi 19 H_2S production: sal ~ 50psu	50m	**0.48**	0.02	Shallow aquifer
PWA 1	750	**0.37**	0.02	Lower aquifer	Ein Qeden south H_2S: saline (spring at Dead Sea shore)	*	**0.14**	0.02	Surface
Bet Fajar	350	**0.67**	0.02	Upper aquifer	Ein Qeden middle H_2S saline (spring at Dead Sea shore)	*	**0.09**	0.02	Surface
Bet Fajar	350	**0.69**	0.02	Upper aquifer	***Wadi rain from mountain***	*	**3.89**	0.10	Surface
Arab Rashaydeh	500	**0.02**	0.03	Lower aquifer	Samar Paddel Local rain from Dead Sea shore	*	**3.84**	0.09	Surface
Arab Rashaydeh	500	**0.09**	0.16	Lower aquifer	Fesh Cha south: spring at nature resort: light saline	*	**0.89**	0.03	Surface
Izzariya-2	750	**0.06**	0.01	Lower aquifer	Fesh Cha 7 observation well	*	**0.15**	0.01	Surface

Table (4.3) shows some data of tritium analysis collected from the study of (Avrahamov & others, 2010). All the samples were collected from **Wadi Arugot springs.** The last sample was collected from the Dead Sea. Both samples of the Dead Sea collected from the water level surface and the deep samples had the same results, thus only one was mentioned.

Table (4.3): tritium collected from Arugot spring at different dates.

Ein Arugot sample no.	Sampling Date	TU
1	11.2003	1.2
2	1.2003	0.7
3	3.2004	2.8
4	2.2007	2.4
5	12.2007	1
6	11.2007	1.1
7 w.l	11.2007	1.5
8	1.2007	2.1
D.S. w.l	12.2007	3.5

When the ground water contains low concentrations of ^{3}H it implies that this type of ground water would be formed a long time ago belonging to paleo-groundwater and has little connection to the recent atmospheric precipitation (Li, Zhang and Hou, 2007).

The relation between ^{18}O and T is shown in Figure (4.1). From the plot, two specific clusters can be observed: the lower cluster belongs to ground water with a T content between 0 and 1.5 TU. The second cluster values fall between 3 and 4 TU, and belong mostly to surface water, rainfall and Dead Sea. When comparing the T rain value of 3.89 TU to groundwater values, it is clear that the water reflects an older age in comparison since most of its values fall bellow 1 TU.

In reference to table (4.1), the values of water below 0.8 are said to be sub-modern while a value between 0.8 – 4 is taken as a mixture of modern and sub-modern. However, since surface water and rainfall do not exceed 4 TU, the values in the table are adjusted accordingly. Thus, the groundwater values between 0.5 and 1.5 are considered a mix of modern and sub-modern age, indicating a slight mixture between the Upper (modern water) and Lower aquifer (sub-modern water).

Surface water, DS, rainfall and springs fed by Upper Aquifer with values between 3 and 4 are taken as modern in age, meaning, that the Upper Aquifer is fed relatively fast but with evidence of evaporation during the infiltration process.

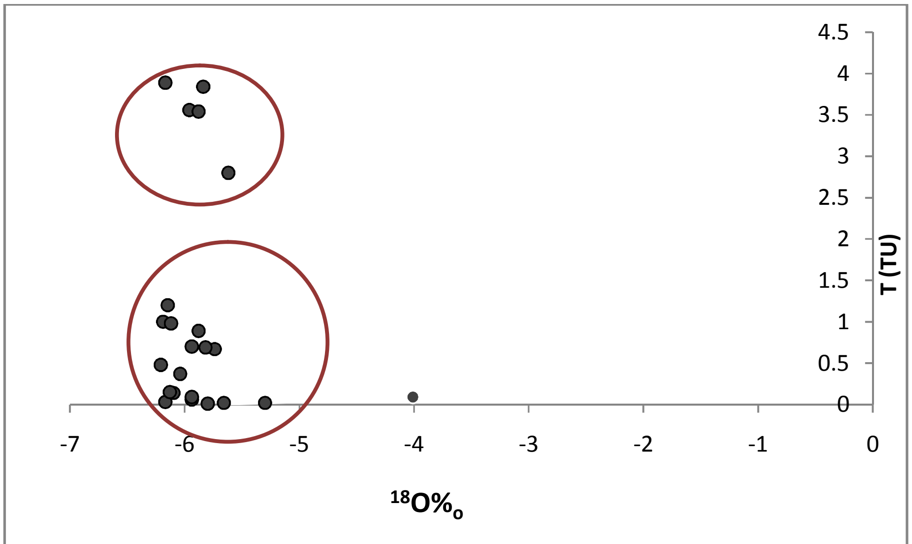


Figure (4.1): coorelation between ^{18}O and T for collected samples.

Figure (4.2) shows the plot of tritium in relation to depth. The Graph also supports the claim of sub- modern water in the lower aquifer since the amount of tritium in TU decreases with depth. The less tritium concentration there is the older is the water.

Moreover, the fresh surface water collected from the vicinities of the Dead Sea (eg. running water of wadi surface-flow and rain collected at Dead Sea Shore in addition to Some Springs like Fawar and Ein Jedi springs) and the samples from the Dead Sea itself are very close in range with a high concentration of tritium of more than 2 TU.

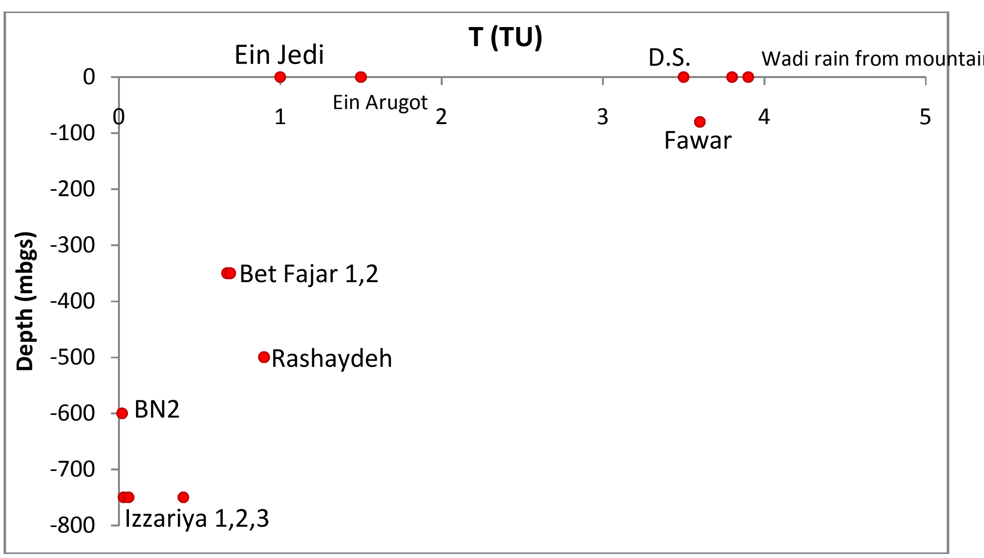


Figure (4.2): Correlation between Tritium in (TU) and Depth in (mbgs)

The tritium signature shows that the lower aquifers water is older than 100 years, it is water slowly infiltrates by leakage thus it's not easily replenished.

The excessive abstraction from wells is consuming from the aquifer much more than its replenishment rate. Hence, the over abstraction is causing a severe draw down in the water table of the upper aquifer. The catchment area of the lower aquifer is not enough to replenish the lower aquifer since only 4.5 MCM infiltrated through it.

The catchment area of the lower aquifer extends away from the catchment of Wadi Ghar, thus The pesometric pressure of the lower aquifer decreased in the last 20 yrs.

6. Chloride /Bromide Molar Ratio

Bromide chloride molar ratio analysis is used in addition to isotopical signatures to uncover the water origins and movement mechanism that infiltrates the aquifer. According to (Ghabayen, 2006), the Br/Cl ratio can determine several information as in table (5.1).

Table (5.1): Classification of water according to Br/Cl molar ratio.

Classification	Seawater intrusion	Flow from Eocene rocks	Deep brines up-coning	Wastewater seepages	Agriculture return flows
Br/Cl	0.0015	0.0014 – 0.0015	0.0014 – 0.0016	0.0005	0.02
Reference	-Vengosh and Rosenthal, 1994 -Vengosh et al.,1999	-Vengosh et al.,1999	-Vengosh and Ben-Zvi, 1994. -Vengosh et al.,1999.	Vengosh et al.,1999	Vengosh et al., 1994.

Cl/Br ratios in atmospheric bulk deposition have helped to distinguish groundwater in which Cl derives only from atmospheric sources, from groundwater in which Cl is contributed by endogenous, lithological or anthropogenic sources. Only Br/Cl ratio can clearly distinguish wastewater from other sources (Ghabayen, 2006).

The Cl/Br ratio appears to be a good tracer for discriminating non-atmospheric Cl contributions to groundwater, provided chemical analyses are accurate, since its variability is not wide. The Cl/Br ratio can also be helpful in identifying the groundwater flow-system when salinity increases due to rock-water interaction (Alcala, 2008).

When bulk Cl and Br masses are suspended in the atmosphere they can be carried inland by winds. Atmospheric Cl and Br availability decreases along the wind path with increasing distance from the ocean, resulting in higher Cl and Br deposition rates near the coast than inland (Alcala, 2008).

i. Chloride /Bromide analysis data

Bromide analysis data is shown in table (5.2). For the bromide analysis the sension™4 Laboratory pH/ISE/mV meter was used. This instrument is designed for laboratory use and operates on 115/230 VAC power. Two channels are available for electrode connection. In the ISE mode, the meter measures from 0 to 19900 with the highest resolution as ten thousands [0.0001] (SensION4 cataloged).

The Cl and Br concentration was measured in rainwater. The data was collected since 2007 as shown in table (1), APPENDIX A.2. The Br/Cl molar ratio had been calculated for rainwater also and was found to be 0.008.

Table (5.2): the bromide analysis of water in wells of the catchment area

Well Name	Br- in (ppm)	Cl^- in (mg/L)	Cl/Br	Br/Cl
BN 2	0.499	45.3	204.3	0.0049
Bet Fajar	0.569	50.4	199.4	0.0050
BN 2	0.366	42.5	261.3	0.0038
Arab Rashaydeh	0.215	70.9	672.7	0.0015
PWA 11	0.123	39.7	726.6	0.0014

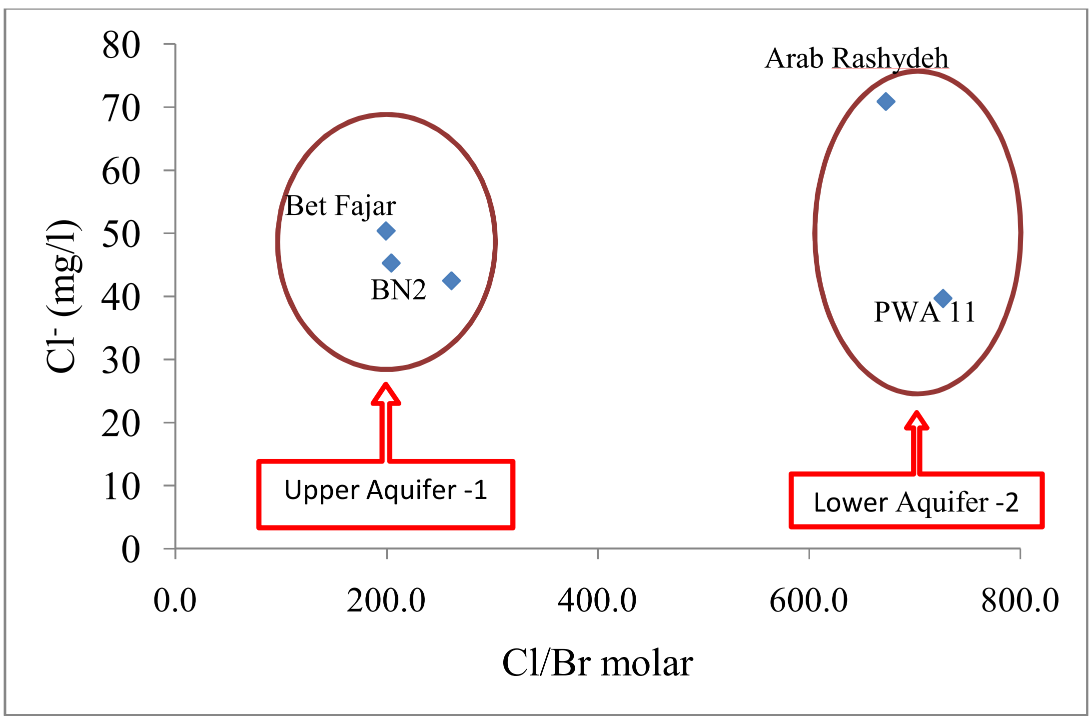


Figure (5.1): Plot of Cl^- vs. Cl/Br^- molar for the groundwater samples collected.

According to (Alcala, 2008), The seawater Cl/Br ratio is 655 ± 4 with a Cl content of about 19345 mg/l. Cl/Br ratios may be increased up to 1500 in groundwater by the infiltration of wastewater with NaCl content or leaching of solid waste with a Cl content of approximately 2500 mg/l. In the same way it can be decreased to 300 by the use of Br-based pesticides or leaching farm-animal or septic waste. Leaching and dissolution of natural and industrial NaCl, and of gypsum-rich formations containing NaCl may yield Cl/Br ratios between one thousand and several thousand. Although leaching of potassium halides near salt mines produces Cl/Br ratios below the seawater ratio. Groundwater with a relatively long residence time (tens of years for deep groundwater), having Cl/Br ratios between 600 and 700.

Data graphed in figure (5.1) of Br/Cl ratio show that two main clusters have formed. The first cluster [grouping most of the wells] is believed to be from the Upper aquifers water between 230 and 570 m of depth. The ration of Br/Cl lower than 300, can be correlated to the high presence of Br in the aquifers water either from leaching of the minerals in the aquifers rocks (especially carbonate aquifers) or by high-content-Br pesticides infiltration to the groundwater (which is not likely since there are minimal agricultural activities around the study area). On the other hand, Israeli settlements surrounding wadi Arugot, discharge untreated wastewater to run freely in the close wadis. The high source of Br could be caused by leaching from the settlements untreated wastewater to the underground rock formations.

The second cluster shows that PWA 11 and Arab Rashaydeh wells, that are deep wells more than 800 mbs, perforate the Lower aquifer. These wells have a much higher Br/Cl Ratio. According to Alcala, 2008 groundwater with a relatively long residence time (tens of years for deep groundwater) has a Cl/Br ratio between 600 and 700.

Distance to the sea controls the movement of Cl and Br ions inland from the ocean along rain pathways producing a progressive reduction in the Cl/Br ratio from around 655 to less than 300. Additional sources of Cl and Br are gradually added to the marine aerosol. Natural sources of Cl are mainly from halite, raising the Cl/Br ratio sup to 1200 while anthropogenic sources mainly contribute Br-rich substances, lowering the Cl/Br ratios to 300. Cl/Br ratios in atmospheric bulk deposition control the ratios expectable in phreatic water affected only by saline evap-concentration (Alcala, 2008).

In a study made by B. Petrides (2005) in Australia, it was reported that oceans have molar Cl/Br ratios of 550-700. Coastal precipitation has similar Cl/Br ratio, however, inland precipitation, especially in arid or semi arid climates, may have lower Cl/Br ratio due to tendency for Cl to be removed in early rainfall near coastal areas.
Arab Rashaydeh well, has a Cl/Br ratio of 673, this confirms that both wells penetrate the Lower Aquifer. However, this seems to be very close to the sea water ratio, in addition the Br/Cl ratio is about 0.0015 which is correlated mostly to sea water intrusion according to table (5.1). But since the Dead Sea has a very unique constitution and is characterized by a high Br/Cl ratio of 10.45, the mixing between Lower aquifer and Dead Sea water intrusive bodies is not likely.

Physical processes taking place in soil (dilution, evaporation, transpiration, mixtures, etc.) can change the absolute concentrations, but do not significantly modify the Cl/Br ratio of -not too saline- groundwater.

Other factors, such as vegetation cover, proximity to cities and industrial centers, mining facilities, evaporitic rock out-croppings, etc., can contribute locally both natural (e.g., smoke) and anthropogenic (e.g., industrial activity, fuel combustion, etc.) atmospheric dust and organic molecules, in both coastal and inland areas. Normal saline evapo-concentration during recharge does not change Cl/Br ratios in groundwater. Salinity in atmospheric bulk deposition controls the expectable Cl/Br ratios in groundwater anywhere recharge of water has a short residence time in the unsaturated zone, and the contributions of non-atmospherically derived sources of Cl and Br to groundwater are negligible.

7. Chloride Mass Balance (CMB)

The sampling bottles used were low-density polyethylene 1 little bottles for samples of wells and springs. A 60 ml low-density polyethylene bottle was used to collect rainwater from the rain gauges. As for the sampling, the Canada- British Columbia Agreement (2005) recommended the sampling procedure. Chloride analysis of water from multiple wells in Hebron Governorate is shown in table (6.1).

Table (6.1): Physical and Chemical analysis for groundwater, around Ghar catchment area**.**

Well Name	Well Depth (m)	EC (µS/cm)	Cl^- (mg/l)
BN 2	580	-	42.5
Arab Rashaydeh	-	-	70.9
Herodion (1) 2A	350	453	35.5
Herodion (2)	770	703	30.5
Herodion (3)	800	268	30.5
Herodion (4)	350	598	30.5
PWA (1)	600	553	33.3
PWA (11)	851	765	35.5
Al Rehea	425	409	56.0
Al Fawar	100	577	94.1
Asamoua	191	545	104.6
Hindaza	740	546	34.5
Izzariya (1)	996	322	36.6
Izzariya (2)	793	360	33.1
Izzariya (3)	835	475	51.8
JWC 4	460	513	33.3
Bet Sahur	-	-	42.5
Bet fajar	237	-	35

Figure (6.2) of Cl content in groundwater versus Depth, shows an overwhelming clustering of the wells around 40 ±10 mg/L of Cl content for deep well (>500 mbs), these values are constant with the rainfall Cl concentration values table (1- appendix A) with a mean concentration of about 37 mg/l.

However, there are two outliers; Al Fawar and Al Samu'u wells. These two wells have in common there shallow depth 100 and 190 mbs. From figure (3) Appendix A-1, it can be observed that both these wells fall on the Jerusalem formation, with such a low depth it could be improbable that they fed from the Upper Aquifer, so it may be deduced that both of these wells feed from a sub-aquifer or pocket aquifer, with water recharge from rainfall and high evaporation losses during infiltration and so explaining the higher Cl content.

From another viewpoint, the high Cl content on the surface maybe caused by high evapotranpiration rates in the area of 200 ±20 mm in dry months and 100 ±10 mm in wet months as in figure (3.3.a) - section (3.i), Chapter 2. Nevertheless, evaporation rate has been much higher in the last 3 years due to climate change [An average of 250 ±20 in dry months and 120 ±20 in wet months].

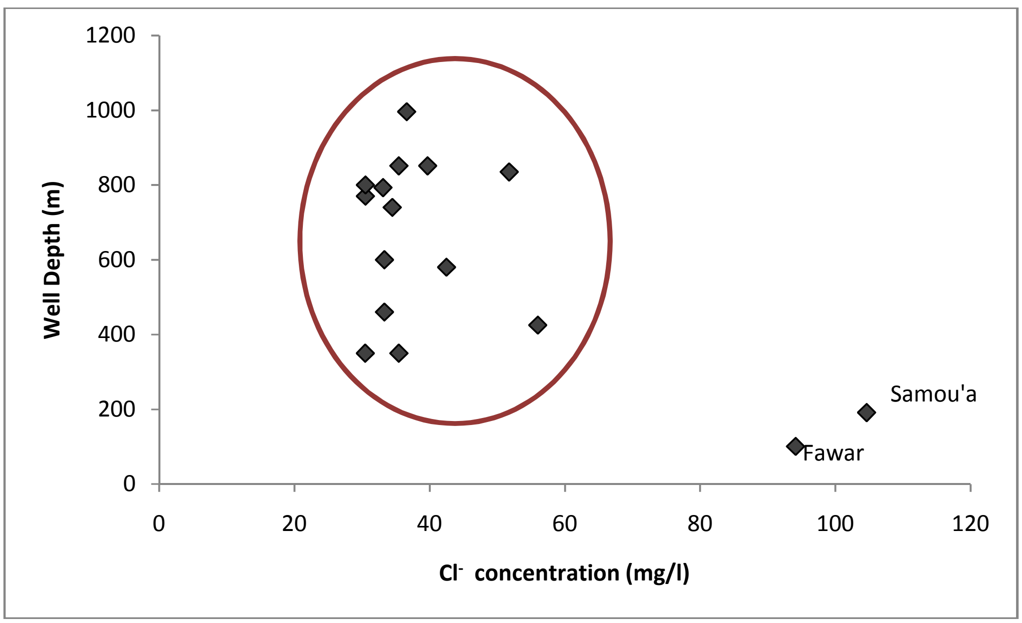


Figure (6.2): Plot of the Cl^- content of Groundwater with well Depth.

A.Guendouz and others (2005) The study also showed a graph correlating ^{18}O to chloride. The evaporated feature of the phreatic aquifer is exhibited by a range of -3.5‰ of ^{18}O vs. 180mg/l of chloride; this is when it undergoes mineralization. There are two stages of mineralization:

1- First will be when ^{18}O varies from -2‰ to 0‰ and chloride concentration will be ~250 mg/L and a ^{2}H excess in the range of +10‰ to +15‰.
2- The second mineralization point occurred when ^{18}O in the water was -2.5‰ and chloride concentration ranging from 150 to 1350 mg/L.

Figure (6.3) shows a plot of Cl vs ^{18}O content in ground water, since ^{18}O ranges from 5 to 6.2 and the Cl content is below 120 mg/l it is improbable that mineralization occurs as stated by Guendouz 2005.

M. Matter and others (2005) stated that increased chloride concentration and less depleted ^{18}O values are trades of ophiolite aquifers (highly karstic Triassic carbonates, mainly limestone aquifers). Since as in figure (6.3) the Cl has a medium value range and the ^{18}O is also relatively medium in value (not too depleted) it can be concluded that the aquifers characteristics are indeed limestone aquifer but moderatly Karstic in nature.

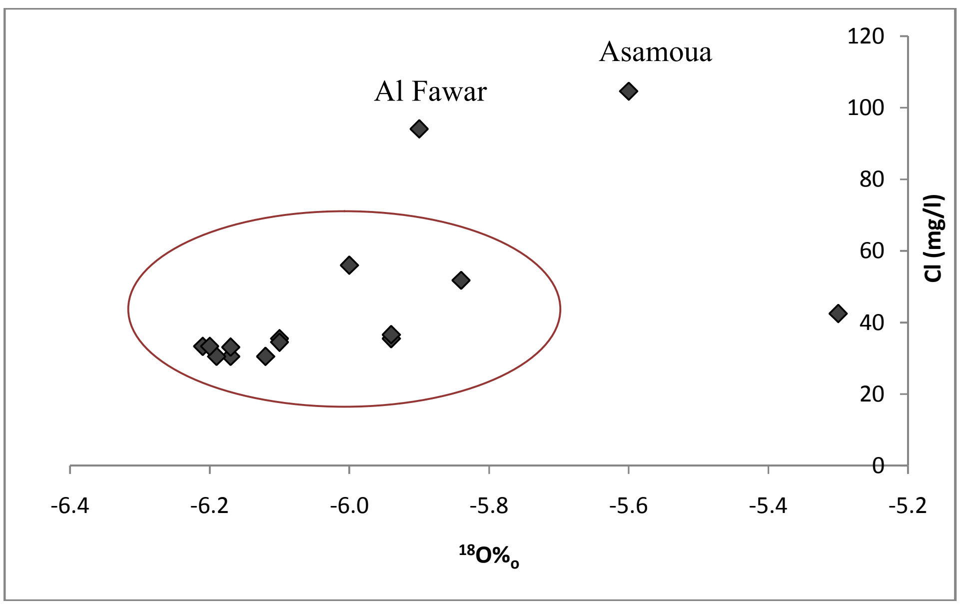


Figure (6.3): Chloride concentration in relation to ^{18}O content in groundwater samples.

8. Quantifying the Recharge Volume

According to Bajjali (2004) study in Jordan, Recharge can be also calculated from the ratio of chloride concentration in rainfall to that of chloride concentration in groundwater through Edmunds and Sharma (1998) equation:

$$R = \frac{P * Cl^-_p + D}{Cl^-_s}$$

To calculate the Recharge following the CBM equation, the Average rainfall of each city was calculated from the year 2000 to 2009 as in table (7.1). In addition, the Cl content in Rainfall according to Marei 2010, is 9.57. Moreover, the average Cl content in soil was taken as **30 mg/l.** after inserting the equation into 'Microsoft Excel' the Recharge (R) for each location is as in table (7.1). The values where mapped as in Figure (7.1) using GIS 9.3 version.

Table (7.1): Average rainfall, and Recharge rate into aquifer for each locality in Hebron Governorate.

City	**Average Rainfall from 2000/09**	**Cl- in Groundwater (mg/l)**	**Cl- in Rainwater (mg/l)**	**Recharge (CMB) [RF*9.57/ 30] mm/yr**
Hebron city	543	39.7	9.57	173.2
Al-Arroub	609	35.5	9.57	194.2
Halhool	455	30.5	9.57	145.0
Yatta	397	30.5	9.57	126.7
Dura	464	30.5	9.57	148.0
Dahryya	314	33.5	9.57	100.2
Beit Ola	450	35.5	9.57	143.5
Alsamou	330	104	9.57	105.2
Beni Naim	394	94.5	9.57	125.6
Idna	422	33.1	9.57	134.5
Tarqumia	458	51.8	9.57	146.2
Bet Mersem	152	33.3	9.57	48.4

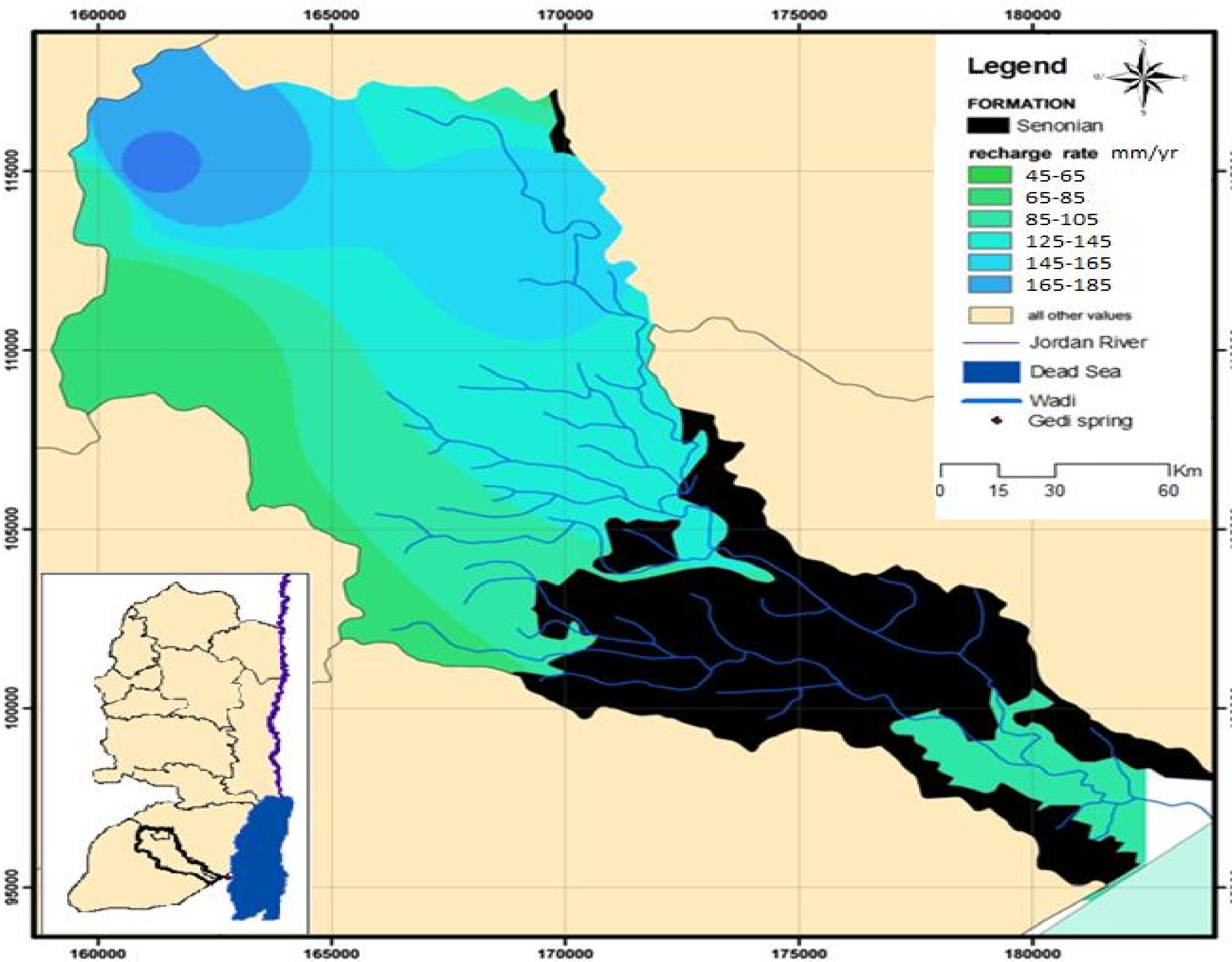


Figure (7.1): The simulated distribution of the calculated recharge potential (mm/yr) in Wadi Ghar catchment area

Table (7.2): The precipitation volume and recharge volume in MCM in Wadi Ghar catchment.

Formation	Area in (Km^2)	Area in (m^2)	% Area	Precipitation (mm)	Precipitation Volume in MCM	Direct Recharge (mm/yr)	Recharge Volume in MCM
Abu Dees	58.7	58700	26.1	340	19958000	0	0
Jerusalem	94.3	94300	41.8	380	35834000	110	10 373 000
Bethlehem and Hebron	43.6	43600	19.3	550	23980000	140	6 104 000
Yatta	19.2	19200	8.5	525	10080000	180	3 456 000
Upper Bet Kahel	9.5	9500	4.2	475	4512500	75	712 500
Total	**225.3**	**225300**	**100.0**		**94 364 500**		**20 645 500**

Most of the recharge occur in the upper part of the surface catchment area of Wadi Ghar as demonstrated by the values given by the isotope signature of ^{18}O and CMB method as in Figure (7.1), where the highest infiltration rate happens in the most upper part through the Hebron, Bethlehem, Jerusalem, Upper Beit Kahel and lower Yatta formations.

Moreover, the Jerusalem Formation has recharge rate of 100 mm/yr and recharge volume of 10 MCM; it is then followed by the Hebron and Bethlehem Formation with a recharge rate of less than 140 mm/yr and a recharge volume of 6 MCM. Yatta formation as well in comparison with the others has the highest infiltration rate of 180mm/yr and a total of 3.5 MCM recharge volume. In addition Bait Kahel formation has a recharge volume of 75 mm/yr and a Recharge volume of about 0.7 MCM.

Although Beit Kahel Formation is considered as an excellent aquifer, the low infiltration rate may be due to the high urbanization level of Halhul city that covers this particular formation (about $4km^2$) in the catchment of wadi Ghar, thus increasing the surface runoff and degreasing the infiltration rate. On the other hand, the Senonian formation has not infiltration capacity at all and is regarded as a complete Aquiclude.

From table (7.2), it can be calculated that the total volume of precipitation over the catchment area of Wadi Ghar is about 95 MCM, and the calculated recharge volume of the infiltrating water to the aquifer is about 21 MCM, thus the recharge of the Ghar catchment is about 22% of annual rainfall. This result is consistent with the ranges calculated in previous studies like CDM & Morganti 1997, Rofe & Raffety 1963, 1965 in addition to Black and Goldsmith 1947 that was mentioned in the study of Marei 2009, with an estimate between 15-50% (Marei, 2010).

Figure (7.2) shows the estimated draw down in the water table from 1999 until 2012. Thus it is clear that the over pumping is causing the regression in the water table.

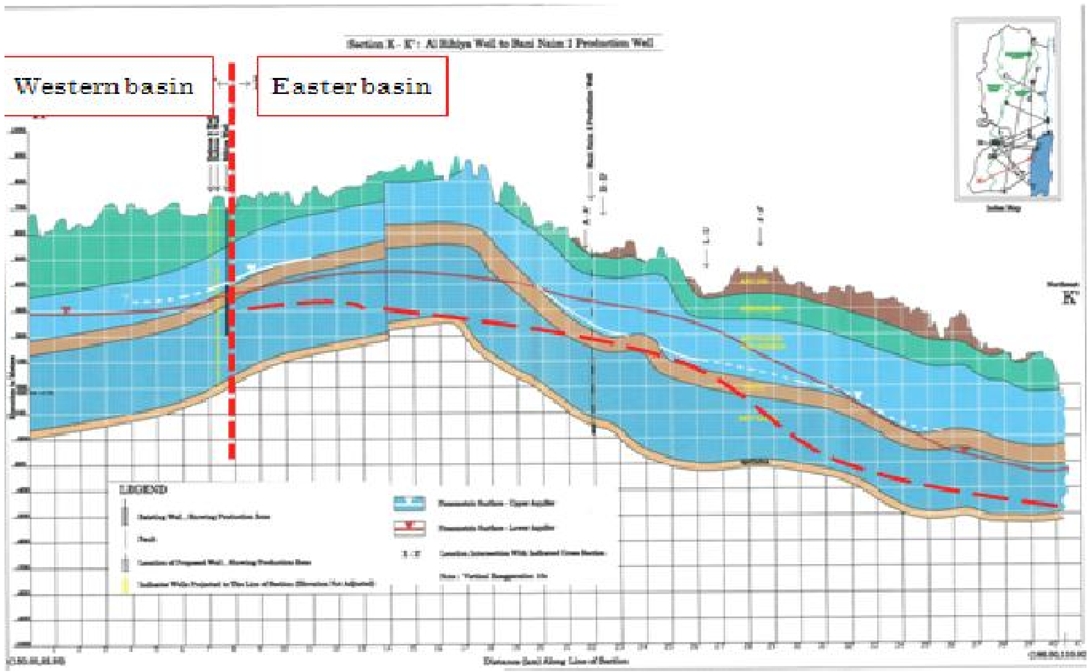


Figure (7.2) shows the estimated draw down in the water table from 1999 (straight red line) until 2012 (dashed red line).

Groundwater recharge estimation is an iterative process. When estimating few remarks should be kept to mind:

1- Realistic estimation depends on first identifying important features influencing recharge for a given locality and probable flow mechanism for the aquifer.
2- It is best to apply and compare multiple independent approaches.
3- The model used for estimation should be appropriate and compatible to actual field conditions.
4- For semi-arid groundwater system with a large relaxation time, a residual head or hydraulic gradient is likely to exist from paleo-climatic conditions.

According to (De Vries, 2002) groundwater recharge has been repeatedly shown to be highly variable; the greater the aridity, the smaller and potentially more variable the natural flux.

Some of the problems in general in estimating water recharge (especially in semiarid areas) can be summarized as following:

1- Variability of recharge in time and space. [eg. Effects of climatic and land use changes on tracer profile /mass balances; determination of representative water balance parameters]
2- The assessment and regional hydrological consequences of localized and indirect recharge
3- The impact of urban development on ground water recharge

The surface run off will be calculated using 'Schulumberger' Divers, they measure and conserve the data for long periods of time and they are standarized according to demand on a computer program to best fit the purpose of the study. These instruments (4 divers) were placed on the main wadies of Ghar catchment area. The function of the divers is to calculate the water pressure and EC submerging it. Another Master Graduate of Environmental Sciences from AQU, *Hussam Utair - "Estimation of Total Discharge From Wadi Arugot to the Dead Sea Area Using Rainfall-Runoff Model" (2012)* - thesis for the same catchment shows a more detailed study on how to calculate the surface runoff by using the 'Schulumberger' divers. In this study, the results of (Utair, 2012) for surface runoff water in the Ghar catchment of 958000 m^3 will be used, and evapotranspiration will be calculated using Mathematical means.

In order to calculate the recharge volume, the basic equation of balance is used:

Precipitation = Infiltration +Evapotranspiration + Surface Runoff

In order to calculate the total amount of evaporation, the transpiration was overlooked since it contributed minimally to the total evaporation of water due to the minimal vegetation cover of the study area.

Rearranging the equation to calculate the infiltration we get:

Infiltration = Precipitation – (Evapotranspiration + Surface Runoff)

20645500 = 94364500 - (Evapotranspiration + 958000 CM)

Evapo = 74677000 CM

The results show that the evaporation in Wadi Ghar about 75 MCM accounts to 79% of the total precipitation volume of the area which is about 94MCM.

9. Aridity index:

As described in the aridity section (ii) – part 3, Chapter 2, the following equation is used for the calculation of aridity index in the Hebron Governorate.

$$X = P / (10 + T)$$

In order to calculate the aridity index the following will be considered:
Mean precipitation (P): 580 mm
Mean Temperature (T): 15.5 C^o

The equation will be given as: $X = 580 / (10+15.5)$

⟶ Then **X = 22.7**

The aridity index calculation for the Hebron area was 22.7. In reference to table (3.1) – section 3, Chapter 2, Hebron area under *De Martonne* classification is a 'Humid' area while under the *Muria and Honda* classification Hebron is a 'Grassland' area. From the continuous field visits and field work, in my prospective the classification of *Muria and Honda* is more precise.

Chapter 5
Conclusion and Recommendations

1. Conclusion:

Groundwater recharge is defined in the general sense as the downward flow of water reaching the water table, forming an addition to the ground water reservoir (Pradeep K. Naik, 2003). In this study this is our main focus, to know how the groundwater is recharged and how much. This study focused on three main techniques to trace water movement, the first is Chloride Mass Balance. The second technique is Bromide/ Chloride molar ratio and the third is stable isotopes tracing of ^{3}H, ^{2}H and ^{18}O.

The data collected, has provided a clear picture of the mechanisms and quantity that the runoff water uses to infiltrate into the sub-laying aquifer.

Through a data collection of more than 30 years of rainfall history and meteorological record, an Isohytal map of the rainfall distribution was created. The new map shows a rainfall average of 550-600 mm in the most upper section of the catchment on the elevation of 1000 m while it decreases continually to reach the value of 320 mm in the most lower section of the catchment over the elevation of 200-300 m. At the end-section (Dead Sea) the rain average does not exceed the 100 mm/yr.

Moreover, the meteorological data was essential for the calculations of the CBM method for recharge determination. A map showing the recharge rate in mm/yr for the catchment of Wadi Ghar was also done by integrating the different data available of precipitation, Cl concentration in groundwater and in rainfall.

Detailed geological cross sections provided a full view of the areas structures and formation. Major faults, as well as sinclines, monoclines and anticlines were observed.
It is believed that the effect of the Fault system and geological formation of the area play a major role in water movement and distribution in the two aquifer system of the Eastern Basin.

The data analyzed of isotopes and Cl/Br ration fortify the idea of water mixing between the upper and lower aquifer. This mixing time happens according to the T data analyzed. The major factor causing the mixing is believed to be the eight fault systems across the Jerusalem desert to the Dead Sea area, in addition to the karsts found in the limestone and dolomitic formations of the Upper and Lower Cenomanian, Albian and part of the Turonian age. However, the lower section of the surface catchment composed of Senonian formation (aquiclude) is believed to be an impermeable layer with no infiltration occurrence.

The aridity index of the Hebron Governorate was calculated to be 22.7, this represents a grass land environment according to the description of Mutia & Honda.

The calculated recharge rate were computed, taking into consideration the change in the concentrations between the recharge zone and the wells downstream, where the actual runoff potential, infiltration rate and losses can be estimated, accordingly. Recharge Volume was found 21 MCM/year for the catchment area.

The model data shows about 95 MCM of annual rainfall over the whole area, it can be divided according to chloride mass balance between 21 MCM as infiltration (22% of precipitation volume) and the rest as evaporation loss about 79% of precipitation volume.

The total amount of Wadi discharge to the plain area is about 958000 CM (Utair, 2012), This results shows an increase in amount of discharge as Rofe & Raffety 1993, study (about 400 000 CM).

2. Recommendation:

After doing multiple field observations throughout two years of work, the following recommendations are given for a more accurate data collection, computation and analysis.

- Since there were so many hindrances with collecting precipitation using the manual rain gauge method, it is recommended in future studies that other types of rain gauges [eg. Electronic gauge with direct input of data to computer] are better to be used, since the data is measured and uploaded instantly and the information loss is minimum. Moreover it will save transportation costs and time required to and from the station locations.

Ground water recharge depends on the following:

1. Effective precipitation: the soil moisture surplus that is available for the direct recharge or runoff.
2. Actual recharge: downward percolating water that reaches the potentiometric surface within the uppermost aquifer below an area.
3. Recharge coefficient: that proportion of effective precipitation that becomes actual recharge (Fitizimons & Mister, 2005).

This area has a great potential for water management, and if the three factors mentioned by (Fitizimons & Mister, 2005) are applied properly the 'water banking' techniques can be effective. Water banking or (Managed Aquifer Recharge) is a conjunctive technique that seeks to deliberately increase the amount of water stored in an aquifer, which is then recovered by pumping. By storing water underground, loss of water to evaporation can be greatly reduced and the water savings returned to the users.

The catchment area has great potential for agriculture due to its soil coverage and surface area. The soil covering the upper half of the catchment is mainly composed of two types; the first is terra roza, and the second is rendzina as in figure (1.1) - appendix A. Both types of soil are fertile and good media for agricultural activities. The areas size is large (around 225 km^2) and not highly urbanized (urbanized areas cover about 17 km^2), thus the area has more than 90 km^2 of non-reclaimed agricultural land. The biggest hindrance for utilizing this land is the water availability, especially in the lower half of the catchment. Hence, the best recommendations would be:

1. Building subsurface dams in the upper part of the catchment area to collect the water and give it more time to infiltrate into the lower aquifer which is feeding most of the domestic wells in the southern part of the West Bank.
   (Raju, 2005), conducted a study in India about the possibility of constructing underground dams in order to capture the runoff water of monsoon period rainfall. The water harvesting turned out to be successful in replenishing the groundwater and increasing the water table level.
2. Build collection ponds in the upper part of the catchment area where most precipitation volume occurs, and try artificially recharge the aquifer with the storm-water collected during heavy rainfall.
3. In a paper written by Peter Dillon (2005) there are multiple systems for water capture, use and artificial recharge. Some of the systems proposed in the paper are bank filtration, dune filtration, infiltration pond, percolation tank, rainwater harvesting, soil aquifer treatment, underground dams, sand dams and recharge release. This technology, if used correctly can also be used in Wadi Ghar catchment area for the collection of runoff water.

Water banking and subsurface storage advantages reside in the little evaporation of water, widely distributed water availability [due to the large size of aquifers], operational efficiency of the water collected and availability of water on demand.

However, the limitations reside in slow recharge rate, possibility of groundwater contamination and high cost of extraction in relation to the recoverable fraction volume.

Although, water banking can be used to treat water for certain water quality problems such as bacteria and some pesticides, it can be vulnerable to contamination if the water is not suitable or it overwhelms the ability of the aquifer to process the waste. This is why water banking schemes need to be strictly monitored. Groundwater salinisation and groundwater pollution are certainly the most pressing key issues of this method (www. Connectwater.go).

Some of the Water Banking methods are described according to the Australian Government water management policy as follows:

a- Bank filtration is a type of filtration that works by passing water to be purified for use as drinking water through the banks of a river or lake. It is then drawn off by extraction wells some distance away from the water body. The process may directly yield drinkable water, or be a relatively uncomplicated way of pre-treating water for further purification. Thus, runoff water in the wadi can be utilized and treated in this manner for efficient use and direct relocation of water. This method can be very efficient in Wadi Ghar since in the study, about 80% of the precipitation is lost as evaporation. By decreasing the runoff time and distance of the water running in the wadi tributaries, the water lost in evaporation will be reduced as well.

b- Dune filtration is another type of water banking that is used primarily for water treatment. Pretreated water is pumped into a dune swale and then reharvested at a lower level after gravity transport through the dune. Biological and chemical processes within the dune remove residual organic material, nitrogen and pathogenic microorganisms.

c- An infiltration pond is one of the simplest and most effective methods of increasing the amount of recharge into an aquifer. Water is pumped into a permeable area above the target aquifer to allow water to infiltrate by gravity into the groundwater system. In many ways, it is the opposite of a traditional dam, where leakage is kept to a minimum, instead of encouraged. The ponds are highly effective but like most water bank techniques, they suffer from clogging, though this can be managed by mechanical scourers and pretreatment.

d- Rainwater harvesting is a variant to traditional rainwater collection using a tank as storage. Rainfall is collected from a catchment surface and stored in an above ground tank. This method has been used in Palestine for generations where the old houses architectures included a basement or an underground room for rainfall storage collected during storms using the house rooftops. Since this method is acceptable to people and is quit efficient in residential areas, the precipitation water can be stored in an underground percolation tank where it recharges the groundwater system. The water is then available to be exploited from a nearby bore.

e- Underground dams are a low technology solution to storing water that is well suited to fractured rock terrain or regions with limited resources. A low permeability barrier is introduced into an aquifer either through injection or excavation, which stops the flow of groundwater until the water level rises above the obstacle. Water that would normally drain away is then available to be exploited. For these techniques, there must be further detailed investigation in Wadi Ghar to identify the geo-structures and the highly karstic locations in order to implement a more efficient water management system. The major eight faults along minor ones can be exploited in recharging the aquifer using the underground dams or as infiltration ponds. Especially in the lower region of the catchment where Abu Dees formation acting as an aquiclude reduces the natural infiltration of water.

f- Water banking, via recharge releases, makes use of existing (or purpose built) dams that capture surface water during floods and then release for slower infiltration. The water is then re-harvested down gradient by production bores. It is a useful technique in steep terrains, where water normally flows too quickly to allow significant infiltration to the groundwater system. Since the slopes of the Jerusalem Desert are steep, this method can be considered as efficient in exploiting the natural high infiltration surface areas with Hebron, Bethlehem and Jerusalem formations coverage.

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APPENDIX A

1. **Maps**

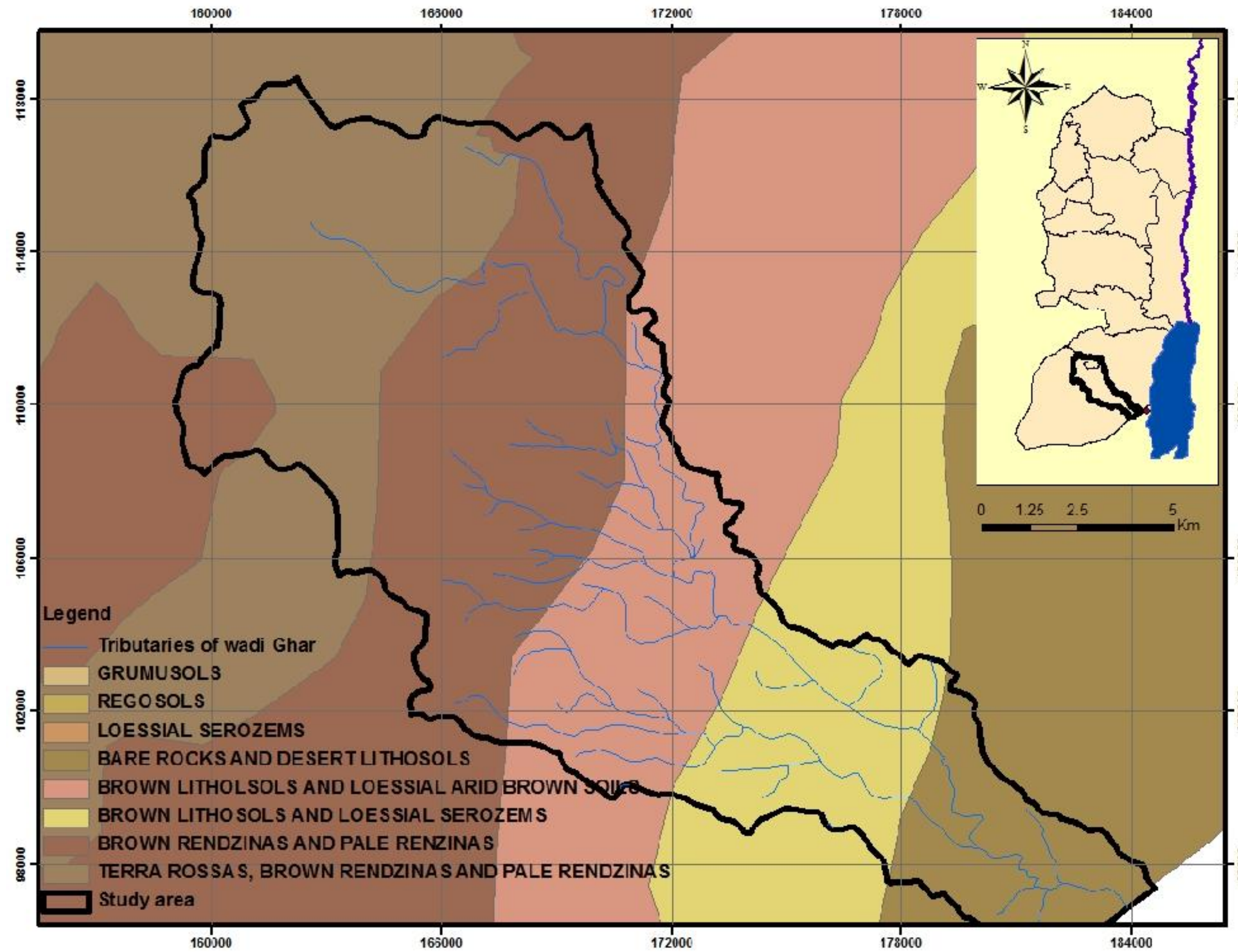


Figure (1.1): soil type and distribution over Ghar catchment area and surroundings

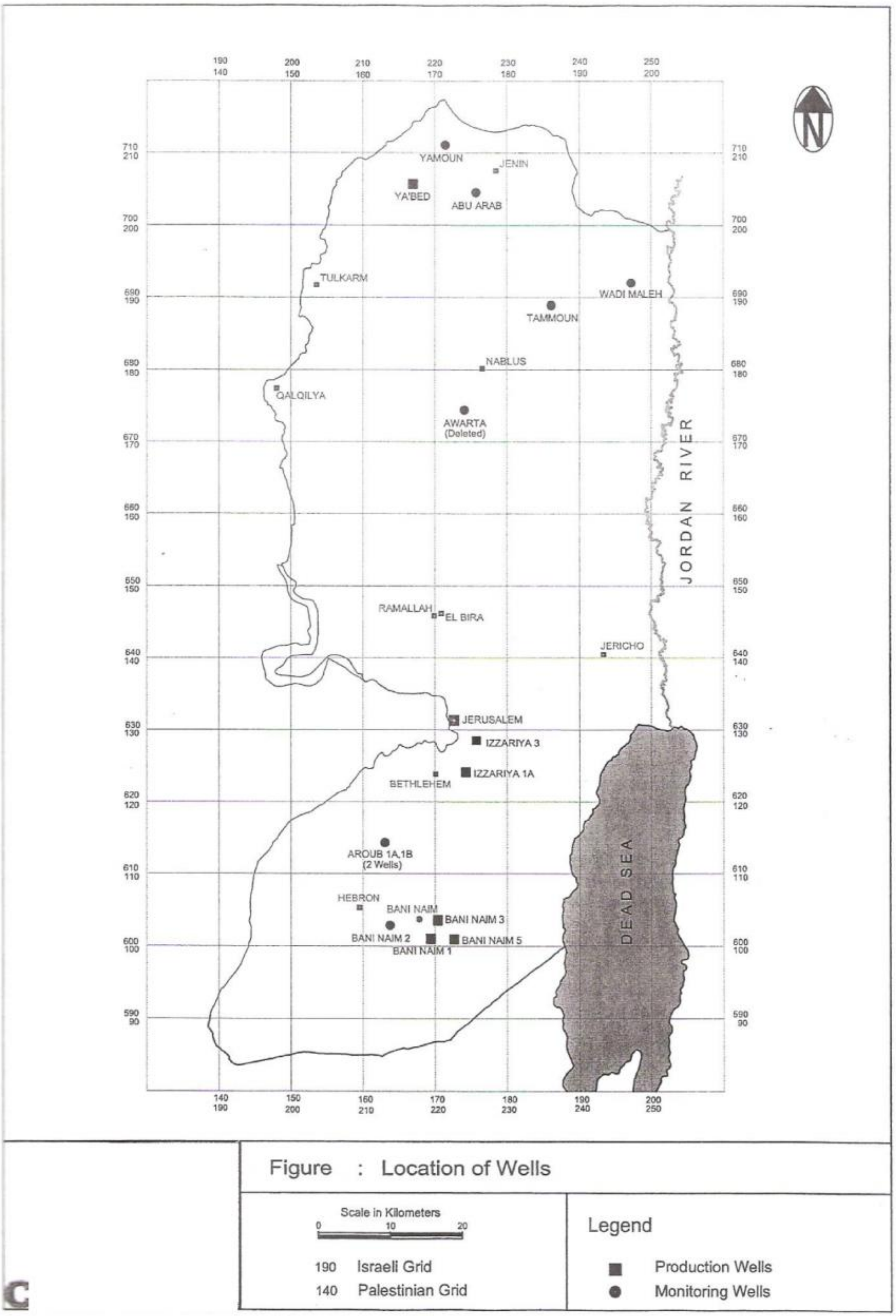
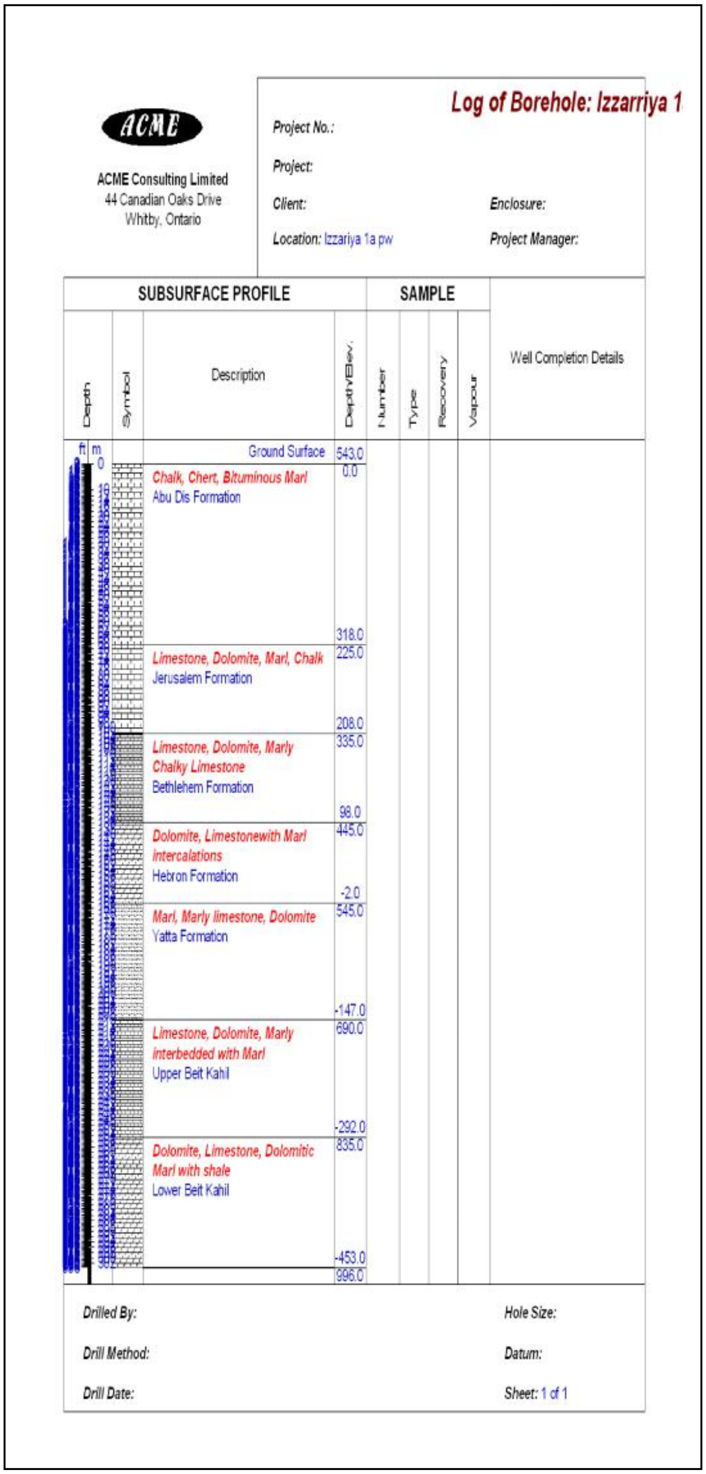


Figure (1.2): Locations of wells with detailed Lithology.



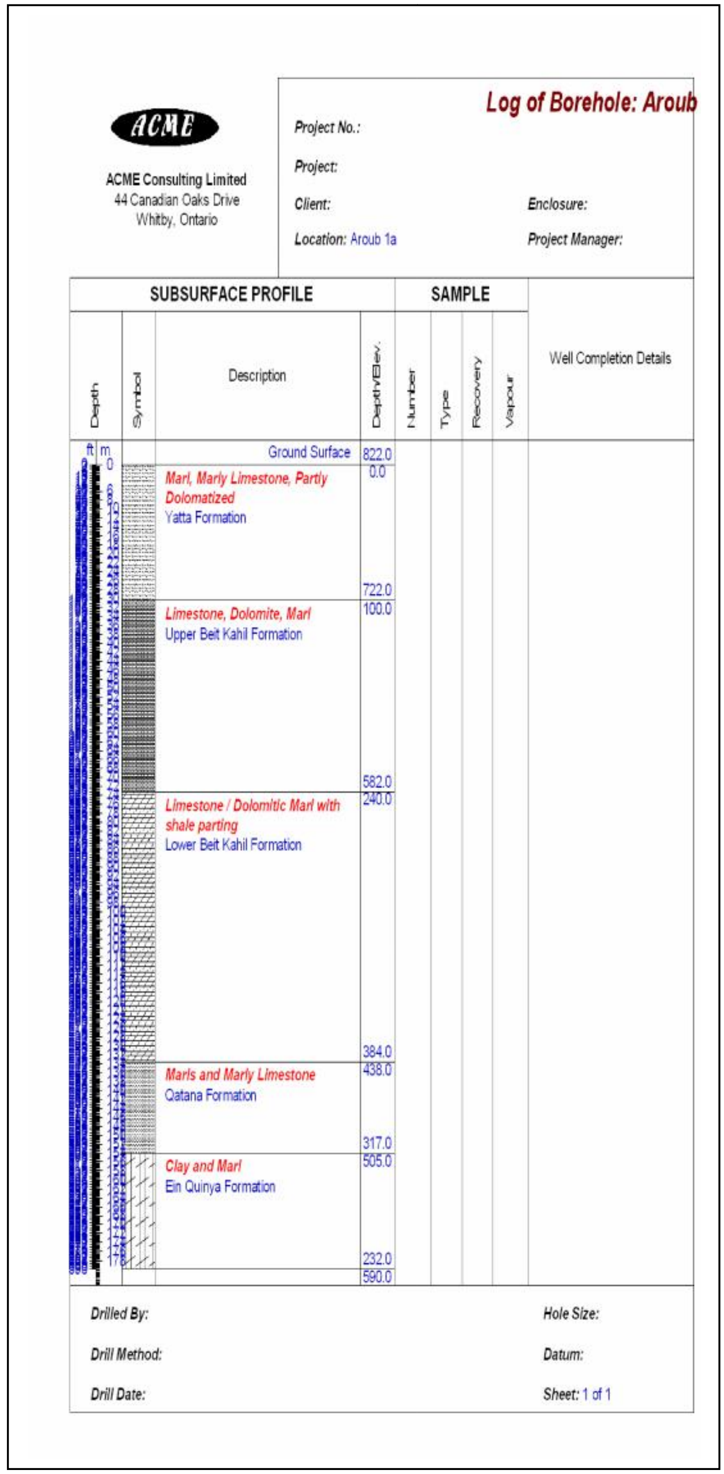


Figure (4.a): Lithology of wells Izzariya 1a PW, Aroub 1a.

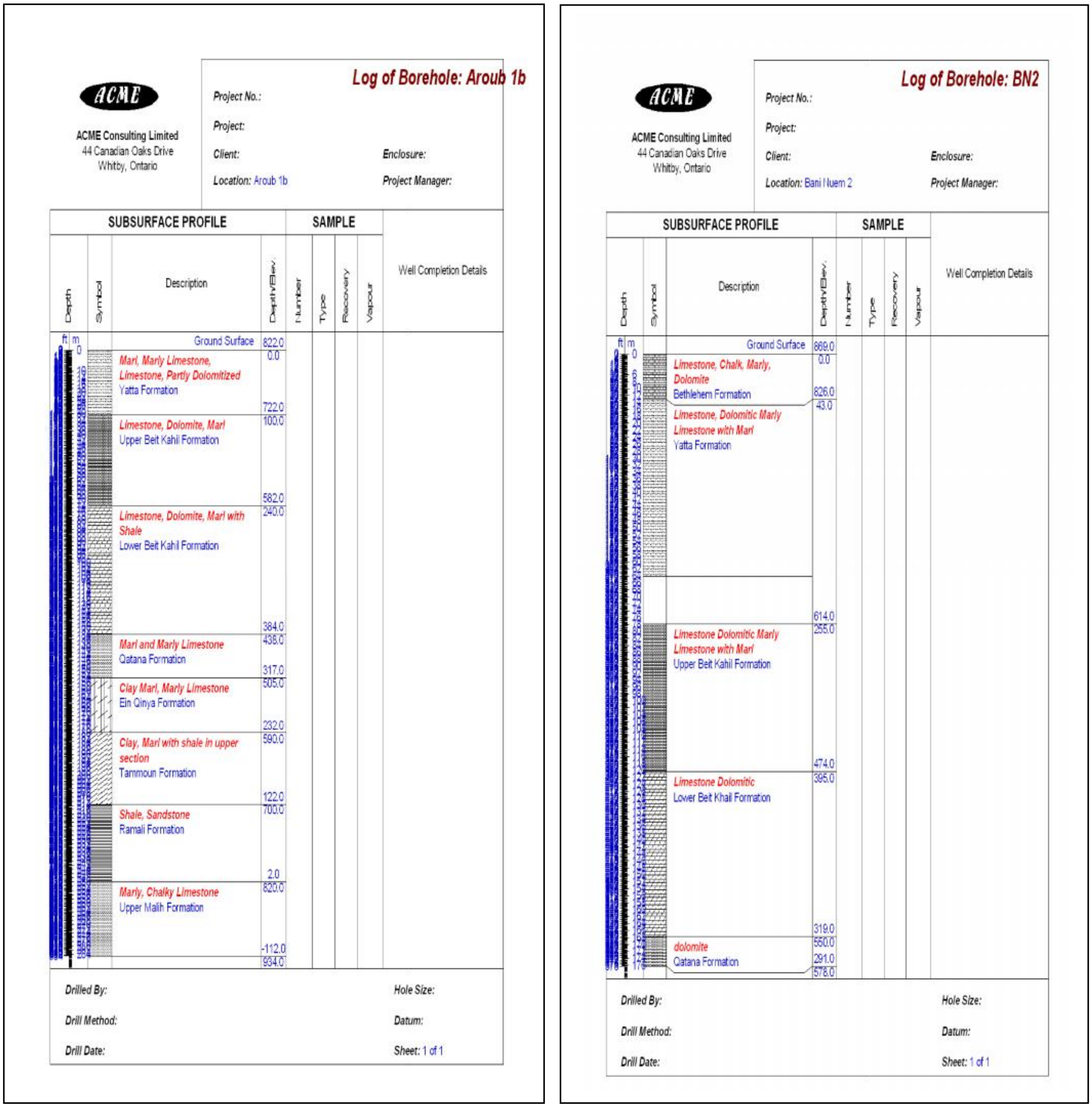


Figure (4.b): Lithology of wells 1b MW and BN2 MW.

2. **Hydrology – Rainfall**

Table (2.1): Chloride and bromide analysis for rainwater from 2007 to 2011.

Date	Cl- (mg/l)	Br- (mg/l)
Nov-07	77.99	4.05
Nov-07	200.00	0.93
Nov-07	27.30	0.48
Nov-07	35.80	0.49
Nov-07	49.50	1.37
Dec-07	54.00	0.33
Dec-07	42.30	0.49
Dec-07	21.27	0.89
Dec-07	28.40	0.89
Jan-08	44.80	0.38
Jan-08	49.40	0.40
Jan-08	24.47	0.74
Jan-08	73.75	0.36
Jan-08	39.78	0.29
Feb-08	132.60	0.91
Feb-08	42.50	-
Feb-08	15.00	0.49
Feb-08	15.03	0.85
Feb-08	15.30	0.71
Feb-08	31.91	-
Feb-08	46.70	0.26
Feb-08	39.20	0.33
Mar-08	46.00	-
Oct-09	21.30	-
Oct-09	30.50	0.18
Nov-09	11.00	0.13
Nov-09	3.60	0.07
Nov-09	5.00	0.07
Nov-09	-	0.20
Dec-09	14.18	0.82
Dec-09	14.18	0.08
Jan-10	14.18	0.06
Jan-10	7.09	0.02
Jan-10	212.70	2.18
Jan-10	19.18	0.30
Feb-10	21.27	0.81
Feb-10	14.18	0.03
Feb-10	42.54	0.32
Feb-10	21.27	0.30
Feb-10	28.40	2.18
Feb-10	-	1.28
Jan-11	21.27	-
Jan-11	7.09	-
Jan-11	21.27	-
Feb-11	7.09	1.27
Feb-11	7.09	-
Feb-11	7.09	-
Mar-11	14.18	-
Average	**37.36**	**0.68**

APPENDIX B

1. Titration Procedure:

Chloride concentration analysis was done using titration method as shown in figure (3.4). The following procedure was used:

1. 0.1M $AgNO_3$ is placed in a Burette and used as a titrant.
2. 100 ml sample is placed in a flask.
3. 2 drops of Sodium Chromate is dropped onto the 100 ml sample in the flask as an indicator.
4. The sample is titrated with the 0.1M $AgNO_3$.
5. The procedure is repeated three times for each sample and the average is taken.
6. The average result of the titration volume is multiplied by 70.9 factor. The result is documented.

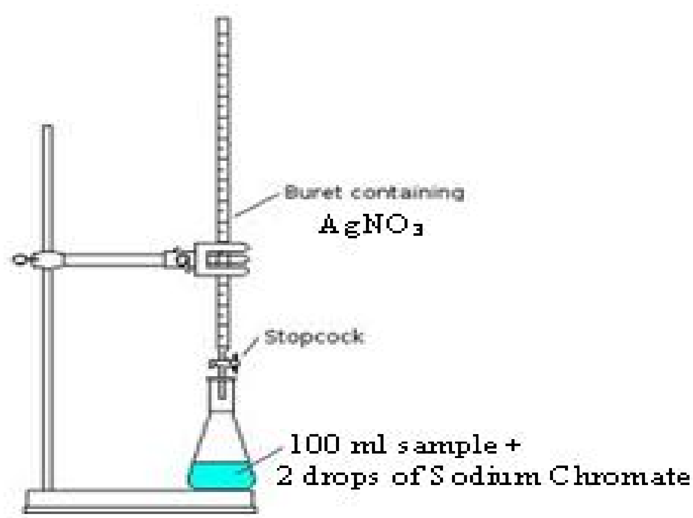


Figure (2.1): Titration equipment for Chloride analysis

2. Sampling Procedure of Water:

1- Usage of –very well Cleaned and closed- sampling bottles in the field. 1 L bottle are usually used for sample collection.
2- Removal of the caps from the bottles just before sampling while preserving the caps of the sampling bottle clean while collecting the sample.
3- Cleaning and washing the sampling bottle with sampled water before water collection at least 3 times before filling it with sample water.
4- The bottle is submerged in sampled water and allowed to be filled. If from a moving water body, upstream direction is preferable for sample collection.
5- The bottle is lifted out of the sampled water. If required, a small amount of water is decanted and the bottle is re-caped immediately, ensuring no hands contact with the insides of the bottles or caps.
6- Collection Bottle is labeled with ID and Date using a water resistant marker.
7- The sampling bottles must be packed and kept cool [but not frozen, otherwise the sample is damaged and unusable] in order to be transported back to the laboratory. The bottles must be kept out of the sun and away from any other heat sources.
8- Data Sheet Sampling Information must be filled. The following must be included in the sheet: Bottle ID, Date of collection, collector, location of collection plus GPS position of location, Field measurements with Multi-sampler, for the pH, EC, Temp., D.O, Salinity, ROP, ect…
9- Analysis of sample collected must be completed within a maximum time of 48 hours. It also depends on the substance desired to be analyzed since some analysis [eg. Bacteria] must be done instantly.
10- Most importantly, all safety precautions must be completed while sampling in the field and completing analysis in the laboratory.

APPENDIX C

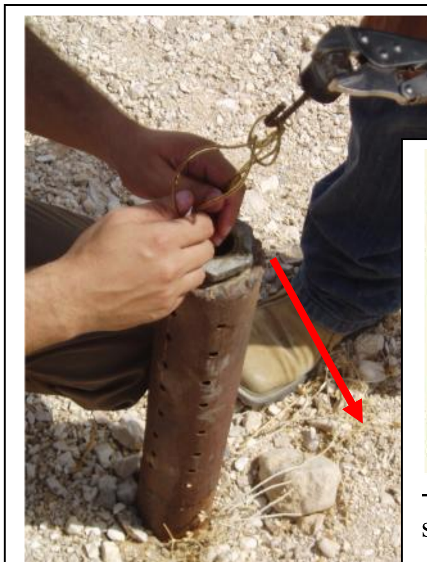
In this appendix, some photographs of the study area are shown.

Tributary number 1

Tributary number 2

Tributary number 3

Tributary number 4



-Divers used on the field for estimating the surface runoff of the wadies.

-4 different main tributaries were targeted to collect the data as presented in the pictures above.