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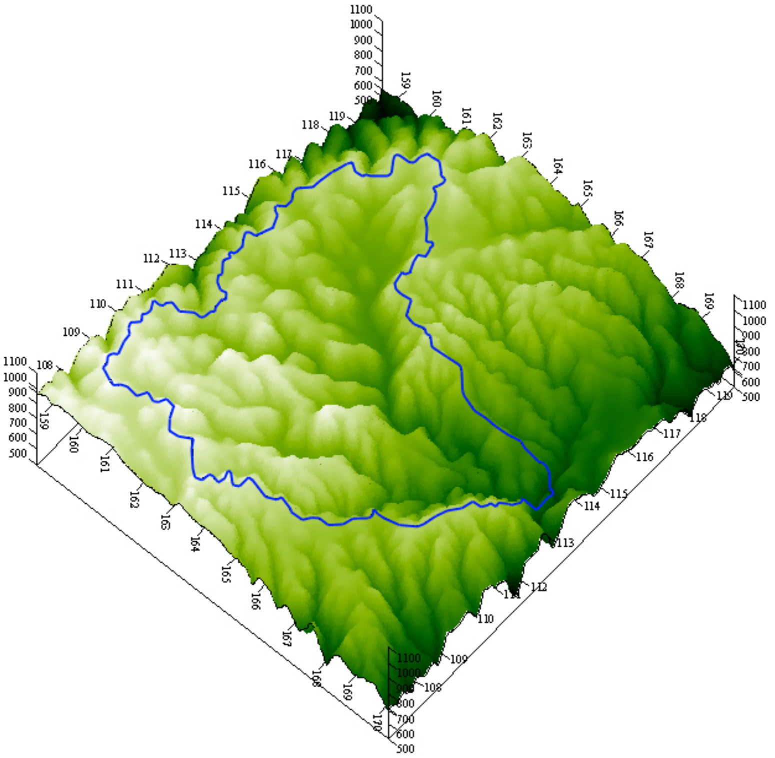

A hydrogeological, hydrochemical and environmental study in Wadi Al Arroub drainage basin, south west Bank, Palestine

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Ins Impressum

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Dedication

To my mother who supported me and lights up my life since my birth to this date

To my lovely wife "Taghreed" for her efforts, moral support and endless encouragement

To my children "Ahmed, Hazem and Mariam", for the understanding during my absence, with my love to them all.

Ziad

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ABSTRACT

This thesis contains the results of hydrological, hydrogeological, geomorphological and hydrochemical studies conducted between 1998-2002 on Wadi Al Arroub drainage basin / Palestine. The study catchment with an area of 61 km^2 is a sub-basin of the Dead Sea-Jordan River Basin and part of the Eastern Basin of the Mountain Aquifer. This work aims to compensate for the lack of information about this drainage catchment as well as to identify the different pollutants, their possible sources and impact on the water resources, to study the changes in the chemistry of the recharge water during the infiltration through the vadose zone, and to pinpoint on possible measures to improve the situation.

The main structure of this study includes; interviews to obtain information on the water related issues, fieldwork to confirm the results of the interviews and to identify and mapping the existing water resources. A digital elevation model was compiled to confirm the manually drawn water divide, incorporating the drainage system and to determine the coordinates and elevations of the wells and springs as a replacement of the GPS, which was not available for the researcher mainly because of political constrains. A landuse map was produced to show the main activities in the area and to be used in computing the runoff and recharge using the Soil Conservation Method (SCS) method. The DTM, landuse, geological, geomorphological and hydrogeological maps were compiled with the help of the GIS software package TNT-mips. Geological cross sections were also plotted.

The geology of the area is composed of sedimentary carbonate rocks of Albian to Holocene age. The deep wells tap the Albian and Turonian-Cenomanian regional aquifers, while the springs and dug wells discharge perched aquifers of Quaternary age.

The geomorphological study shows that the topography has more effect on the drainage pattern than the structure. The main effect of topography is in the W-E direction, while that of structure is mainly in the NNW-SSE direction and to some extent in the N-S direction. The relatively high relief ratio of Wadi Al Arroub drainage basin and the high elongation ratio (0.78) indicate that the study area is among the sub-basins that contributes strongly to the flooding in the Dead Sea-Jordan River Basin.

The hydrological study, which aimed mainly to estimate unavailable data such as runoff and recharge, shows that the annual precipitation over the area is 38.14 Mill.m^3. Based on daily data the average pan coefficient, potential evapotranspiration, runoff and actual evapotranspiration were calculated to be 0.72, 1108 mm/yr, 6.44 Mill. m^3/yr and 8.87 Mill. m^3/yr respectively. The empirical formulas of Wundt and Turc for the estimation of the actual evapotranspiration are not suitable for implementation in the study area. The aridity indices of De Martonne, UNESCO and Thornthwaite classify Wadi Al Arroub drainage basin as humid.

The hydrochemical study which involved collection and analysis of water samples from the deep and dug wells, springs, tap water, rain water and waste water showed that the rain water is the only source of ground water recharge. Mixing with the waste water leaking from the poorly designed cesspits and the waste water conduit and/or the infiltration of the leachates from washing the piles of animals dung by the rainfall in winter are the main factors responsible for the modifications in the water types and quality recorded in the area. Cluster analysis supported by the Kruskal-Wallis and Mann-Whitney tests classified the analyzed water samples into two main groups: Group A which consists of three subgroups, Group A1 includes the springs and dug wells located between the houses showing slight contamination;

group A_{2a} including the deep wells and Group A_{2b} including the dug wells and springs away from the conduit and housing showing a good water quality. Group B including the dug wells close to the conduit show the highest contamination. This statistical grouping is consistent with the classification of Piper and Durov.

The isotopical study aimed to determine the age and origin of the ground water bodies and to offer support for the hydrochemical analysis. To achieve this purpose samples were collected on April, 30th 1998 from 7 springs and wells and analyzed for ^{2}H, ^{18}O and ^{3}H and data was quoted from literature about the isotopic composition of precipitation. The study shows that the isotopic composition during the rainy season ranges for $\delta^{18}O$ between -12 ‰ and +4 ‰ and for $\delta^{2}H$ between -80 ‰ and +20 ‰. The isotopic content of the analyzed water samples plot on the Mediterranean Meteoric Water Line with average $\delta^{2}H$ of -25.9 ‰, $\delta^{18}O$ of -5.9 ‰ and d-excess of 21.1 ‰, proving their meteoric origin. The present ^{3}H content in precipitation is 5-6 TU, thus 5.7 TU in the water of El Bas spring, suggests recent recharge and tritium of meteoric origin. 0.4 TU in the water of Herodion well 4 tapping the Albian aquifer dates its water back to the early 1950's, while 1.5 TU in the water of Beit Fajjar well tapping the Turonian-Cenomanian aquifer dates it back to the late 1950's. The relatively enriched ^{2}H (-23.8 ‰) and ^{18}O (-5.56 ‰) and low ^{3}H (3.8 TU) in the water of the dug well of Haj Hamid-1, close to the conduit, supports the inference from the hydrochemistry, that the water of the well undergoes mixing with waste water leaking from the conduit.

To study the effect of the waste water conduit on the chemistry of the rain water during its infiltration through the vadose zone, soil water samples were collected with the help of the suction cup method at two different locations. The first location lies below the flooding level of the waste water conduit while the second is higher than it. The samples were collected at depths of 30, 60 and 90 cm. The results of the analysis showed that the soil water above the conduit indicated a calcium water type with increased alkalis (sodium) and prevailing bicarbonate at all sampling depths. Below the conduit, the calcium still dominating despite the gradual increase in sodium with depth. At the depth of 30 cm the bicarbonate dominates the anions, but with depth the chloride increases and it dominates the anions at the depth of 90 cm. In Durov diagram the samples collected from below conduit plot higher along the mixing line than those from below it indicating mixing of the infiltrated rain water with waste water of the conduit as evidenced by enhanced concentrations of sodium and chloride. The results reveals that all the measured parameters were much higher for the samples collected below the conduit than those from above it. The variations in the dominancy of the mineral phases at the two locations may be responsible for the variation in the calcium, magnesium, and silicate content of the soil water but not for the significant variations in the sodium, potassium, chloride, sulfate and nitrate which is predominantly attributed to mixing with waste water from the conduit. The electrical conductivity (EC) of the recharge water increase significantly in the first 30 cm of infiltration (from 64 µS/cm to 790 µS/cm above the conduit and to 1425 µS/cm below it and then increases gradually to reach 1180 µS/cm above the conduit and 1660 µS/cm below it at 90 cm depth. The increase of the EC with the depth mirrors generally a similar increasing trend of all the major parameters. It is obvious that the increase of the concentrations of the main chemical components becomes less with depth. This could be attributed to the decreasing aggressiveness of the infiltrating rain water as a result of its dissolution of mineral phases through its infiltration.

ZUSAMMENFASSUNG

Die Arbeit enthält die Ergebnisse von hydrologischen, hydrogeologischen, geomorphologischen und hydrochemischen Studien, die zwischen 1998-2002 im Einzugsgebiet des Wadi Al Arroub durchgeführt wurden. Das Arbeitsgebiet besitzt eine Fläche von 61 km^2 und ist ein Teil des östlichen Beckens des Mountain Aquifer bzw. ein Teil des Dead Sea - Jordan River Basins. Diese Arbeit hat das Ziel, wesentliche Informationsdefizite bezüglich des Einzugsgebietes zu schließen, sowie Schadstoffe und ihre möglichen Quellen und Wirkungen auf die Wasser-ressourcen zu identifizieren. Weiterhin werden die Änderungen des Sickerwasserchemismus während der Infiltration in der ungesättigten Wasserzone untersucht und mögliche Maßnahmen zur Verbesserung der Umweltsituation vorgeschlagen.

Wesentlicher Bestandteil der Studie war die Durchführung von Gesprächen mit Fachleuten bzw. Behörden, um wasserrelevante Informationen zum Untersuchungsgebiet zu erhalten. Darauf folgten Feldarbeiten mit dem Ziel, die existierenden Wasserressourcen aufzuzeigen, zu klassifizieren und zu kartieren. Ein digitales Geländemodell wurde erstellt, um die abschnittsweise, unsichere Lage der Wasserscheide zu verifizieren, das existierende Abflusssystem abzubilden sowie weitere, notwendige Informationen, wie Raumkoordinaten der Brunnen und Quellen - als Ersatz für eine GPS-Ausrüstung, die nicht für den Forscher hauptsächlich wegen politischen Begrenzungen vorhanden war, abzuleiten. Um die Hauptnutzungsaktivitäten im Untersuchungsgebiet aufzuzeigen und deren Berücksichtigung bei der Berechnung von Oberflächenabfluss und Grundwasserneubildung mit Hilfe der Methode des Bodenerhaltungsservice (SCS) zu gewährleisten, wurde eine Landnutzungskarte erstellt. Zusammengefasst und verdichtet wurden alle zur Verfügung stehenden Ergebnisse in thematischen Karten zur regionalen Geologie, Geomorphologie sowie Hydrogeologie mit Hilfe des GIS-Softwarepaketes TNT-mips. Zusätzlich werden geologische Profile präsentiert.

Die Geologie des Gebietes ist durch sedimentäre Carbonatgesteine des Albs bis Holozän gekennzeichnet. Die Wässer der tiefen Brunnen entstammen den Alb- und Turon-Cenoman-Aquiferen, die Wässer der Schachtbrunnen und Quellen dagegen oberflächennahen Aquiferen des quartären Alters.

Eine Analyse der geomorphologischen Situation ergibt, dass die Topographie einen weitaus bedeutenderen Einfluss auf das Abfluss- als das Störungsmuster ausübt. Erstere gibt die dominierende W-E-Richtung vor, das Störungsmuster dagegen ist in NNW-SSE- bis N-S-Richtung angelegt. Die verhältnismäßig hohe Reliefenergie im Einzugsgebiet von Wadi Al Arroub sowie das große Längungenverhältnis (0,78) zeigen, dass es sich um ein bedeutendes Subbecken handelt und einen großen Beitrag zum Wasserabfluss in das Becken des Toten Meers-Jordangraben leistet.

Die hydrologischen Untersuchungen und Datenauswertungen, die hauptsächlich darauf ausgerichtet waren, bisher nicht verfügbare Daten zu Oberflächenabfluss und Grundwasserneubildung zu liefern, belegen unter anderem einen geschätzten, mittleren Jahresniederschlag von 38,14 Mio. m^3/a über dem Gebiet. Basierend auf Tagesdaten wurden Verdunstungskoeffizient, potentielle Evapotranspiration, Oberflächenabfluss und aktuelle Evapotranspiration mit 0,72, 1108 mm/a, 6,44 Mio. m^3/a und 8,87 Mio. m^3/a berechnet. Die Anwendung der empirischen Formel von Wundt und Turc für die Ermittlung der aktuellen Evapotranspiration muss aufgrund des heutigen Kenntnisstandes für das Untersuchungsgebiet

abgelehnt werden. Aufgrund der Dürreindizes von De Martonne, Thornthwait sowie der UNESCO lässt sich das Einzugsgebiet des Wadi Al Arroub als humid einstufen.

Durch die Studien zum hydrochemischen Charakter der gewonnenen Proben aus Tief- und Schachtbrunnen, Quellen und Leitungssystemen sowie von Regenwasser und Abwasser, konnte gezeigt werden, dass der Niederschlag die einzige Neubildungsquelle für Grundwasser ist. Vermischung von Niederschlag mit Abwasser aus unzulänglich gesicherten Senkgruben und dem Abwasserkanal bzw. die chemische Aufkonzentration mit umweltrelevanten Verbindungen bei der Durchsickerung von ungeschützten Lagerflächen für Tierdung durch Niederschlagswasser sind die Hauptfaktoren für die Entstehung modifizierter Wassertypen und die geringe Wasserqualität im untersuchten Gebiet. Eine durchgeführte Cluster-Analyse, gestützt auf die Tests nach Kruskal-Wallis und Man-Whitney unterteilt die analysierten Wasserproben in zwei Hauptgruppen A und B. Für die Gruppe A, welche ausschließlich nicht- bis gering kontaminierte Wässer einschließt, lassen sich des weiteren drei Untergruppen ausweisen. Quellen und Schachtbrunnen, die sich zwischen den Häusern befinden und eine geringe Kontamination zeigen, werden als Gruppe A1 zusammengefasst. Eine gute Wasserqualität weisen alle Tiefbrunnen (Gruppe A2a) auf. Dies gilt ebenfalls für die Schachtbrunnen und Quellen, die sich nicht in direktem Einflussbereich von Abwasserkanal und Häusern befinden und somit den Stamm der Gruppe A2b bilden. Sehr hohe Kontamination ist für die beprobten Schachtbrunnen der Gruppe B charakteristisch. Sie liegen nahe des Abwasserkanals. Diese statistische Einteilung ist vergleichbar mit der Klassifikation von Piper und Durov.

Zur Stützung der getroffenen Aussagen aus den hydrochemischen Analysen wurde am 30.4.1998 eine Beprobung von sieben Quellen und Schacht- bzw. Tiefbrunnen auf ihre ^{2}H-, ^{18}O- und ^{3}H-Gehalte vorgenommen. Isotope sind im allgemeinen gute Tracer für die Ermittlung von Eintragspfaden und mittleren Verweilzeiten des Grundwassers. Daten über die Isotopenzusammensetzung des Niederschlages wurden der zugänglichen Literatur entnommen. Die Isotopenzusammensetzung während der regnerischen Jahreszeit (Winter) schwankt für δ^{18}O zwischen –12 ‰ und +4 ‰ und für δ^{2}H zwischen -80 ‰ und +20 ‰. Die δ^{18}O- und δ^{2}H-Werte aller Proben liegen auf der Mediterranian Meteoric Water Line mit Mittelwerten für δ^{2}H von –25,9 ‰ für δ^{18}O von –5,9 ‰ und einem Deuteriumexzess von 21,1 ‰. Dies beweist ihren meteorischen Ursprung. Der gegenwärtige ^{3}H-Gehalt des Niederschlages liegt bei durchschnittlich 5-6 TU. Die Tritiumanalyse für die Quelle El Bas (5,7 TU) legt aus diesem Grund einen jungen, meteorischen Ursprung nahe. Als praktisch tritiumfrei kann das aus dem tiefen Alb-Aquifer geförderte Grundwasser des Tiefbrunnens Herodion 4 aufgefasst werden. Dessen Tritiumgehalt von 0,4 TU weist auf einen Infiltrationszeitpunkt von spätestens in den frühen 50er Jahren hin, während der Gehalt von 1,5 TU in der Probe vom Tiefbrunnen Beit Fajjar 3 (Turon-Cenoman-Aquifer) auf die späten 50er Jahre hinweisen könnte. Vermutungen zur Mischung von Niederschlags- und Abwasser in Abhängigkeit zur örtlichen Situation werden ebenfalls durch die Isotopenanalysen untermauert. Dies wird deutlich durch die relativ hohen ^{2}H- (-23,8 ‰) und ^{18}O-Werte (-5,56 ‰) sowie dem erniedrigten ^{3}H-Gehalt von 3,8 TU im Wasser des Schachtbrunnen von Haj Hamid 1, der neben dem Abwasserkanal liegt. Dies ist eine weitere Bestätigung für die Aussage, dass es sich um die genannten, durch Zutritt von Abwasser aus dem leckenden Abwasserkanal zum Grundwasser gebildeten Mischwässern handelt.

Um den Einfluss des Abwasserkanals auf die Chemie des Regenwassers während seiner Infiltration durch die vadose Zone zu studieren, wurden Sickerwasserproben mit Hilfe von Saugkerzen aus zwei unterschiedlichen Positionen entnommen. Die erste Position liegt unterhalb des Überschwemmungsniveaus des Abwasserkanals, die zweite darüber. Die Proben wurden in den Tiefen von 30, 60 und 90 cm gesammelt. Die Resultate der Analyse zeigen, dass Sickerwasser oberhalb des Kanals als Kalziumkarbonat-Typ, mit erhöhten Alkalien (Natrium) und vorherrschendem Hydrogenkarbonat an allen Abnahmestellen vorliegt. Unterhalb des Kanals herrscht Kalzium trotz teufeabhängiger Zunahme von Natrium vor. In einer Tiefe von 30 cm dominiert Hydrogenkarbonat gegenüber Chlorid, welches mit der Tiefe zunimmt und bei 90 cm unter Geländeoberkante vorherrscht. Im Durov Diagramm liegen alle analysierten Wasserproben auf der Mischungsgeraden. Die Proben von unterhalb des Kanals sind auf der Mischungsgeraden weiter in Richtung Natrium-Chlorid-Typ verschoben, als die Proben von oberhalb des Kanals. Somit ist die Mischung des eingesickerten Regenwassers mit Wasser aus dem unabgedichteten Abwasserkanal anhand der erhöhten Konzentrationen von Natrium und Cl nachgewiesen. Das Ergebnis zeigt, dass alle gemessenen Parameter für die Proben unter dem Kanal viel höher waren als darüber. Die Veränderungen der verschiedenen Mineralphasen im Boden können zwar eine Variation im Kalzium-, Magnesium-, Hydrogenkarbonat- und Siliziumoxid- Gehalt des Sickerwassers erklären, jedoch nicht für die bedeutenden Schwankungen für Natrium, Kalium, Chlorid, Sulfat und Nitrat verantwortlich sein. Dies ist auf das Mischen von Abwasser aus dem Kanal mit dem Sickerwasser zurückzuführen. Die Leitfähigkeit des Sickerwassers nimmt in den ersten 30 cm erheblich zu, von 64 µS/cm auf 790 µS/cm für oberhalb des Kanals gelegene Areale bzw. auf 1425 µS/cm für unterhalb gelegene. Bis 90 cm Tiefe steigt die Leitfähigkeit kontinuierlich auf 1180 µS/cm bzw. 1660 µS/cm an. Dieser Anstieg geht mit der generellen Tendenz steigender Gehalte der Hauptparameter einher. Auffallend ist die geringer werdende Zunahme für die genannten chemischen Hauptkomponenten mit der Tiefe. Zuzuschreiben ist dies der abnehmenden Aggressivität des infiltrierenden Regenwassers, hervorgerufen durch das Lösen von Mineralphasen auf seinem Sickerpfad durch den Boden.

ملخص

تحتوي الأطروحة على نتائج الدراسات الهيدرولوجية والهيدروجيولوجية والجيومورفولوجية والهيدروكيميائية التي تم إجرائها خلال الفترة ما بين عامي 1998 و 2002 في حوض وادي العرّوب/ فلسطين. يعتبر هذا الحوض جزءاً من حوض نهر الأردن – البحر الميت والحوض الشرقي للخزان الجبلي وتبلغ مساحته قرابة 61كم^2.

تهدف هذه الدراسة إلى التعويض عن نقص المعلومات المتعلقة بهذا الحوض، بالإضافة إلى تحديد مصادر الملوثات المختلفة وأثرها على مصادر المياه. وتهدف الدراسة أيضاً إلى دراسة التغيرات في كيميائية مياه التغذية خلال عملية الترشيح عبر نطاق التهوية، إضافة إلى ذلك تحديد الإجراءات اللازمة لتحسين هذا الوضع.

تضمنت المحتويات الرئيسية لهذه الدراسة، المقابلات الشخصية من أجل الحصول على المعلومات المتعلقة بقضايا المياه، العمل الميداني لتثبيت المعلومات المتحصل عليها من خلال المقابلات ومن أجل تحديد مصادر المياه في منطقة الدراسة. وقد تم إنجاز النموذج الرقمي للارتفاعات للتثبت من تحديد حدود الحوض ونظام التصريف وتحديد مواقع الآبار والينابيع للتعويض عن طريقة نظام تحديد الموقع الذي لم يتوفر للباحث بسبب الأوضاع السياسية. تم أيضاً إنتاج خارطة استعمالات الأراضي من أجل تحديد النشاطات الرئيسية في الحوض للإستفادة منها في حوسبة الجريان السطحي والرشح وذلك بإستخدام طريقة المحافظة على التربة. ولقد تم إعداد النموذج الرقمي للإرتفاعات و خارطة استعمالات الأراضي والخرائط الجيولوجية والجيومورفولوجية والهيدرولوجية بإستخدام رزمة برمجيات نظام المعلومات الجغرافية والمساحة TNT-mips. وقد تم أيضاً رسم مقاطع جيولوجية لمنطقة الدراسة.

تتكون جيولوجية المنطقة من الصخور الرسوبية الجيرية والتي تعود إلى العصر الألبي وحتى الهولوسين (الحديث). تخترق الآبار العميقة صخور العصر الألبي والتوروني والسينوماني والتي تشكل خزاناً جوفياً واسع الإنتشار في حين أن الينابيع والآبار اليدوية المحفورة في المنطقة تخترق الخزانات الجوفية المعلقة من العصر الرباعي.

دلت نتائج الدراسة الجيومورفولوجية أن لطوبوغرافية المنطقة أثراً أكبر على نظام التصريف من التراكيب الجيولوجية وأن أثر الطوبغرافيا الأساسي هو في إتجاه شرق – غرب في حين ان للتراكيب الجيولوجية الدور الأساسي في إتجاهات شمال شمال غرب – جنوب جنوب شرق وبدور أقل في إتجاه شمال – جنوب. ويمتاز حوض وادي العرّوب بنسبة عالية للانحدار ونسبة استطالة مرتفعة (0.78) وهذا يشير أن حوض وادي العروب من الأحواض المشاركة بفعالية في فيضانات حوض البحر الميت – نهر الأردن.

هدفت الدراسة الهيدرولوجية إلى تقدير معدلات الجريان السطحي والرشح وقد تبين أن معدل حجم الأمطار السنوية على الحوض تصل إلى 38.14 مليون متر مكعب/سنة. وبالإعتماد على البيانات اليومية تم حساب معامل حوض التبخر(0.72) والتبخر - نتح الكامن وهي (1108 ملم/سنة) والجريان السطحي (6.44 مليون متر مكعب/سنة) بالإضافة إلى التبخر- نتح الحقيقي (8.87 مليون متر مكعب/سنه). وبينت الدراسة أن المعادلات التجريبية لفندت (Wundt) وتيرك (Turc) غير مناسبة لحساب التبخر – نتح الحقيقي لمنطقة الدراسة. وباستخدام معاملات الجفاف المختلفة فقد تبين بأن منطقة الدراسة يمكن إعتبارها رطبة.

وبينت الدراسة الهيدروكيميائية والتي تتمثل بجمع وتحليل عينات المياه من الآبار العميقة والمحفورة يدوياً والينابيع ومياه الشبكة ومياه الأمطار والمياه العادمة بأن مصدر المياه الجوفية الوحيد هو مياه الأمطار. وبينت أن إختلاط المياه مع المياه العادمة المتسربة من الحفر الإمتصاصية سيئة التصميم ومن شبكة المجاري ومن ترشح العصارة الناتجة عن غسل فضلات الحيوانات بواسطة مياه الأمطار في فصل الشتاء هي العوامل الرئيسية المسؤولة عن تغير نوعية ونوع المياه في المنطقة. بالإستفادة من التحليل العنقودي وفحوصات (Kruskal – Wallis and Mann – Whitney) تم تصنيف عينات المياه المحللة إلى مجموعتين رئيسيتين. المجموعة (A) والتي تشتمل على ثلاث مجموعات فرعية، المجموعة A1 والتي تتضمن الينابيع والآبار المحفورة يدوياً والواقعة بين المنازل وأظهرت وجود تلوث طفيف والمجموعة A2a والتي تتضمن الآبار العميقة والمجموعة A2b والمتضمنة الآبار المحفورة يدوياً والينابيع البعيدة عن شبكة المجاري والمنازل وأظهرتا نوعية مياه جيدة. وأما المجموعة الثانية (B) والتي تتضمن الآبار المحفورة يدوياً والقريبة من شبكة المجاري فلقد أظهرت أعلى نسبة من التلوث. وهذا التصنيف الإحصائي متوافق مع تصنيفات Piper and Durov.

هدفت دراسة النظائر إلى تحديد عمر وأصل المياه الجوفية بالإضافة إلى المساعدة في تفسير التحليل الهيدروكيميائي. ومن أجل تحقيق هذا الهدف، تم جمع مجموعة من العينات من سبعة ينابيع وآبار في تاريخ 1998/4/30 وتم تحليل ^{3}H, ^{18}O, ^{2}H إضافة إلى ذلك فقد تمت الإستفادة من المعلومات السابقة المتوفرة حول التركيب النظائري لمياه الأمطار. أظهرت الدراسة أن التركيب النظائري خلال الموسم المطري لـ $\delta^{18}O$ يتراوح ما بين –12‰ و +4‰، أما بالنسبة $\delta^{2}H$ فقد تراوحت ما بين –80‰ و + 20‰. وجد أن المحتوى النظائري لعينات المياه المحللة يقع على خط مياه البحر المتوسط Mediterranean Meteoric Water Line بمعدل –25.9‰ $\delta^{2}H$ و5.9‰ لـ $\delta^{18}O$ ، بينما كان معدل الفائضة يساوي 21.1‰، مثبتاً اصلها جوي meteoric. محتوى مياه الأمطار الحالي من ^{3}H هو 5-6 وحدات ترتيوم (TU)، لذلك فإن وجود نسبة 5.7 وحدة ترتيوم (TU) في مياه نبع (البص) تشير إلى تغذية حديثة وأصل جوي للتريتيوم. يشير وجود 0.4 وحدة ترتيوم (TU) في مياه بئر (هيروديون4) المتغذي من الخزان الألبي (Albian aquifer) إلى عمر مياه يعود إلى بداية الخمسينات، بينما وجود وحدة ترتيوم ونصف في مياه بئر بيت (فجّار) المتغذي من الخزان التوروني – السينوماني تشير إلى عمر مياه يعود إلى نهاية الخمسينات. وجود إثراء نسبي لـ ^{2}H (23.8‰) و ^{18}O (0.06‰) وإنخفاض ^{3}H (3.8 وحدة ترتيوم) في مياه بئر (حاج حامد / 1) الضحل القريب من شبكة المجاري يدعم الاستنتاج الهيدروكيميائي بأن مياه البئر تتعرض لعملية خلط مع المياه العادمة المتسربة من شبكة المجاري.

لدراسة تأثير قناة مياه المجاري على كيميائية مياه الأمطار خلال عملية الترشيح عبر نطاق التهوية تم جمع عينات مياه تربة باستخدام أكواب الامتصاص في موقعين مختلفين. الأول يقع فوق مستوى فيضان قناة مياه المجاري وأما الثاني فيقع تحت مستوى الفيضان. تم جمع العينات على أعماق 30سم و 60سم و 90سم. أظهرت نتائج التحليل أن مياه التربة الواقعة فوق مستوى الفيضان من نوع كربونات الكالسيوم مع زيادة في القلويات (الصوديوم) ونوع البايكربونات في جميع الأعماق. تحت مستوى الفيضان، لا يزال الكالسيوم سائد بالرغم من الزيادة التدريجية للصوديوم مع العمق. على عمق 30 سم كانت البايكربونات هي السائدة على الأيونات السالبة، ولكن مع العمق يزداد الكلوريد ويكون هو السائد على عمق 90سم. وقعت العينات التي تم جمعها تحت مستوى الفيضان على مخطط دروروف (Durov) أعلى من خط الخلط وهذا يدل على عملية خلط مياه الأمطار المترشحة مع المياه العادمة من الشبكة، ومما يدل على ذلك زيادة تراكيز الصوديوم والكلوريد. كشفت النتائج أن كل العوامل التي تم قياسها كانت أعلى بكثير للعينات التي جمعت تحت مستوى الفيضان من تلك التي جمعت فوقه. قد تكون التغيرات في سيادة أطوار المعادن في كل من الموقعين هي المسؤولة عن تفاوت محتوى مياه التربة من الكالسيوم والمغنيسيوم والسيليكات وهذا ليس لها علاقة كبيرة في تفاوت محتوى الصوديوم والبوتاسيوم والكلوريد والكبريتات والنترات، والتي تعزى لعملية الخلط مع المياه العادمة من شبكة المجاري. تزداد قيم الإيصالية الكهربائية (EC)

لمياه التغذية بشكل كبير في أول 30سم من عملية الترشح من 64 ميكروسيمنز/سم إلى 790 ميكروسيمنز/سم فوق مستوى الفيضان وإلى 1425 ميكروسيمنز/ سم تحته، وبعد ذلك تزداد بشكل تدريجي لتصل إلى 1180 ميكروسيمنز/سم فوق مستوى الفيضان وإلى 1660 ميكروسيمنز/سم تحته على عمق 90سم. تتوافق زيادة الإيصالية الكهربائية (EC) مع العمق بشكل عام مع إتجاه زيادة متماثلة لكل العوامل الرئيسية الأخرى. من الواضح أن الزيادة في تراكيز المكونات الكيميائية الرئيسية أصبحت بشكل أقل مع العمق، وهذا قد يعزى إلى نقصان قدرة الإذابة لمياه الأمطار المترشحة كنتيجة لإذابتها لأطوار المعادن خلال عملية ترشحها.

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#	number
$	US dollars
%	percent
and	and
°	degree
°C	degree centigrade (Celsius scale)
°F	degree Fahrenheit (Fahrenheit scale)
‰	per mil
1°	first order (geomorphology)
^{18}O	oxygen-18
2°	second order (geomorphology)
^{2}H	deuterium
3°	third order (geomorphology)
^{3}H	tritium
4°	fourth order (geomorphology)
A	area
AD	after the birth of Christ (anno domini in Latin)
AET	actual evapotranspiration
Al_2O_3	aluminium oxide
ALPA	Albian lower perched aquifer
AMC	antecedent moisture classes
ANOVA	analysis of variance (between groups)
ARIJ	Applied Research Institute-Jerusalem
ArrLPA	Arroub lower perched aquifer
ArrUPA	Arroub upper perched aquifer
As	arsenic
ASTM	American Society for Testing and Material
Asym.	asymmetric
AUPA	Albian upper perched aquifer
B’TSELEM	Israeli Information Center for Human Rights in the Occupied Territories
BC	before Christ
BOD_5	biological oxygen demand (five days)
Ca^{2+}	calcium (ion)
CAS-Nr	Chemical Abstract Service Number
Cd	cadmium
CenLPA	Cenomanian lower perched aquifer
Cen-Tur	Cenomanian-Turonian
CenUPA	Cenomanian upper perched aquifer
C_{gw}	chloride concentration of the ground water
Cl^-	chloride (ion)
Cl_2	chlorine
cm	centimeter
CN	curve number
CO_2	carbon dioxide
COD	chemical oxygen demand
CP	pan coefficient
C_p	weighted average chloride concentration in precipitation
Cr	chromium

Cu	copper
D-excess	measure of deuterium enrichment that exceeds the $\delta\ ^{18}O$ value by more than 8 times
DO	dissolved oxygen
ΔS	depression storage
DTM	digital terrain model
DVWK	Deutscher Verband für Wasserwirtschaft und Kulturbau
Dw	dug well
E	east
EC	electrical conductivity
EDTA	ethylenediaminetetraacetic acid
e.g.	for example
EPD	Environmental Planning Directorate
ESP	Environmental Strategy Plan
et al.	and others
ETP	potential evapotranspiration
F^-	fluoride (ion)
F_a	rain water retained in the watershed
FAO	Food and Agriculture Organization - United Nations
FC	fecal coliform bacteria
Fe	iron
Fig.	figure
GC-MS	gas chromatograph – mass spectrometer
GIS	Geological Information System
GPS	Global Positioning System
GSF	Forschungszentrum für Umwelt und Gesundheit - München
GTZ	Deutsche Gesellschaft für Technische Zusammenarbeit
h	hour
HCl	hydrochloric acid
HCO_3^-	bicarbonate (ion)
I	interception
I_a	initial abstraction
IAEA	International Atomic Energy Agency
i.e.	that is
K^+	potassium (ion)
K_{IAP}	ion activity product
Km	kilometer
Km^{-1}	per kilometer
Km^2	square kilometer
K-S	Kolmogorov-Smirnov
K_{sp}	solubility product
L	liter (volume)
L	stream length (geomorphology)
m	meter
m^3	cubic meter
masl	meter above sea level
Max.	maximum
mbgl	meter below ground level
mbsl	meter below sea level
MCL’s	maximum contamination levels

MEnA	Ministry of Environmental Affairs
meq	milliequivalent
mg	milligram
Mg^{2+}	magnesium (ion)
Mill. m^3/yr	million cubic meter per year
Min.	minimum
Mio. m^3/a	million cubic meter per annum
mm	millimeter
MMWL	Mediterranean Meteoric Water Line
Mn	manganese
MOPIC	Ministry of Planning and International Cooperation, Palestinian Authority
MWL	meteoric water line
N	north (direction)
N	stream number (geomorphology)
Na^+	sodium (ion)
NE	northeast
NEAP	National Environmental Action Plan
Ni	nickel
NNE	north-northeast
NNW	north-northwest
NO_3^-	nitrate (ion)
Nor.	normal
N_u	stream number of (u) order
NW	northwest
P	precipitation
Pb	lead
PCBS	Palestinian Central Bureau of Statistics
PE	potential evaporation
PE_c	potential evaporation – mesh corrected
PEnA	Palestinian Environmental Authority
PET	potential evapotranspiration
PG	Palestinian Grid
pH	acidity value
pH_c	acidity values at equilibrium with calcite
PNAMO	Palestinian National Authority – Meteorological Office
PO_4^{3-}	phosphate (ion)
PVC	poly vinyl chloride
PWA	Palestinian Water Authority
Q	runoff
R	recharge (hydrology)
R	resistivity (hydrochemistry)
R_b	bifurcation ratio
R_c	circularity ratio (geomorphology)
R_e	elongation ratio (geomorphology)
RH%	relative humidity
RSC	residual sodium carbonate
S	siemens (units of EC)
S	south (direction)
S	potential retention (hydrology)

SAR	sodium adsorption ratio
SCS	Soil Conservation Service - USA
SE	southeast
SI	saturation index
Sig.	significant
SiO_2	silica
SMOW	standard mean ocean water
SO_4^{2-}	sulfate (ion)
Sp	spring
SSE	south-southeast
SSP	soluble sodium percentage
SSW	south-southwest
std. dev.	standard deviation
SW	southwest
T	temperature
TC	total coliform bacteria
TDS	total dissolved solids
Temp	temperature
TS	total solids
TSS	total suspended solids
TU	tritium units
TUBAF	Technische Universität Bergakademie Freiberg, Freiberg, Sachsen / Germany
U	stream order (geomorphology)
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNRWA	United Nation Relief and Works Agency
US	up stream
VOC’s	volatile organic chemicals
WA	Wadi Al Arroub
WB	Wadi El Bas
WD	Wadi Ed Dur
WHO	World Health Organization
WK	Wadi Kuweisiba
WL	water level
WM	Wadi Marina
WQ	Wadi Qufeen
WSERU	Water and Soil Environmental Research Unit – Chemistry Department, Bethlehem University, Palestine.
WSh	Wadi Esh Shinar
WShKh	Wadi Esh Sheikh
WShrq	Wadi Esh Sharq
WT	Wadi Eth Tharwa
X	aridity index
yr	year
Zn	zinc
ΔM	change in the soil moisture
α	significant level
δ‰	deviation of the isotopic concentration in water from the SMOW
μm	micrometer
μS	micro siemens

1 INTRODUCTION

The scarcity of the water resources in the West Bank, due to arid to semi-arid climate, overexploitation, mismanagement as well as the fact that these resources are shared with Israel, gave it a great importance. It is the most valuable and precious resource of the region. Because of this importance, water become the central issue in the bilateral and multilateral peace talks. The area of this study, Wadi Al Arroub drainage basin, suffers from the water scarcity as do the whole West Bank. The people experience frequent interruptions or even absence of tap water supply for long periods. This forces the people to utilize the water of unprotected springs and open pits (dug) wells, and/or to pay a 4-5 fold price obtaining water from trucks to fulfill their basic domestic needs. The scarcity of water is also a main reason that causes the farmers not to cultivate their land and thus allowed urban expansion on agricultural land.

The area of Wadi Al Arroub drainage basin enjoys a Mediterranean climate with hot and dry summers and mild and wet winters. The average annual rainfall from 1953 to 2001 was about 607 mm. However from 1991 to 1992 1200 mm was determined, on contrary from 1998 to 1999 only 212 mm. The average annual potential evaporation of about 1600 mm is more than two times the average annual rainfall. The elevation attains it highest altitude with 1020 masl at Jabal Halhul at the southwestern edge of this catchment and drops to 700 masl at the eastern edge where Wadi Al Arroub joins Wadi Ghar. The ground water resources in this area are mainly endangered by inadequate waste water disposal since Wadi Al Arroub is used as an open conduit for untreated waste water from Al Arroub Refugee Camp. Furthermore about 5000 to 6000 poorly designed cesspits are used for the disposal of black water.

The Wadi Al Arroub drainage basin was chosen for the present study, as there is a lack of data concerning the hydrology, hydrogeology and hydrochemistry. Secondly, evidence of serious pollution from the many springs in this basin as well as the sewage flow along the talweg is a significant health hazard for the local inhabitants. Talweg is a geomorphological term meaning the line of lowest points along a valley floor, normally the stream channel (Grimes 1995 and Papy and Souchere 1993). This study attempts to compensate for the lack of information available about this conduit, the springs discharging to this drainage catchment as well as relevant dug wells in the area.

1.1 Location

Wadi Al Arroub drainage basin with an area of 61 km^2 is situated midway between Hebron and Bethlehem. It is part of the Hebron District which represents the southern part of the West Bank / Palestine. The selected catchment area lies within 35°05`00" and 35°13`51" longitude 31°32`50" and 31°40`20" latitude respectively between 108-120 N and 158-170 E referenced on the Palestinian Grid (Fig. 1.1). This catchment, that drains part of the Hebron Mountains, is a sub-basin of the Jordan River-Dead Sea basin. The Wadi Al Arroub is a tributary to the Wadi Ghar joining it at the western edge of the Jerusalem Desert.

1.2 Landuse

Wadi Al Arroub drainage basin includes within its boundaries all or part of nine Palestinian communities, Arroub Camp, Shuyukh Al Arroub, Kuweisiba, Urqan Tarrad, Si'ir, Esh-Shuyuk, Beit Ummar, Halhul and Beit Fajjar and parts of 3 Israeli settlements: Kefar Ezyon, Karme Zur and Asfar. Various landuse activities could be identified in this area (Fig. 1.2).

The landuse map was drawn with the help of the GIS program TNT-mips (Microimages Inc. 2001) based on a helicopter-photo (1985), development plans for the Palestinian communities (Local Councils, personal communication 1999) as well as the help of 1:50 000 topographic map. The area and the distribution of the main landuse activities in Wadi Al Arroub drainage basin are summarized in Table 1.1.

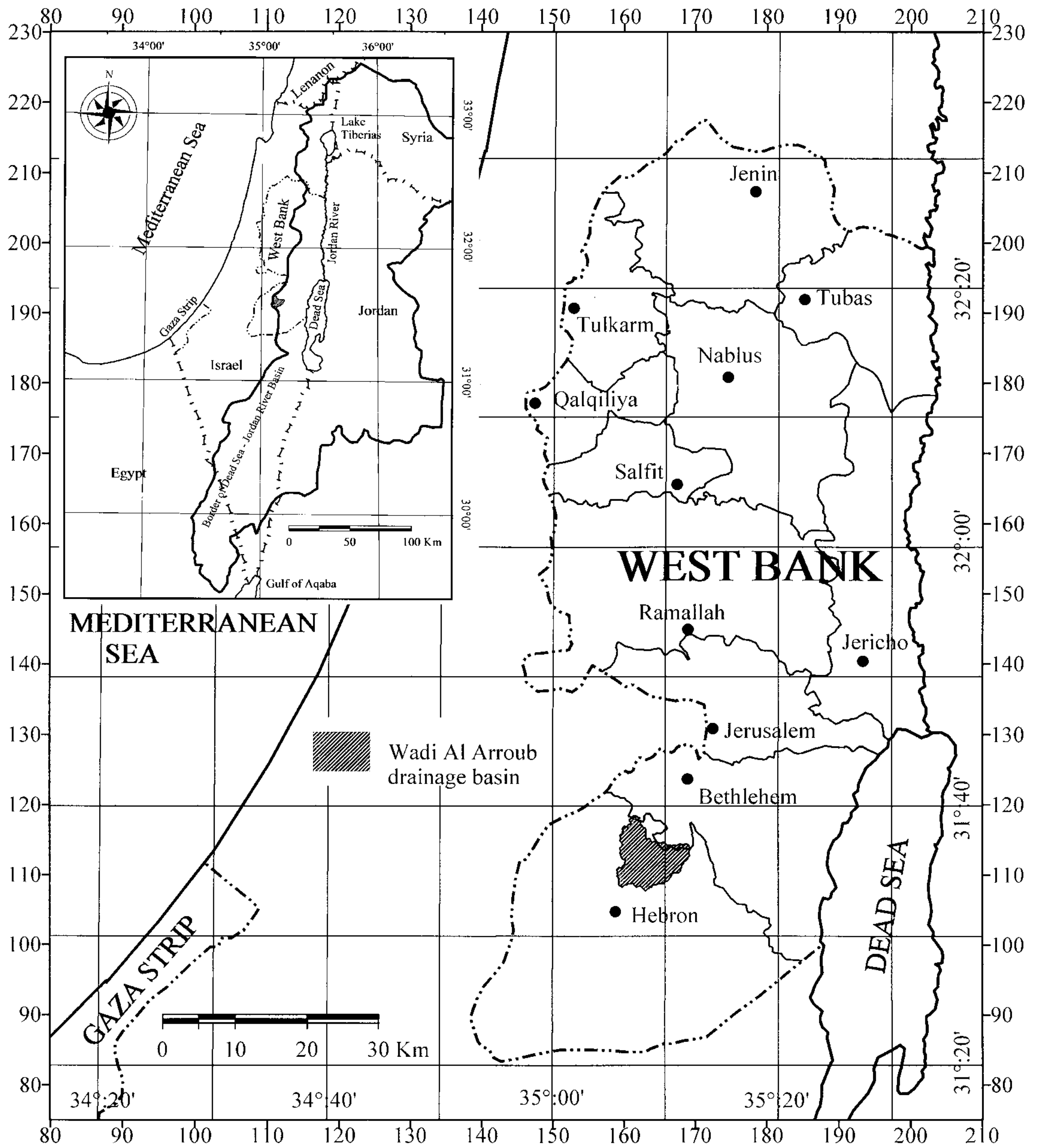


Fig. 1.1: Map of the Wadi Al Arroub drainage basin.

1.3 Population

Based on the study of the PCBS (1999), the Palestinian population of Wadi Al Arroub drainage basin was estimated to be about 39,000 inhabitant; 7000 in Arroub Camp, 1500 in Shuyukh Al Arroub, 1000 in Kuweisiba and Urqan Tarrad, 11000 in Si'ir, 6000 in Esh-Shuyukh and approximate 1500 in Beit Fajjar, 5000 in Beit Ummar and 6000 in Halhul.

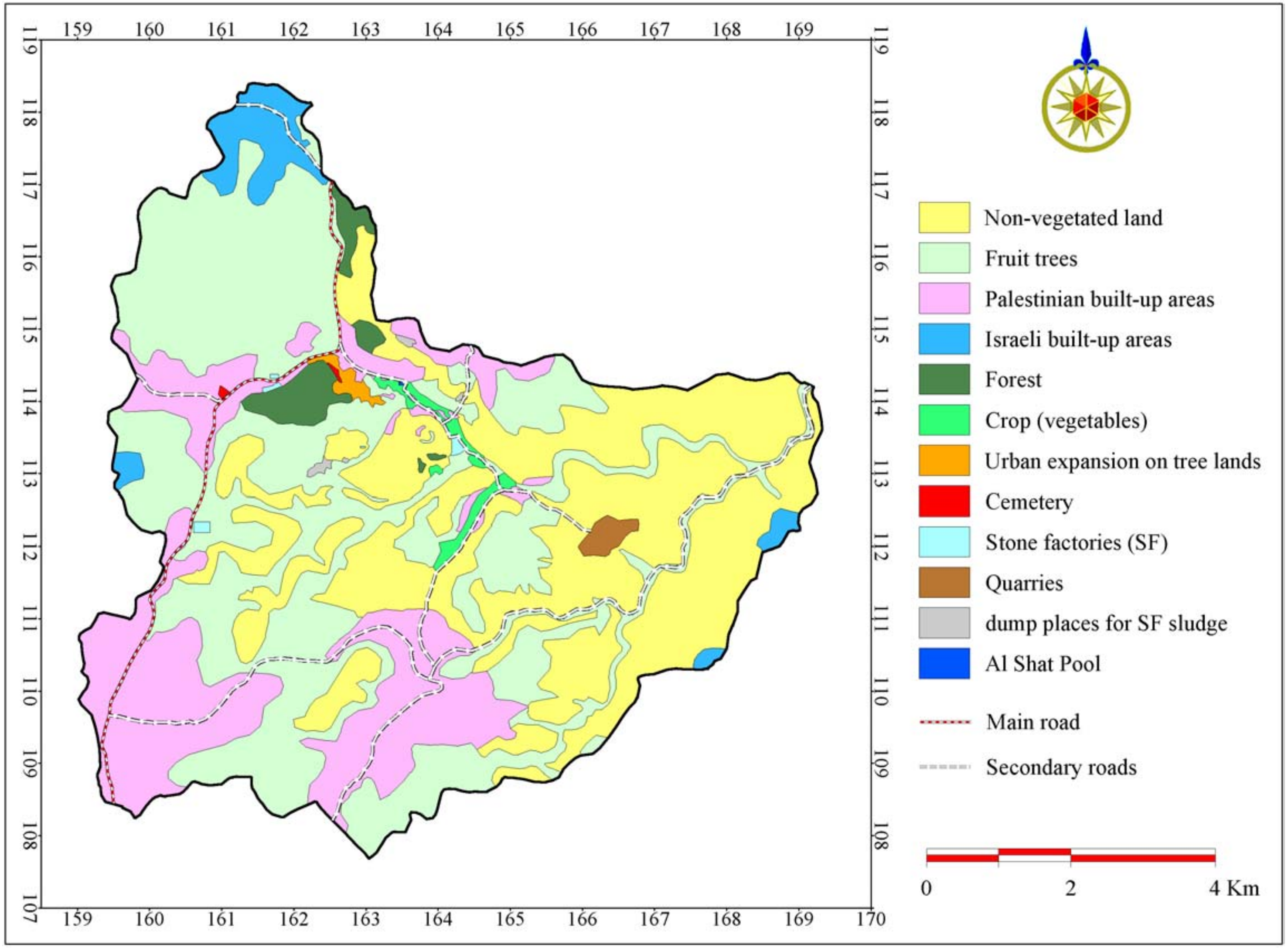


Fig. 1.2: Landuse map of Wadi Al Arroub drainage basin (1999).

Table 1.1: The main landuse activities in Wadi Al Arroub drainage basin.

Landuse	Area (m^2)	Percentage
Congested Palestinian areas	$1.14 * 10^7$	19.34
Israeli settlements	$1.96 * 10^6$	3.23
Forest	$1.44 * 10^6$	2.37
Fruit trees (Almonds, peaches, plums, grapes, etc.)	$2.12 * 10^7$	34.81
Unexploited land	$2.33 * 10^7$	38,37
Crops (mainly vegetables)	$7.00 * 10^5$	1.15
Stone factories	$7.91 * 10^4$	0.13
Cemeteries	$3.17 * 10^4$	0.05
Quarries	$5.79 * 10^4$	0.10
Dumps (Solid waste and sludge of stone factories)	$5.99 * 10^4$	0.10
Tree-land endangered by urban expansion	$2.06 * 10^5$	0,34

Note: The roads in this study were considered as part of the congested areas as the majority of them pass through these areas.

1.4 Soils

Despite the small size of West Bank, a variety of soils can be found. The major causes of this variety are the extreme conditions which form these soils: climate, arid in the east and wet in the mountainous ridge; variable geology: sedimentary rocks, sand dunes, alluvium, etc., and different topographic circumstances: topography varying from 400 masl at the western edge to 1000 masl at the mountain ridge to 410 mbsl at the Dead Sea area. Also, physical weathering from both water and wind modifies the soils.

According to Orni and Efrat (1980), Wadi Al Arroub drainage basin includes within its boundary two main soil associations: Terra Rossa stemming from dolomite and hard limestone. Terra Rossa has a reddish brown color and its depth varies between 0.5 and 2 meters. The second soil dominating are the brown and pales rendzinas with reddish and brown color, loamy with 30 % stones. These soils develops from marl and chalk. According to Dan et al. (1975), the brown rendzina has a clayey soil texture with 59.5 %, 16.6 %, and 23.9 % of clay, silt and sand, respectively, While the pale rendzinas has sandy clay soil texture with 45.2.8 %, 0 %, and 54.8 % of clay, silt, and sand, respectively.

1.5 Previous studies

The environment, geology, hydrogeology, and hydrochemistry of Wadi Al Arroub drainage basin were first described by Qannam (2000) and Qannam and Merkel (2002). Qannam (1997), Abed Rabbo et al. (1999) are more generalized studies that included some of the springs covered in this study.

1.6 The importance of Wadi Al Arroub drainage basin

According to MOPIC (1998), Wadi Al Arroub drainage basin is a highly sensitive recharge area, highly valuable agricultural land, of high ecological significance, and of a second-degree landscape. This was based on the relatively high rainfall averages in this area, being part of the recharge area for the Upper and Lower regional aquifers of the West Bank, karstic features, fertile soil, about 55 springs and dug wells, and about 40 % of the area used for cropping and forestry. During the time of the Romans (63 BC – 325 AD) the water of the springs namely that from Ein El Fawwar, Kuweisiba, El Bas, Dilbi, and Al Baradah was collected in a pool (Al Shat, storage capacity of 20,000 m^3) and conveyed through a 40 km stone-carved rock channel (Al Sabeel) to the city of Jerusalem. The pool and the channel were rehabilitated three times during the Islamic period (1483, 1505, 1520) (Taha 1999). This gives the area also a historical as well as a tourist importance.

1.7 Aims and scope

The main aim of this study is to provide a hydrogeological, hydrological, hydrochemical and water quality database for the surface and subsurface water in the Wadi Al Arroub drainage basin, to specify the different pollutants, their possible sources and their actual impact on the ground water resources and to pinpoint on possible measures to improve the situation.

The hydrochemical study aimed to determine the physical and chemical parameters of the rain water, soil water, springs and wells and waste water as well as to evaluate the suitability of the water resources for domestic and agricultural purposes. Further goals are to study the changes in the waste water quality along the wadi floor, to evaluate the effect of the waste water conduit on the spring and well in the floor of the wadi as well as to study the changes in the rain water quality as it infiltrates in the soil profile. The analysis of the water samples for the environmental isotopes was conducted to determine the origin and age of the water. The hydrological study was conducted to estimate missing data such as the rainfall average, runoff, recharge, potential and actual evapotranspiration. On the other hand, the hydrogeological study aimed to identify and collect the basic hydrogeological data of the springs and well in the study area, to identify the exposed aquifers, and to determine the characteristics of the perched aquifer supporting the springs and dug wells in the floor of Wadi Al Arroub. Presentation of a digital terrain model and basic maps of the area such as the landuse, drainage system, exposed aquifers and geological cross section were among the aims of this study.

2 METHODOLOGY

2.1 Literature review

The literature review aimed mainly to collect the available scientific papers, maps and documents, as well as unpublished academic environmental studies on the, hydrogeology and hydrochemistry of Wadi Al Arroub drainage basin and its surrounding.

2.2 Personal communications and interviews

Interviews and personal communications with Palestinian National Authority (PNA) officials, particularly members of the Palestinian Water Authority (PWA) and the Head of Hebron Agricultural Department, with municipal mayors, chairpersons of local councils, local water and sanitation engineers, health and sanitation field officers, were conducted between 1999 and 2001. The aim of the interviews was to update the data that has been collect throughout the literature review, to identify the water resources that are not mentioned in the literature, as well as to collect data about the situation of the drinking water networks concerning; age, loss, and continuity of supply. Data about the waste water and solid waste disposal methods was also collected. Interviews with the local inhabitants and farmers were also conducted to evaluate the effect of the uncontrolled waste water disposal on the, health, agricultural and socioeconomic situation in the area as wells to collect the data about the springs and dug wells as names, estimated pumping rate were measurement is not possible.

2.3 Field work

Field work and field surveys were basic modules in every aspect of this study, especially to confirm the data collected during the interviews, to identify and mapping the existing water resources, water sampling and measurement of waste water flow rate.

2.4 GIS and mapping

A digital elevation model was compiled to confirm the manually drawn water divide, incorporating the drainage system and to determine the coordinates and elevations of the wells and springs as a replacement of the GPS, which was not available for the researcher during the study period mainly because of political constrains. A landuse map was produced to show the main activities in the area and to be used in computing the runoff and recharge using the SCS method. The DTM, landuse, geological, geomorphological, hydrogeological, sampling, and location maps were compiled with the help of the GIS software package TNT-mips (Microimages). Geological cross sections were also produced. The TNT-mips was also used as area and length measurements tool (i.e. the area of the study catchment, area for each landuse activity, length of the drainage lineation). All the coordinates of the maps, wells, springs, et…are according to the Palestinian grid.

2.5 Geomorphology

The drainage divide of Wadi Al Arroub drainage basin was delineated using the elevations contours (10 m contour intervals) and identified point elevations on a topographic map of 1:50000 scale. It was confirmed with the help of watershed analysis using the GIS package TNT-mips. The watershed process deals with the influence of terrain on surface hydrology, the movement of water over the land surface. The process computes the local directions of flow and defines the stream network and the boundaries between watersheds, and the areas drained by particular stream systems. This process requires input elevation information in the form of a digital elevation model. In order, to study the effect of the local structure and topography on the drainage lineation, all straight or nearly straight segments of the drainage system were drawn as straight lines. All the segments were then measured in millimeters and their azimuth was measured in degrees. Intervals of ten degrees for the azimuth were chosen. The azimuth frequency of number and length were constructed for all stream segments and plotted on a rose diagram. To understand the characteristics of the drainage system six geomorphological parameters were studied including: ordering of the stream network using Horton's Stream Order System, bifurcation ratio, drainage density, relief (relief, relief ratio and relative relief), basin shape and valley and stream network patterns.

2.6 Climate, meteorology and recharge

To replace missing meteorological values linear regressions between the records of Al Arroub Meteorological Station and the Hebron Meteorological Station, which has more continuous and completed records were performed. The monthly and yearly averages as well maximums and minimum for the rainfall, temperature, relative humidity, wind speed and sun duration were calculated and presented as bar and line plots.

2.6.1 Potential evapotranspiration

To estimate the potential evapotranspiration, the Class-A pan potential evaporation was corrected for the mesh effect and the pan coefficient was estimated.

2.6.1.1 Correction of the potential evaporation for mesh effect

According to Maidment (1993), covering the exposed water surface of the Class-A pan with a mesh lowers the evaporation measurement by 10-20 % depending on the mesh dimensions. In the case of Al Arroub Meteorological Station a mesh of 1x1 cm cells covers the pan and the wires have a diameter of 1 mm. This means that the active pan surface is being reduced by 10 % as a result of the mesh presence. Therefore the measured values was considered to be only 90 % of the actual values, which will be estimated here by multiplying the measured values by a factor of (100/90). The actual values are equal to 111 % of the recorded values and they are used as values for the potential evaporation in further calculations

2.6.1.2 Estimation of the pan coefficient

The average pan coefficient was estimated based on the empirical pan coefficients, that were tabulated by Doorenbos and Pruitt, (1977), and with the help of the monthly relative humidity and wind speed averages at Al Arroub Meteorological Stations.

2.6.1.3 Estimation of the potential evapotranspiration

The potential evapotranspiration (PET) was calculated based on the formula of Maidment (1993):

$$PET = PE * CP$$

Where:

PE is the potential evaporation, measured by the Class-A pan and CP is the pan coefficient.

2.6.2 Aridity of the area

For the evaluation of the aridity of the study area three aridity indices and classifications were used:

2.6.2.1 Aridity index of Murai and Hunda

Based on the aridity index of Murai and Hunda (1991), which is a revised index from that of De Martonne (1926), five classes of climatic regions were identified (Table 2.1).

Table 2.1: Aridity indices of the different climatic regions (Pahari and Murai 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.

2.6.2.2 UNESCO aridity index

The UNESCO (1979) has taken the ratio of precipitation (P) to potential evapotranspiration (PET) as aridity index, based on which four climatic regions of aridity were identified (Table 2.2).

Table 2.2: Aridity indices of the different climatic regions (UNESCO 1979).

Index	**Class**
P/ETP < 0.03	hyper-arid zone
0.03 < P/PET <0.2	arid zone
0.2< P/PET <0.5	semi-arid zone
P/PET >0.5	humid zone

2.6.2.3 Thornthwaite classification

Thornthwaite (1931) classified the climatic regions into five classes (Table 2.3) based on the precipitation effectiveness index (PE), which is computed from the monthly values of precipitation and temperature. The index is given as:

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

where, P = monthly precipitation in inches; T = temperature in °F; and n = months = 12.

Table 2.3: The classifications of the climatic regions based on the precipitation effectiveness index (Thornthwaite 1931).

PE Index	**Climate**
More than 128	Wet
64 - 127	Humid
32 - 63	Sub-humid
16 - 31	Semi-arid
Less than 16	Arid

2.6.3 Water balance

In this section the total volume of the rainfall over the area, the recharge, actual evapotranspiration were calculated.

2.6.3.1 Mean annual rainfall

The average depth of the rainfall over the study area was determined using the isohytal method. This method involves the measurement of the areas between each two rainfall contour lines, multiplying this by the average precipitation between them, and then by dividing the summation of these products by the total area of the catchment as in the following formula (Chow et al. 1990):

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

Where:

P_m: mean areal rainfall in (mm); A_i: sub area; P_i: average precipitation between two successive contour lines e.g. P_1 and P_2, equals $(P_1 + P_2)/2$ and A: total area, which is equal to $\sum A_i$.

2.6.3.2 Estimation of the surface runoff

The surface runoff in the area was estimated with the help of Goldschmidt formula and the US Soil Conservation Service method (SCS).

2.6.3.2.1 Goldschmidt formula

According to Goldschmidt in (Arad and Michaeli 1967) soil surfaces of low hydraulic conductivity could lead to average annual runoff that may reach 20 % of the annual precipitation. Goldschmidt propagates a regression equation for the storm runoff in such areas:

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

Where:

Q is the average annual runoff, and P is the average annual rainfall. Both Q and P are in mm/yr.

This regression equation is considered to be valid in Wadi Al Arroub area as it is covered by clayey loam and sandy clay soils, which are of low hydraulic conductivity.

2.6.3.2.2 Soil Conservation Service (SCS) method

The SCS method is widely used for estimating floods on small to medium-sized not gauged drainage basins. The hypothesis of the SCS method is that no runoff occurs until rainfall equals the initial abstraction and that the ratio of the actual to the potentials infiltration is equal to the ratio of the actual to the potential runoff that is:

$$F_a / S = Q / (P-I_a)$$

By substituting $F_a = P_e$-Q, and Ia = 0.2 S, empirical relation adopted as the best approximation from observed data, the above equation will lead to the general equation used for estimating the runoff (Maidment 1993):

$$Q = (P - 0.2 S)^2/(P + 0.8*S)$$

Where:

F_a: infiltration, S; potential maximum retention which equals $F_a + I_a$, Q: runoff, P: precipitation, I_a: initial abstraction before bonding, P_e: effective rainfall which equals P-I_a. (all are in inches),

The relation between the potential retention (S) and the Curve Number (CN) was given as:

$$S = (1000/CN)-10$$

The value of the CN depends mainly on the soil class, vegetation and dormancy, antecedent moisture class and landuse.

2.6.3.3 Estimation of infiltration and recharge

To estimate the recharge in the study area, the SCS method, the chloride mass-balance method as well as the Goldschmidt and Jacobs formula were applied.

2.6.3.3.1 Soil Conservation Service (SCS) method

The infiltration in this method is calculated from the following equation:

$$R = Pe – Q$$

Where, R, P_e and Q are infiltration, effective rainfall and runoff respectively in (mm/yr).

2.6.3.3.2 Chloride mass-balance method

The chloride mass-balance method assumes that chloride only enters the ground water through precipitation. Since it is non-volatile its concentration increases with evapotranspiration (Eriksson and Khunakasem 1969 and Bazuhair and Wood 1996). This method assumes as well that chloride is conserved in the system, i.e. it doesn’t react and disappear when mixed with other components of ground water. It is further assumed that steady-state conditions are maintained in the system, so that long term average concentrations and rainfall amounts are used in the calculation. Finally, it is also assumed that surface runoff is known and that evaporation from the ground water does not occur.

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

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

Where:

R is the annual recharge (mm), P is the average annual precipitation (mm), Q is the average annual runoff (mm), C_{gw} is the chloride concentration of ground water and C_p is the weighted average chloride concentration in precipitation (wet and dry deposition) and both in (mg/L).

2.6.3.3.3 Goldschmidt and Jacobs formula

According to Goldschmidt in (Lerner et al. 1990), the recharge in catchments of Turonian and Cenomanian limestone aquifers in Israel and the West Bank, example of which is Wadi Al Arroub drainage basin, can be calculated from the following equation:

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

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

2.6.3.4 Estimation of the actual evapotranspiration

The actual evapotranspiration was estimated using the hydrometeorological method and the Penman-Gridley model. It was calculated also using some empirical formulas for comparative purposes and for checking the validity of theses formulas in the study area.

2.6.3.4.1 Hydrometeorological method

The general water balance equation has the following components:

$$P = AET + Q + R + \Delta M+ \Delta S + I$$

Where

P: the average amounts of the rainfall, AET: actual evapotranspiration, Q: runoff, R: recharge, ΔM: change in the soil moisture, ΔS: depression storage, and I: interception. All the parameters are given in mm/yr. Because there are no measurements for the ΔM, ΔS and I, they will be included in the AET.

2.6.3.4.2 Penman – Gridley assumption

Based on Penman-Gridley approach (Lerner, et al. 1990) the actual evapotranspiration (AET) could be derived from the potential evapotranspiration (PET) as follows:

$$AET = PET \qquad \text{when } P \geq PET$$
$$AET = P \qquad \text{when } P < PET$$

2.6.3.4.3 Empirical formulas

Examples of the empirical formulas are those of Turc and Wundt, where the actual evapotranspiration (AET) is represented as function of annual values of precipitation (P), mean annual temperature (t) and annual potential evapotranspiration (PET).

2.6.3.4.3.1 Wundt

In this formula the actual evapotranspiration is represented as a function of the average annual precipitation and the mean annual temperature (Wundt 1937):

$$AET_{.\,(Wundt)} = P / [\, 0.95 + (\, P / f_{(t)}\,)]^3$$

$$f_{(t)} = 1400 + 170 * t + 5.5 * t^2 + 0.15 * t^3$$

Valid for: $-5°C \leq t \leq +20°C$ and $P / f_{(T)} \geq 0.05$

2.6.3.4.3.2 Turc formula 1

This formula shows the dependence of the evapotranspiration on the average annual precipitation (P) and the mean annual temperature (t in °C) (Gray 1970):

$$AET_{(Turc)} = P / [\, 0.9 + (P/L)^2\,]^{0.5}$$

Where:

$L = 300 + 25 * t + 0.05 * t^3$.
When $(P/L) \leq 0.316$ then AET = P can be assumed.

2.6.3.4.3.3 Turc formula 2

Another examples for empirical equations is that of Turc (1954), in which the evapotranspiration is represented as a function of annual values of precipitation and annual values of potential evapotranspiration (Reynolds and Thompson 1988).

$$E = P / [(0.9) + (P / PET)^2]^{0.5}$$

2.7 Hydrogeology

Field work was necessary for identifying and mapping the springs and the dug wells as well as to measure the water level and pumping rates of the dug wells. Based on the differences in the water levels of the dug wells and the regional water tables, the dug wells were correlated to perched aquifers, that has been also named.

2.7.1 Border of Arroub upper perched aquifer

To identify the border of the Arroub upper perched aquifer there was a need to identify the exposure of Moza Formation. Because there is no available detailed geological map of the area showing the boundaries of the Moza Formation, and it was not possible to identify the boundary in the field due to the alluvial cover, it was estimated by subtracting two surface models of the top Yatta Formation and the topography. First of all, a 10 m contour structural map for the top of Yatta was drawn, based on the outcrops, well logs, cross sections, and the structural map, bottom of Moza, prepared by Hirsch (1983) which, however, reaches only to line 160000 East. Based on the data available from the logs of the wells of PWAI, PWA II, Hebron 1 and the geological maps of Kolton (1972) and Hirsch (1983) for the area around the study area, and based on the depth of the dug wells, the thickness of the Moza was assumed to be 15 meters. Areas included within the contour line of 15 meters below the top of Yatta were assigned to the Moza Formation, and this contour line was assumed to be the extent of the Moza outcropping on the surface. This work was done with the help of the GIS TNT-mips (Microimages Inc. 2001) and with the help of (Surfer-7) scientific graphics software (Golden software Inc. 1999). The border assigned to the Moza Formation is only estimated, so further field studies are necessary.

2.7.2 Names and codes for the springs and dug wells

Three-suffixed codes were given to the different springs and wells in the area. These codes are shown in Appendix 7.1. Following two example of the codes given to the wells and springs in the study area.

WA-Sp-1
WA-Dw-1

The first suffix (WA) is referred to the wadi in which the spring or well is located. The second (Dw) distinguishes the springs from the dug wells and the third is a serial number counting from upstream towards downstream. In this dissertation these codes were not used, because they are still unknown and the results will be much helpful if they are introduced to the public with the common names of the wells and the springs.

2.8 Hydrochemistry

2.8.1 Preparation of sampling bottles

Three bottles were prepared in the laboratory of the Water and Soil Environmental Research Unit (WSERU) - Bethlehem University for each sampling site. A 330 ml glass bottle for collecting bacterial samples, one liter and 50 ml polyethylene bottles for collecting samples for chemical and heavy metal analysis respectively. The preparation of the bottles included washing with distilled water followed by acid soaking and then final washing with distilled water before left for air drying. The glass bottles were either disinfected with 70 % alcohol or sterilized by autoclave.

2.8.2 Sampling

The bottles were filled by direct flow of the spring water into the bottle. The dug wells were sampled with the help of the installed pumps. However, in cases of pumps malfunctioning or missing pumps a stainless steel bailer was lowered 1-2 meters below the surface of the water in the well for sampling. Before sampling the deep wells and tap water the water was allowed to flow for few minutes before the samples were taken. Rain water was collected quantitatively by allowing the water to accumulate in a large funnel dripping into a narrow-headed bottle to reduce the evaporation effects on the collected rain water. Large-headed bottles were used to collect samples from the waste water conduit, where the bottles were immersed in the running conduit until they were totally filled.

As a general rule all the bottles were first rinsed with the water intended for sampling and then filled completely. Samples of 50 ml were filtered using 0.2 µm pore-sized filters and acidified by 1 ml concentrated analytical nitric acid to be analyzed for the heavy metals. All the collected and filtered samples were placed in a cold box until analysis in the laboratory.

2.8.3 Field and laboratory analysis

Direct measurements were made at each site with a Mettler Toledo field set of probes, giving readings for temperature, electrical conductivity (EC), dissolved oxygen (DO) and pH. In the laboratory of WSERU, the samples were analyzed according to the standard methods for the examination of water and waste water (American Public Health Association 1995) for the major ions (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, HCO_3^-, Cl^-, SO_4^{2-} and NO_3^-), for SiO_2, for the minor ions F^- and PO_4^{3-}, for heavy metals (Fe, Cu, Mn, Pb, Cd and Zn) and for the total and fecal coliform bacteria. The waste water samples were also analyzed for total solid (TS), the biological oxygen demand (BOD) and chemical oxygen demand (COD). Part of the analysis for the heavy metals was conducted in the lab of the Department of Hydrogeology at the TU Bergakademie Freiberg.

The samples were analyzed for total and fecal coliform as well as for bicarbonate immediately after the samples were brought to the lab. A list of the analytical methods used for determining the various parameters is shown in Table 2.4.

2.8.4 Precision of analysis

The detection limits of the parameters measured at the WSERU and TUBAF laboratories are summarized in Table 2.5.

The accuracy of the analysis was tested based on the error in the electrical balance, which was calculated as:

$$\text{Error \%} = [(\text{total cations} - \text{total anions}) / (\text{total cations} + \text{total anions})] * 100$$

Applying this equation on the results leads to errors of less than 5 %.

Table 2.4: Analytical methods used in the determination of the various parameters.

Parameter	Method of analysis
Temperature, DO, EC, and pH-value	Field multi-electrode meter (Mettler Toledo)
Ca^{2+}	Titration with Na_2-EDTA using Murexide indicator
Total Hardness (Ca^{2+} and Mg^{2+})	Titration with Na_2-EDTA using Eriochrome black-T indicator
Na^+ and K^+	Flame Photometer
Alkalinity (CO_3^{2-}/ HCO_3^-)	Titration with HCl using phenolphthalein and bromocresol- green indicators
SO_4^{2-}	Turbidimetric method, Spectrophotometer (λ=220 nm)
Cl^-	Titration with $AgNO_3$ using potassium chromate indicator
NO_3^-	UV-Spectrophotometric method (λ=220 nm)
F^-	SPADENS method, Spectrophotometer (λ=570 nm)
PO_4^{3-}	Stannous chloride, Spectrophotometer (λ=700 nm)
SiO_2	Molybdosilicate, Spectrophotometer (λ=510 nm)
Fe, Cu, Mn, Pb, Cd, Zn, Cr, Ni and As	Graphite furnace / atomic absorption
Total (TC) and Fecal (FC) coliform bacteria	Filter membrane method

Table 2.5: The detection limits of the parameters measured during this study.

Chemical parameter	Detection limit		Chemical parameter	Detection limit
Ca^{2+}	1 mg/L		Fe	0.5 µg/L
Mg^{2+}	0.5 mg/L		Mn	0.5 µg/L
Na^+	0.5 mg/L		Zn	6 µg/L
K^+	0.4 mg/L		Cd	0.1 µg/L
HCO_3^-	10 mg/L		Cu	0.6 µg/L
Cl^-	1 mg/L		Pb	0.7 µg/L
SO_4^{2-}	0.13 mg/L		Cr	0.5 µg/L
SiO_2	1 mg/L		Ni	0.7 µg/L
F^-	0.1 mg/L		As	1.5 µg/L
PO_4^{3-}	0.1 mg/L			

2.8.5 Analysis of water for volatile organic chemicals using GC-MS

The combination of gas chromatography and mass spectrometry (GC-MS) in analyzing volatile organic chemicals (VOC's) enables the rapid separation and identification of individual compounds in complex mixtures. The gas chromatograph separates the sample extract into individual components, while the mass spectrometer ionizes each component, which provides the energy to fragment the molecules into characteristic ions. These ion fragments are then separated by mass and detected as charged particles, which constitutes a mass spectrum. This spectrum can be used in the identification and quantification of each component in the sample extract (Einfeld et al. 1997).

Generally, the VOC's are sampled by headspace, purge and trap, and spray and trap systems. Using headspace analysis, which is a static mode, a sample vial is closed, thermostated, and allowed to equilibrate so that the vapor pressure of the analytes enriches the vapor phase based on each analyte's partition coefficient. The equilibrated static system is then sampled by withdrawing a portion of the vapor, usually with a syringe.

In purge-and trap also called dynamic headspace, continuous sampling of the headspace above a matrix allows enrichment of volatiles onto a trap or the head of the column. Dynamic sampling allows for pre-concentration of trace quantities to achieve greater detection limits, as well as the ability to exhaustively extract analytes of interest (McNair et al. 2002).

The spray-and trap sampler consists of a mechanical pump to inject a continuous flow of an aqueous sample into a sealed extraction chamber through a spray nebulizer. The droplet formation increases the total interfacial area between the sprayed water and the carrier gas, which supports the transfer of the VOCs into the gas phase. In contrast to the purge-and-trap method, spray-and-trap utilizes a dynamic equilibrium. During water spray, an equilibrium VOC transfer rate between the droplet surfaces and flowing carrier gas is established (Einfeld et al. 1997).

During the period 1999-2000 14 samples were collected from the study area to be analyzed for the VOC's, 7 samples from the springs and dug wells, 6 are soil water samples, and one sample from the waste water conduit. The samples were analyzed at the labs of the TU Bergakademie Freiberg using EM640™ field transportable gas chromatograph / mass spectrometer (GC/MS) system. Because of political constrains it was not possible to bring the system in the field, therefore the samples were collected in 500 ml dark glass bottles few hours before the flight, placed in a cool box until arrival in Germany, were the samples were brought immediately to the lab. During the analysis the sampling was done with spray and trap system (Bruker Daltonik GmbH) consisting of water tube WS100 and drying unit with sprayed simple volume of 135 ± 3 ml. A GC-heating program ranging between 40 and 220 °C enabled the detection of VOC's ranging in their boiling points between 37 °C for dimethylsulfide chloride, and 183 °C for the O-dichlorobenzene. The boiling points and the detection limits of the VOC's recorded in the analyzed water samples is presented in Table 2.6.

Table 2.6: The boiling points and the detection limits of the VOC's recorded in the analyzed water samples

VOC'S	CAS-Nr **	Boiling points	Detection limits
		°C	µg/L
Toluene	108-88-3	110.6	0.13
Methylenechloride	75-09-2	39.7	0.04
Styrene	100-42-5	145-146	0.25
Limonen	138-86-3	177-178	0.85
o-dichlorobenzene	95-50-1	180-183	0.8
Trichloroethylene	79-01-6	87	0.2
Dimethyldisulfide	624-92-0	109	0.1*
Dimethylsulfide	75-18-3	37	0.1*
Diethylsulfide	110-81-6	92	0.1*

* : estimated, **: after Merck (2002).

2.9 Classification of water chemistry data

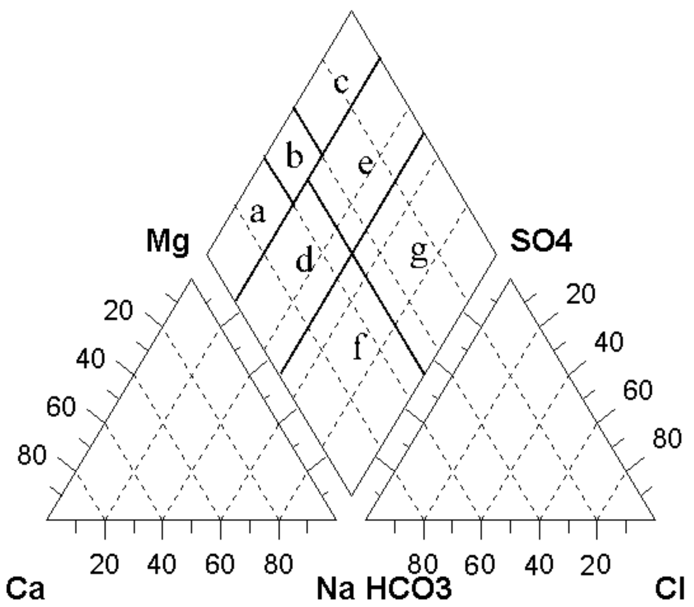
Graphical and statistical methodologies were used to classify the water samples into homogeneous groups. These methodologies include the diagrams of Piper, Durov, Schoeller, Wilcox, Collins and Icon (Chernoff) faces as well as the Q-mode cluster analysis and Man–Whitney and Kruskal-Wallis tests. Other classifications based on the SSP, SAR-EC, as well as the total hardness, were performed and compared.

2.9.1 Water type and ions-ordering

This ordering system based mainly on the meq/L percentages of the major cations (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}) and anions (HCO_3^-, Cl^-, SO_4^{2-} and NO_3^-), the total of which is 100 %. The water type expression is formed by those elements for which the concentration is higher than 10 % is ascending order with the cations first. This 10 % ordering was adopted after the HYDROWIN software package (Calmbach 1995). Based on this system, a water sample having meq % of 0.4 % Na, 37.9 % Ca, 11.5 % Mg, 0.4 % Cl, 40.3 % SO_4, and 9.5 % HCO_3 is of Ca-Mg-SO_4 water type. Other percentages distribution schemes are known.

2.9.2 Piper diagram

Based on the four main cations (calcium, magnesium, and sodium + potassium) and the four main anions (bicarbonate, sulfate, chloride and nitrate), Piper (1944) proposed a trilinear diagram that permits the classification of waters, according to Langguth (1966) into seven types as shown in Fig. 2.1. The HYDROWIN software was used for plotting this diagram.



Water Types:

Normal earth alkaline water

a: with prevailing bicarbonate
b: with prevailing bicarbonate and sulfate or chloride
c: with prevailing sulfate or chloride

Earth alkaline water with increased portions of alkalis

d: with prevailing bicarbonate
e: with prevailing sulfate and chloride

Alkaline water

f: with prevailing bicarbonate
g: with prevailing sulfate-chloride

Fig. 2.1: Piper trilinear diagram

2.9.3 Durov diagram

Durov diagram is based on the percentage of the major ions' in meq/L. Both the positive and the negative ion percentages total 100 %. The values of the cations and the anions are plotted in the appropriate triangular and projected into the square of the main field. The advantage of this diagram is that it displays some possible geochemical processes that could affect the water genesis. Durov diagram for the major cations and anions plotted by HYDROWIN software is illustrated in Fig. 2.2. The fields and lines on the diagram show the classifications of Lloyd and Heathcoat (1985).

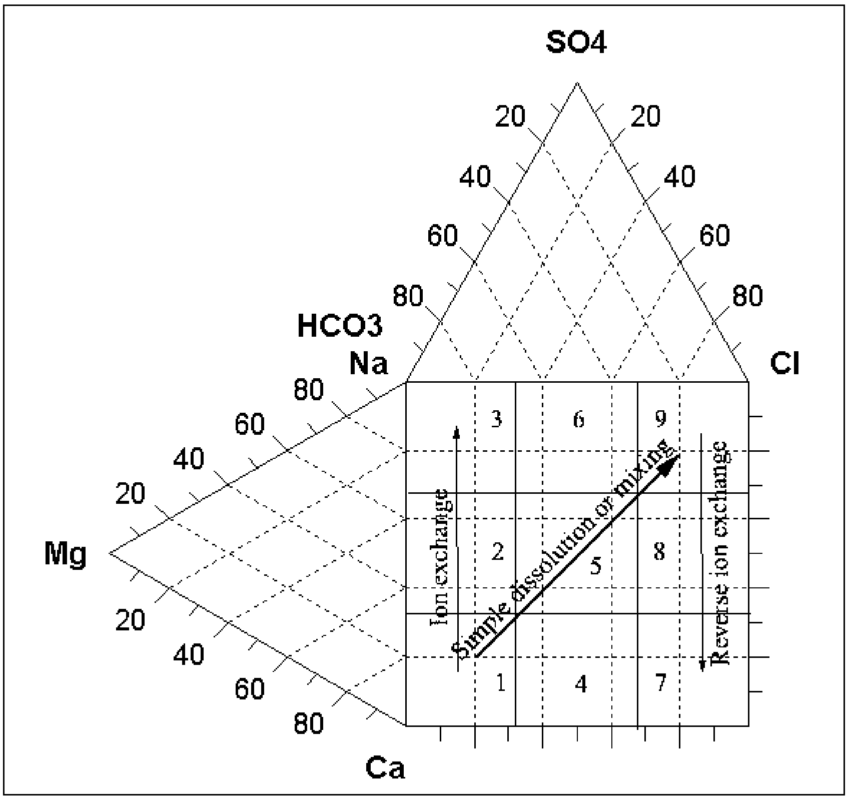


Fig. 2.2: Durov diagram for the major cations and anions (see text for explanations).

Below a summary about the theory behind the divisions in the diagram is given (Lloyd and Heathcoat 1985):

- Field (1): HCO_3 and Ca dominant, frequently indicates recharging waters in limestone, sandstone, and many other aquifers.
- Field (2): This water type is dominated by Ca and HCO_3 ions. Association with dolomite is presumed if Mg is significant. However, those samples in which Na is significant, an important ion exchange is presumed.
- Field (3): HCO_3 and Na are dominant, indicates ion exchanged water, although the generation of CO_2 at depth can produce HCO_3 where Na is dominant under certain circumstances.
- Field (4): SO_4 dominates, or anion discriminant and Ca dominant, Ca and SO_4 dominant, frequently indicates a recharge water in lava and gypsiferous deposits, otherwise a mixed water or water exhibiting simple dissolution may be indicated.
- Field (5): No dominant anion or cation, indicates water exhibiting simple dissolution or mixing.

- Field (6): SO_4 dominant or anion discriminant and Na dominant; is a water type that is not frequently encountered and indicates probable mixing influences.
- Field (7): Cl and Na dominant is frequently encountered unless cement pollution is present. Otherwise the water may result from reverse ion exchange of Na-Cl waters.
- Field (8): Cl dominant anion and Na dominant cation, indicate that the ground waters be related to reverse ion exchange of Na-Cl waters.
- Field (9): Cl and Na dominant frequently indicate end-point waters.

2.9.4 Collins bar diagram

Collins diagram (Collins 1923) present the relative major ion composition in percent milliequivalent per liter. Both the cations and anions have a total of 100 %. In this bar diagram the cations are plotted on the left and the anions are plotted on the right (Fig. 2.3). Using this diagram the ions could be plotted in meq/L with an appropriate scaling.

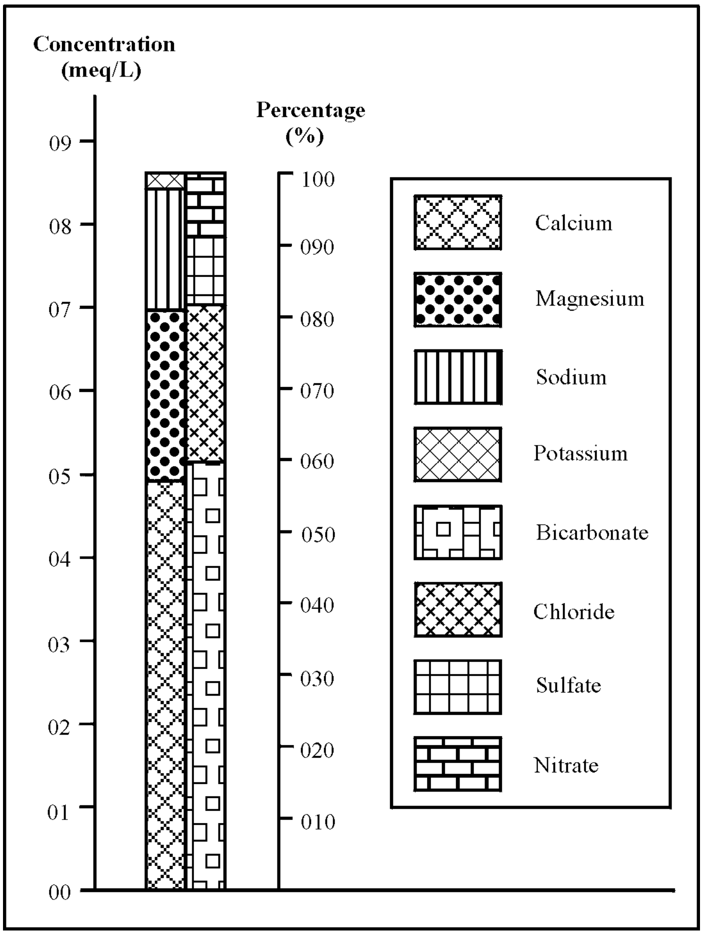


Fig. 2.3: Collins bar diagram presenting the major ions in meq/L as a concentration and as percentages.

2.9.5 Schoellar semi-logarithmic diagram

Semi-logarithmic diagrams were developed by Schoellar (1962) to present major ion analysis in milliequivalent per liter and to demonstrate different hydrochemical water types on the same diagram (Fig. 2.4). The diagram has one advantage over the more universally used trilinear diagram in that actual parameter concentrations are given.

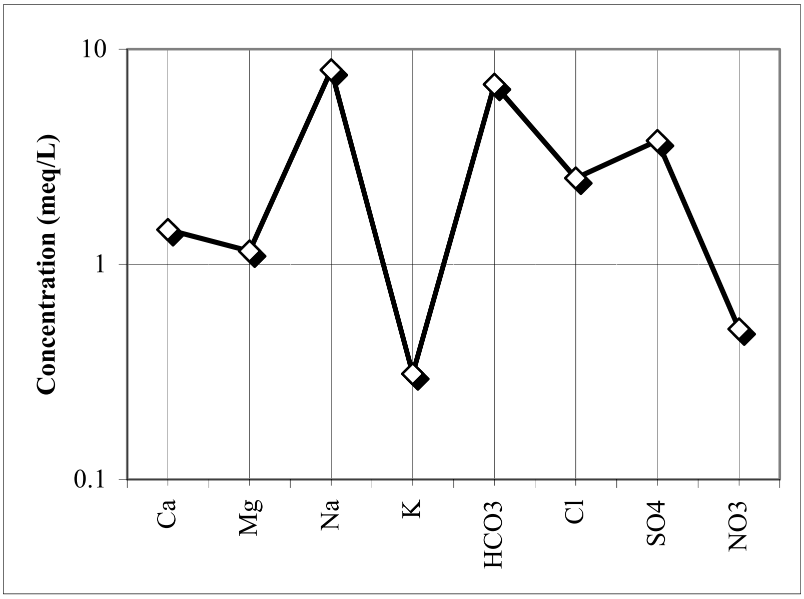


Fig 2.4: Schoellar semi-logarithmic diagram.

2.9.6 Icon (Chernoff) faces

Chernoff faces represent the most elaborate type of icon plots in which cases are visualized by schematic faces such that the relative values of the variables selected for the graph are represented by the variations of specific facial features. Although Chernoff faces provide an effective way of analyzing trend in multidimensional data, they do not contain any information on the actual values which are plotted. This diagram is built-up of 20 feature: face width, ear level, half face height, eccentricity of the upper ellipse of the face, eccentricity of the lower ellipse of the face, length of the nose, position of the center of mouth, curvature of mouth, height of center of eyes, separation of eyes, eccentricity of eyes, half length of eyes, position of pupil, height of eyebrow, angle of brow, length of brow, radius of ear, and nose width. To have a full face diagram 20 variables are needed. If the number of the variables to be plotted is less than 20, thus some features remain constant based on default values (Minty et al. 1996) . This diagram was plotted with the help of the software STATISTICA 5 for windows. An example of this diagram is shown in Fig. 2.5.

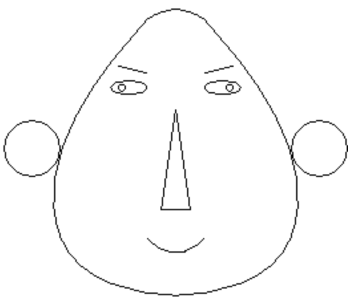


Fig. 2.5: Chernoff faces use facial features to represent multidimensional data.

2.9.7 Statistical analysis

Statistical calculations were conducted using the statistical software packages SPSS 10 for windows (1999) and STATISTICA 5 for windows (1995). Frequency histograms were calculated for all parameters and then tested for normal distribution with the help of the nonparametric one-sample Kolmogorov-Smirnov (K-S) test for goodness-of-fit. The theoretical distribution is set normal when using the K-S test for normality testing. A calculated significance value higher than the proposed significance level (α) indicates a normal distribution of the studied variable. In this study (α) is always equal to 0.05. In calculating the strength of the relation between the different variables studied in this research, the nonparametric Spearman's rank correlation coefficient was used because most of the variables are not normal distributed.

The cluster analysis, was conducted in this study using the statistical package (STATISTICA 5 for windows 1995). It mainly aims to group the water samples according to their major chemical parameters (cations and anions). Tree-clustering of cases (Q-mode cluster) was conducted using different linkage rules (single linkage, complete linkage, Ward's method) and different distance measures (Euclidean distance, City-block (Manhattan) distance and Chebychev distance). The Ward's method linkage and the Euclidean distance was the best clustering of the cases (springs and wells) that represents the actual situation.

In order to prove the differences between the four groups resulting from the cluster analysis, the nonparametric Kruskal-Wallis test and the Mann-Whitney test were conducted using SPSS 10 for windows (1999). The Kruskal-Wallis test is a nonparametric alternative to one-way ANOVA. Significance levels below 0.05 indicate that at least one group is of different mean from the other groups for the considered parameter. Because the Kruskal-Wallis test shows only for which parameters there is a significant difference in the means between the groups and does not show between which groups, Mann-Whitney test was used to distinguish between the means of the different groups

2.10 Water quality evaluation

Evaluation of the water quality for domestic uses was based on a comparison of the biological, physical, and chemical parameters in the water of the springs and wells with the drinking water guidelines of WHO (1995) and the Palestinian drinking water standards (PWA 2001). The main parameters of concern were the fecal coliform bacteria, nitrate, and heavy metals. Evaluation of water for agricultural purposes was based on salinity, sodium hazards, soluble sodium percentages, and residual sodium carbonate.

2.11 PhreeqC

During this study the software package (PHREEQC for windows version 1.5.08) (Parkhust and Appelo 2001) was used to calculate the saturation indices of the major mineral phases, testing for water corrosivity and to apply water mixing models.

2.11.1 Saturation indices

Generally, the saturation indices are used to express the water tendency towards precipitation or dissolution. The degree of water saturation with respect to a mineral is given by:

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

where K_{IAP} is the ionic activity product, K_{sp} is the solubility product, and SI is the saturation index of the concerned mineral. When SI is equal to zero then the water is at equilibrium with the mineral phase, whereas SI values less than zero (negative values) indicate under-saturation and that the mineral phase tends to dissolve, while SI values over zero (positive values) indicate super-saturation and that the mineral phases tends to precipitate.

2.11.2 Corrosivity and scale forming

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

$$\Delta \text{ pH} = \text{pH} - \text{pH}_c$$

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

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

The saturation indices were also used as an other indicator of water agressivity or scale forming. Table 2.7 presents a typical range of SI of calcite that may be encountered in a drinking water and a description of the nature of the water and general recommendations regarding treatment (Wilkes University 2002).

Table 2.7: Classification of the water corrosion potential based on the calcite SI values and recommended treatment.

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

2.11. 3 Mixing

In this section mixing models were conducted between water from different sources as a proposed solution for lowering the nitrate levels in the highly contaminated wells to the acceptable limits. For mixing each of the input solutions is multiplied by its mixing fraction and a new output solution is calculated stoechiometrically (Parkhurst and Appelo 1999).

2.12 Environmental isotopes analysis

The water samples to be analyzed for ^{18}O and ^{2}H were collected in 50 ml dark glass bottles and 500 ml polyethylene bottles for ^{3}H determination. ^{18}O and ^{2}H contents were determined, in the labs of the Institut für Hydrologie / GSF- München, using gas source mass spectrometry with detection limits of 0.15 ‰ for ^{18}O and 1.5 ‰ for ^{2}H. The ^{3}H was analyzed in the labs of Weizman Institute / Israel, using the electrolytic enrichment with a detection limit of 0.2 TU. The reproducibility of the determination is ± 0.15 ‰, ± 1.5 ‰ and ± 0.2 ‰ for the ^{18}O, ^{2}H and ^{3}H, respectively.

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

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

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

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

2.13 Extraction of soil water by the suction-cup method

2.13.1 Preparation of the sampling system

Following the recommendations of Grossmann et al. (1987) and Litaor (1988), the suction cups were cleaned first by a 10 percent hydrochloric acid solution so as to remove the dust and the trace metals, that are common artifacts of the manufacturing process, then they were rinsed with distilled water. To insure the cleaning process and to insure the saturation of the porous section, the sampling probes were immersed in distilled water for one day before the installation. Finally to avoid the strong sorption effect, which new suction cup could exhibit during the first samplings after installation, especially with regards to trace elements, the first two samplings were considered as preconditioning and the samples were rejected and not used for further analysis.

2.13.2 Installation of the suction probe

For the installation of the suction probes holes were drilled by a soil auger having, 19.1 cm diameter, as the shaft of the probe. During the drilling no soil material from the upper horizon was allowed to fall into the hole. Before inserting the probe, slurry from a sieved material from the soil auger was made and was put back in the hole. When the probe was inserted, the slurry began to move upward between the shaft and the soil thereby filling the gaps. The above method was adapted after (Sommer 1976 and Barbee and Brown 1986). Rubber collars were put around the body tube, 5 cm below the ground surface, so as to prevent the water from seeping from the surface down along the body tube as this causes hydraulic short circuits (adopted after Grossmann and Udluft 1991).

Sinking the probe completely into the soil and replacing the slurry with silica flour around the porous cup, toped by screened native soil and a layer of bentonite clay as a collar are other methods, common in literature, associated with the installation of the suction probe (ASTM 1999 and Smith and Carsel 1986).

9.6.3 Sampling and analysis

After the installation, the sampling systems were set exactly as shown in Fig. 2.6. Vacuum of 0.7-0.8 bar was generated in the first system and the valve (stop cock) was closed to seal off the unit. The pump was then disconnected and attached to the next assembly. By this procedure all the sampling assemblies were exhausted. During sampling it was noticed that the vacuum drops to 0.3 bar or even sometimes to less than that especially at low soil moisture (2 or more days after the rainy event) allowing air to enter the system. In that cases vacuum was applied once a day.

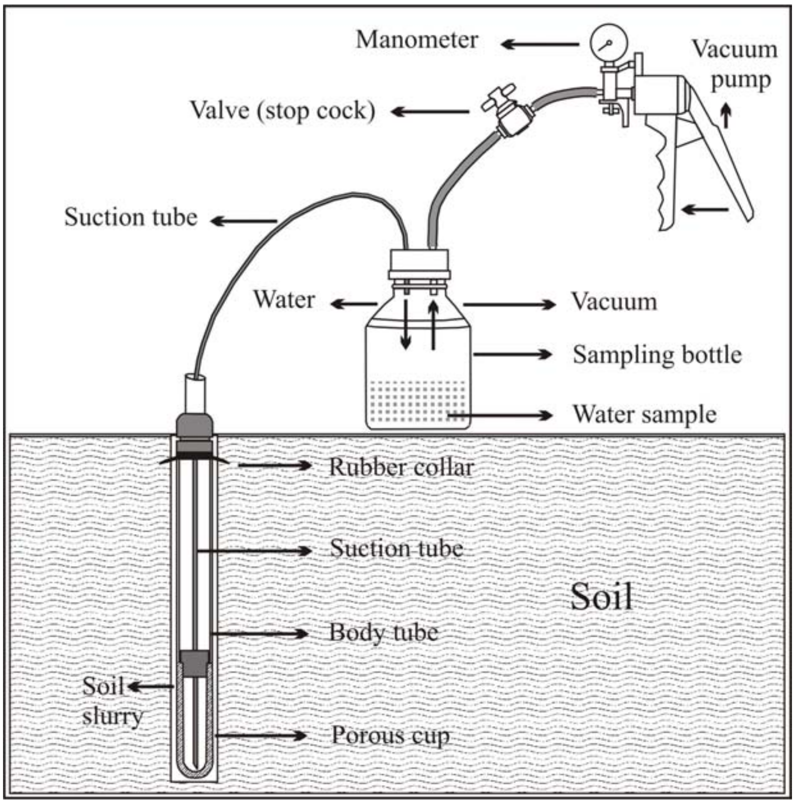


Fig. 2.6: Soil water sampling probes as installed during this study.

Because the suction cups are small in size and for the analysis a much bigger volume is needed the water was allowed to accumulate in the bottles until a volume of about 500-600 ml was collected (about 10-20 days) after which the samples were transferred to the labs of WSERU to be analyzed. During January-February 2000 and 2001 two samples from each depth (30, 60 and 90 cm) were collected and analyzed.

2.13.4 Analysis

The collected samples were analyzed for the major ions (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, HCO_3^{-}, Cl^{-}, SO_4^{2-} and NO_3^{-}), for SiO_2, for the minor ions F^{-} and PO_4^{3-} and for the heavy metals (Fe, Cu, Mn, Pb, Cd, Zn, Cr, Ni and As), and for the volatile organic chemical. The pH, EC and DO were also measured.

2.13.5 Maintenance

At the end of the first sampling season the probe were drawn from the ground, well-washed by water, followed by 0.1 M HCL, then immersed in distilled water for one day before being covered and protected in a save place to be used in the next year. Before installing the probes in the second season they were prepared following the steps in section 2.13.1.

3 ENVIRONMENTAL SITUATION

Protection of the environment and the natural resources in the West Bank and Gaza Strip against degradation and pollution as well as the enhancement of public environmental awareness had a high priority by the Palestinian Authority since its establishment in 1994, represented by the establishment of the Environmental Planning Directorate (EPD) in 1994, Palestinian Environmental Authority (PEnA) in 1997 and finally the Ministry of Environmental Affairs (MEnA) in 1998. Since the establishment of MEnA an Environmental Strategy Plan (ESP) was developed and a National Environmental Action Plan (NEAP) was formulated. The ESP was translated into projects organized according to their priority for the period 2000-2020. Also a general framework of environmental laws, guidelines, and standards for the quality of drinking water, ground water pollution, waste water, pesticides application, emissions, soil protection as well as other environmental issues were approved and promulgated. On the other hand, the division of the West Bank and Gaza into areas A, B and C with different control authorities along with the continued land confiscation, settlement expansion and movement restrictions of Palestinians complicated and diminished the installation and implementation of the control mechanisms, without which the laws are valueless. The environmental situation of the study area during the years 1998-2002 is described below.

3.1 Domestic water resources

The network supply is the main source of domestic water in the area, whereas the house cisterns, tankers as well as the springs and dug wells are of secondary importance. The surrounding environmental conditions as well as the methods of supply and collection are key factors in the quality of the water of these resources. Periodical and routine sampling and analysis of the water for relevant viruses and bacteria as well as for toxic chemicals is the only way to insure the safety of the water for domestic use. Generally, in the West Bank this periodical sampling and analysis when implemented is limited to the deep wells whereas its is rarely implemented on springs and dug wells as the case in the study area.

3.1.1 Drinking water networks

All the Palestinian communities in the area are connected to the drinking water network that conveys the water to the area from the deep wells of the Herodion-Beit Fajjar well field. The networks in the area are characterized by frequent interruptions of supply, 20-50 years old pipes some of which are poorly designed. In many cases the networks pipes were laid on the surface of the ground and thus are vulnerable to damage. These factors together increase the probabilities of water contamination by means of the leaking pipes (negative puncture). Based on the interviews with chairpersons of the local councils in 1999 and the study of MOPIC (1998), the theoretical per capita consumption in this area ranges between 18-25 m^3/yr (49-69 L/person/day). The loss from the network-pipes as a result of the corroded and damaged pipes was estimated to be 20 to 40 % of the tapped water, leading to an effective per capita consumption of 32 to 46 L/day. The quality of the drinking water networks in Al Arroub area was studied by WSERU during 1996-1997. A summary of the results is shown in Table 3.1.

Table 3.1 shows that the water of the network has good drinking water quality with respect to the major constituents which is the general situation. For better evaluation of the water quality analysis for viruses, bacteria and toxic metal(loids) are recommended. Sometimes, in the case of discontinuous supply, which may last for weeks or even for months as happened in

Shuyukh Al Arroub in the years 1998-1999 where the inhabitants received no tap water for about one year, the old corroded network facilitates the leakage of waste water from nearby cesspits to the network. Several such incidents were recorded in Al Arroub Camp during the few years up to 2001. Usually immediate replacement of the contaminated pipes was always the solution.

Table 3.1: The main characteristics of the networks drinking water at Al Arroub Camp (WSERU, personal communication 1999)

Parameter	15.08.1996	10.03.1997
EC (µS/cm)	563	558
pH	7.53	7.46
Cl_2 Residual (mg/L)	0.18	0.09
Ca^{2+} (mg/L)	72.5	67.6
Mg^{2+} (mg/L)	12.1	10.7
Na^{+} (mg/L)	21.8	23.8
K^{+} (mg/L)	1.9	2.1
HCO_3^- (mg/L)	245.5	229.3
SO_4^{2-} (mg/L)	13.2	12.1
Cl^- (mg/L)	39.3	42.3
NO_3^- (mg/L)	14.5	12.8

3.1.2 Household cisterns and roof tanks

Household cisterns are mainly used for collecting rain water in winter. In many other cases they were used as the roof tanks for the storage of the network water during those times when the supply was interrupted. No quality control for cisterns and roof tank water is in operation. Usually the tankers collected the water from deep wells, network of other cities or villages that have supply at that time, or even from springs or dug wells. Periodical cleaning and disinfection of the cisterns and maintaining their walls are very important in preventing possible contamination of the water in the cistern by the leakage of raw sewage water from the nearby poorly designed cesspits. Actually disinfection of the cisterns and roof tanks is not common in the study area, but some inhabitant do disinfect their cisterns and their tanks but not at sufficient intervals. At maximum the cisterns are cleaned once a year and maintained once every 4-5 years, while the roof tanks are cleaned 1-2 times a year. The majority of the people do not clean their roof tanks unless they notice algal growth in the tanks or when the taste or odor of the water indicates unsuitability.

3.1.3 Springs and dug wells

Despite the expansion of the water networks and the increasing public awareness, the inhabitants are still using spring water and water from dug wells to satisfy domestic needs, especially in the case of discontinuous supply in the network. Springs and dug wells such as El Bas-East, Kuweisiba 1, Eth-Tharwa, Bir El Bas were still a significant source of drinking water from 1998 to 2002. Spring water from Ed-Dilbi, Wadi Ed-Dur, Marina and Misleh was consumed from farmers and herdsmen. Generally, the water of all the springs and dug wells in this area is used for domestic purposes other than drinking. The uncontrolled disposal of the raw waste water in the open conduit of Wadi Al Arroub, poorly designed cesspits and in the nearby fields were potential contamination sources endangering the water quality of these resources. Because there is no control on the water quality of the springs and dug wells with respect to the pathogens and bacteria in the study area although it is very important, such control is highly recommended by this study.

3.2 Waste water and its disposal

There was little industrial activity in this area, therefore the only source of waste water in this area were the outlets from households that carried waste water into the drainage basin.

According to ARIJ (1995a), the amount of domestic waste water produced in the West Bank per capita per day is usually 80-90 % of water consumption. Taking 85 % as an average and taking into consideration that the average per capita water consumption in the study area is 21.5 m^3/yr, then 710 000 m^3/yr is the approximate total volume of waste water produced in the area. Table 3.2 summarizes the main characteristics of the waste water in the study area, which is actually an enriched waste water due to the low per capita water consumption.

Table 3.2: Results of analysis of sewage samples collected in May 1999 from Al Arroub sewage conduit.

Waste water Sample	EC µS/cm	BOD_5 mg/L	COD mg/L	Na^+ mg/L	Cl^- mg/L	SO_4^{2-} mg/L	PO_4^{3-} mg/L	NO_3^- mg/L
Upstream	2850	890.5	2746	618	452	59	60.2	65
Downstream	3250	1432	3571	720	525	43	47.3	59

In Wadi Al Arroub drainage basin, there is no installed central collection sewerage systems and no treatment plants. Only in the western part of Arroub camp there is a very simple sewer pipes (4-8 inch in diameter) which discharges in the Wadi just few meters in front of the camp. The waste water disposal method in operation in 2001 was mainly the on-site disposal cesspits.

3.2.1 Cesspits

In Al Arroub Camp, 50-60 % of the waste water is being disposed in cesspits while the remaining percentage is being disposed by the small sewer system to the floor of the wadi in front of the camp forming a small waste water conduit. In all the other communities in the study area the cesspits constituted the only method of waste water disposal. According to the interview with UNRWA-Hebron Sanitation Officer in 1999, every cesspit in Arroub Camp served 6-7 persons. Generalizing this average to the whole area led to a total of 5600-6500 cesspits spreading all over the area. The cesspits in the area were normally single-chamber pits built of concrete, brickwork or natural stones. They are generally constructed for percolation with open bottom and perforated walls. In the decade up to 2001, because of the growing environmental awareness, part of the newly built pits was built double-walled with closed-bottom (septic tanks). The capital and maintenance costs of the pits depended mainly on their size, the amount of waste water, and the permeability of the underlying rocks. Higher permeability means more percolation and less maintenance cost, but on the other hand represented a higher potential hazard for ground water contamination.

In order to save the costs of emptying the pits (2-3 $/$m^3$) some residents disposed their gray water in winter onto the streets. Waste water tankers discharged their load into the Arroub conduit, the conduit in Wadi Es-Samin south of Hebron city, around the nearest hills or even on nearby agricultural fields, thus creating additional sources of pollution and health hazards.

3.2.2 The conduit

Arroub Camp is the only community in this area that had a waste water collecting system which serves only the western side of the camp. This system is very simple and consisted in pipes of small diameters (4-8 inch), therefore it is characterized by frequent clogging and flooding of the sewers leaving stagnant waste water on the streets that constituted a health hazard if exposed to human. The talweg of Wadi Al Arroub represents the end point for raw waste water collected from Arroub camp by this simple sewer system. In many cases the wadi represents also a disposal site for the tankers which emptied the cesspits. In summer the waste water in Wadi Al Arroub flowed for about two kilometers before drying up as a result of evaporation and/or infiltration, while in winter it flows much longer distance since it carries the waste water as well as the runoff water. Waste water of the conduit represents a potential contamination sources for the springs and dug well in the floor of Wadi Al Arroub, through infiltration to the perched aquifer supporting them or through direct flow and mixing with the perched aquifer water.

During May and June 1999, the flow of the conduit was measured at a site near Ein Ayyad at one hour interval over a period of four days. The measurements are presented in Fig. 3.1 which shows that the highest flow of the conduit was at about the mid-day which was the rush hour. The average flow in the wadi was calculated to be 4.847 m^3/hr which is about 3500 m^3/month.

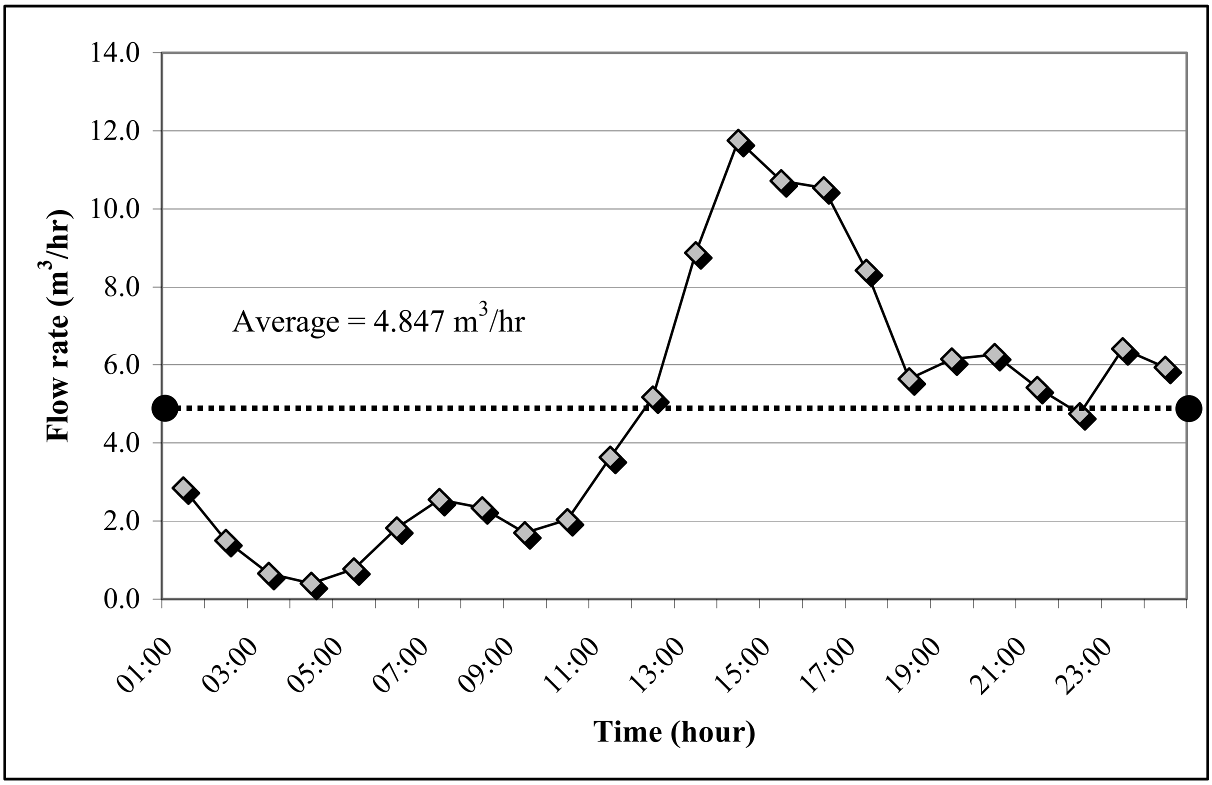


Fig. 3.1: The average flow rate of waste water in Wadi Al Arroub (May-June 1999)

3.3 Negative impacts of the waste water on the local community

The disposal of the raw waste water of Al Arroub Camp in the floor of the wadi as well as its disposal by the tankers in the nearby fields had negative impacts on both the human health and on the socio-economic conditions.

3.3.1 Human health

Water-borne or related diseases represent a significant percentage of the diseases in this area, especially in Al Arroub Camp and the village of Shuyukh Al Arroub. Based on personal interviews with the Hebron-UNRWA Health Field Officer and the chairman of the local council of Shuyukh Al Arroub in 1999, 15 % of the inhabitants of Arroub Camp suffered from Amoebiasis. This percentage was estimated to be 30 % in Shuyukh Al Arroub with the majority suffering from cystic Amoebiasis. The higher percentage in Shuyukh Al Arroub was attributed to the fact that the inhabitants were more directly exposed to the waste water conduit and they depended more on the springs and dug wells to satisfy their domestic needs. Mosquitoes, which are plenty especially in summer, are potential to cause many other diseases.

3.3.2 Socioeconomic situation

Flow of waste water in the floor of Wadi Al Arroub is one of the main reasons that cause the farmers not to cultivate their land and thus allowed urban expansion on agricultural land. The believe that soil in which vegetable crops were grown had been contaminated by raw sewage dissuaded local people from purchasing locally grown vegetables. Furthermore the inhabitant have to pay high medical costs for treatment of water-borne or related diseases. The sewage disposal conduit continues to present social problems between the inhabitants of Arroub Camp (upstream) and those of Shuyukh Al Arroub (downstream), whenever new houses in Arroub Camp are connected to the sewer disposal pipes which transports the waste water from the camp to the conduit or whenever the tankers dump the cesspits into the conduit. This increases the waste water flow in the conduit, which means the waste water will travel longer distance along the wadi and additional agricultural lands owned by the inhabitants of Shuyukh Al Arroub will be flooded. It is important to mention that in the mean time the conduit dries up before it reaches the villages of Kuweisiba and Urqan Tarrad which are further downstream to Shuyukh Al Arroub. Any increase in the amount of waste water disposed to conduit than at present will create the same health and socioeconomic problems faced by the inhabitants of Shuyukh Al Arroub for these two villages.

Destruction of the landscape as well as the inconvenience due to bad odors and the mosquitoes are among the negative impact of the conduit on this area.

3.4 Stone factories – waste water and sludge

The stone cutting factories represented the only considerable industry in the area of Wadi Al Arroub drainage basin. This industry produced dust and noise pollution as well as the waste water sludge deposited on agricultural land, thus contributing to its negative environmental impacts. The trucks transporting equipments and stones to and from the factories also endangered human health, especially where the stone factories are close to the houses.

Dumping of sludge on the wadi shoulders also presents a hazard to households, dug wells and agricultural land during times of heavy rain which facilitates transport to the wadi floor. Disposing the sludge on the top and the shoulders of the mountains, facilitates its transport during heavy rain, thus endangering the houses below, the human health, soil as well as water of the dug wells. Such a situation happened more than once when the sludge heaps disposed by the factories of Beit Fajjar of the top of the mountain collapsed.

3.5 Solid wastes

The quality and quantity of solid waste produced is a function of local habits and industrial activity. The impact of solid waste on the environment is controlled by the type of the waste and the method and site of disposal. Because the domestic solid wastes always contain human pathogens from dippers, paper handkerchiefs, fermented food,...etc., inadequate disposal causes the disposal site to serve as a breeding site for rats, flies, mosquitoes, and insects, which could act as vectors in transmitting the different diseases. So the solid waste could endanger the human health through the direct exposure to pathogens, toxic and hazardous substances as well as the physical injury. Leachates could be formed as a result of heavy rainfall, resulting in potential aquifer contamination.

Generally, the solid waste in the area was composed of 50-70 % organic residues and the remaining percentage was cans, papers, carton, plastics as well as parts of old furniture. The Arroub Camp UNRWA - Service Officer stated in a personal communication in 1999 that Arroub Camp produced about 26 m^3 of solid waste per day leading to an average of 1.36 m^3/capita.yr. About 80 m^3/day solid waste were produced in Beit Ummar (Head of Engineering and Sanitation Department -Beit Ummar Municipality, personal communication 2001). Arroub Camp, Shuyukh Al Arroub, Urqan Tarrad and Beit Fajjar behave in a similar fashion, but Beit Ummar, Halhul, Si'ir and Esh-Shuyukh develop habits related to their agricultural and industrial livelihoods. The entire area is assumed to produce an average of 2.5 m^3/capita.yr of solid waste, thus in total 110000 m^3/yr.

3.5.1 Solid waste disposal

Until the early eighties, all the solid waste in the area was dumped on the nearby fields or burned near to houses. Until 2001, this was the case in Shuyukh Al Arroub, Kuweisiba and Urqan Tarrad. In the Year 2001 the solid waste was collected in containers which were then transferred by trucks to two dumping site, Mza'rah west of Beit Ummar and Baggar west of Halhul. Both dumping sites are to the west of the divide and out of the catchment area, so they did not represent potential contamination source to the shallow ground water of the study area, but could nevertheless contaminate the aquifers underlying them.

4 GEOLOGICAL SETTING

4.1 Stratigraphy and lithology of the West Bank

Within the West Bank, the outcrops are predominantly carbonate sediments and rocks of Tertiary and Cretaceous age. Older rocks cannot be found at the surface though they are known from the boreholes. The oldest exposed rocks belong to the Albian, overlain by younger strata of the Cenomanian, Turonian, Senonian and Eocene, exposed on both flanks of the anticlinal axis in the West Bank. In the Jordan Valley and the shorelines of the Dead Sea, as well in the wadis and the interior valleys, the youngest formations of the Pleistocene-Holocene age are found (Fig. 4.1).

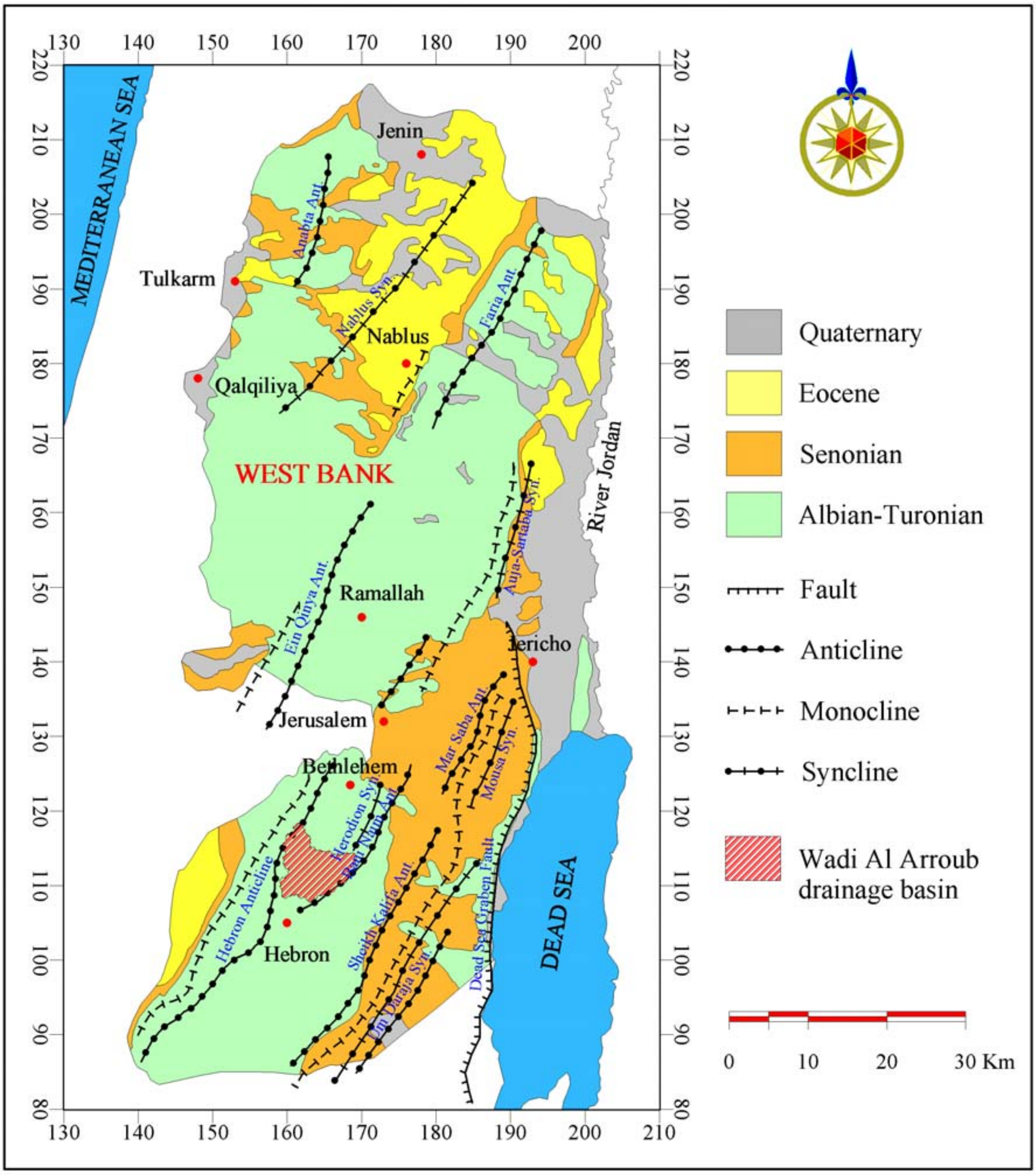


Fig. 4.1: General geological and structural map of the West Bank (modified after Abed Rabbo et al. 1999 and Guttman and Zuckerman 1995).

Concerning the geology and stratigraphy of the West Bank and Israel, there are variations and inconsistencies in the literature, mainly in the demarcation of the Aptian-Albian and the Albian-Cenomanian boundaries. In this study the Aptian-Albian boundary placed by Guttman (2000) and Guttman and Zuckerman (1995) above of the Qatana Formation is placed below the Tammun Formation, based on the evidence of the Hauterivian-Aptian ammonoids and ostracods in the coastal plain Gevar-Am group (Rosenfeld and Raab 1984). These are represented by the Nabi Said and Ein Al Asad formations in the northern West Bank (Eliezri 1965). The Albian-Cenomanian boundary, placed in the middle of the Kefira by Hamaoui (1965) is placed in this study after Lewy and Raab (1976), Lewy (1997) and Hirsch (1983) near the top of the Kesalon Formation. This is based on the evidence of the Albian ammonoids in the Hevyon Formation and of the Early Cenomanian ammonoids in the Ein Yorqe'am Formation. The En Yorqe'am and Hevyon formations of the southern Israel are exposed in the West Bank as Moza-Beit Meir and Giva't Yearim formations respectively (Braun and Hirsch 1994). Different Israeli names are given to the formations as they are exposed in the north, central and southern parts of the country (Fig. 4.2).

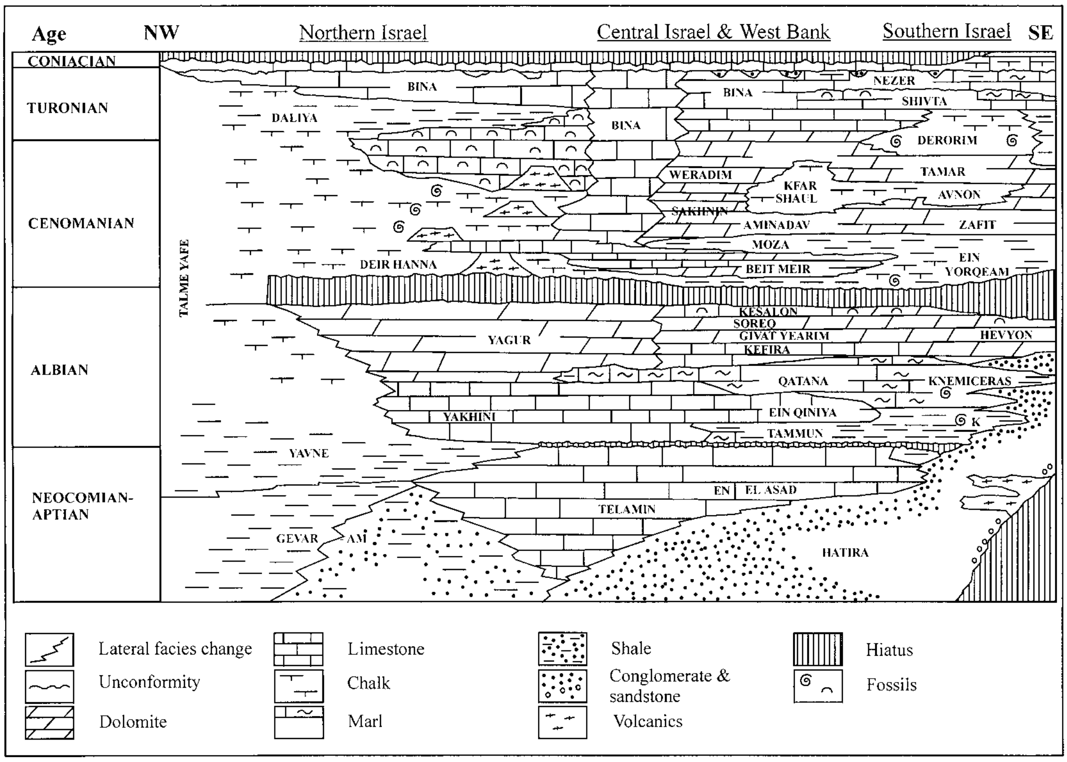


Fig. 4.2: The Cretaceous stratigraphy of the Arabian sub-plate in the transverse of Israel and the West Bank (Braun and Hirsch 1994).

The Tertiary and the Cretaceous rocks in the West Bank are mainly made of limestone, dolomite, chalk and marl with bands of chert. These rocks built-up the two main regional aquifers in the West Bank; the Cenomanian-Turonian aquifer (Upper) in the Jerusalem, Bethlehem and Hebron formations and the Albian aquifer (Lower) in the Upper and Lower Beit Kahil formations. The marls and clays of the Yatta Formation, which represents the main aquiclude in the West Bank, separate the two aquifers. The general stratigraphy of the West Bank and the Israeli and the Palestinian names of the different geological formations in the West Bank as well as their lithology, thickness and aquifer potentiality are described and illustrated in Table 4.1.

Table 4.1: Generalized stratigraphic column of the West Bank (modified after Braun and Hirsch 1994; Millennium Engineering Group et al. 2000, Guttman 2000; Guttman and Zuckerman 1995 and Bartov et al. 1988).

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

4.2 Tectonics and structure of the West Bank

Two major tectonic events have shaped the area of the West Bank. The Syrian Arc System folded up the shelf deposits at the end of the Cretaceous Period and the Red Sea-Aqaba transform fault formed the Dead Sea Graben from the Miocene (Krenkel 1924; Rofe and Raffety 1963 and Andrew 2000).

The Afro-Arabian tectonic plate remained relatively stable from Precambrian to the early Cretaceous. The Cretaceous period began with extensional faulting and volcanism over part of the Levant countries and eastern Mediterranean, and terminated in compression, inversion, folding and faulting processes, expressed in Israel and the West Bank by the anticlines of the Syrian Arc (Krenkel 1924) and fault structures, discerned by lateral thickness variations of the sedimentary section between nil and a few hundred meters. The formation of the Syrian Arc, manifested in the reactivation of the pre-existing faults, resulted in the inversion of the late Paleozoic-Turonian lows and highs (Flexer et al. 1989).

From the mid Miocene to Pliocene and recent times a lateral strike-slip movement between the African and Arabian plates took place. This detached the Arabian Shield from the great African Shield thus initiating the opening of the Red Sea, facilitated by the left-transform fault along the line Aqaba – Dead Sea- Jordan Rift. The West Bank is thus located on the Sinai sub-plate to the west of the fault. This fault system has a vertical, stepped component, forming the rhomb-graben in which the Dead Sea is located. This led to the lowering of the base level of drainage and deposition of the runoff load (Rofe and Raffety 1963).

The Jordan Rift, the SSW-NNE Jerusalem (Judean) Anticline, and Nablus Syncline dominate the structure of the West Bank, where Jerusalem Anticline expresses both Surif (Hebron) and Ein Qiniya Anticlines. On the limbs of the Jerusalem anticline there are a number of minor parallel or sub-parallel folds so that the structure can be considered as an anticlinorium (Fig. 4.1). The Jerusalem Anticline is asymmetrical, with a steeply dipping west limb (mean 30°) and a more gently dipping east limb (mean 15°), (Rofe and Raffety 1963).

4.3 Geology and stratigraphy of Wadi Al Arroub driange basin

The geology of Wadi Al Arroub drainage basin and its immediate surrounding is composed of sedimentary carbonate rocks of Albian to Holocene age. The oldest formations, exposed 2-4 kilometers to the West of the study area, are the marls and clays of Qatana Formation and the marl and marly limestones of the Ein Qiniya Formation (Millennium Engineering Group et al. 2000). The younger formations of lower Beit Kahil, Upper Beit Kahil, Yatta, Hebron, Bethlehem and Jerusalem crop out from west to east (Fig. 4.3). Holocene alluvial deposits cover the wadi floors of the area.

The following discussion about the stratigraphy and the characteristics of the geological formations exposed in the study area is based on the geological well logs of Hebron 1 and 2, PWA I, Herodion 3 and 4, PWA II, Arroub 1B, and the studies of the Millennium Engineering Group et al. (2000), Guttman and Gotlieb (1996) and Braun and Hirsch (1994) as well as the generalized stratigraphic sequence of the West Bank that is shown in Table 4.1.

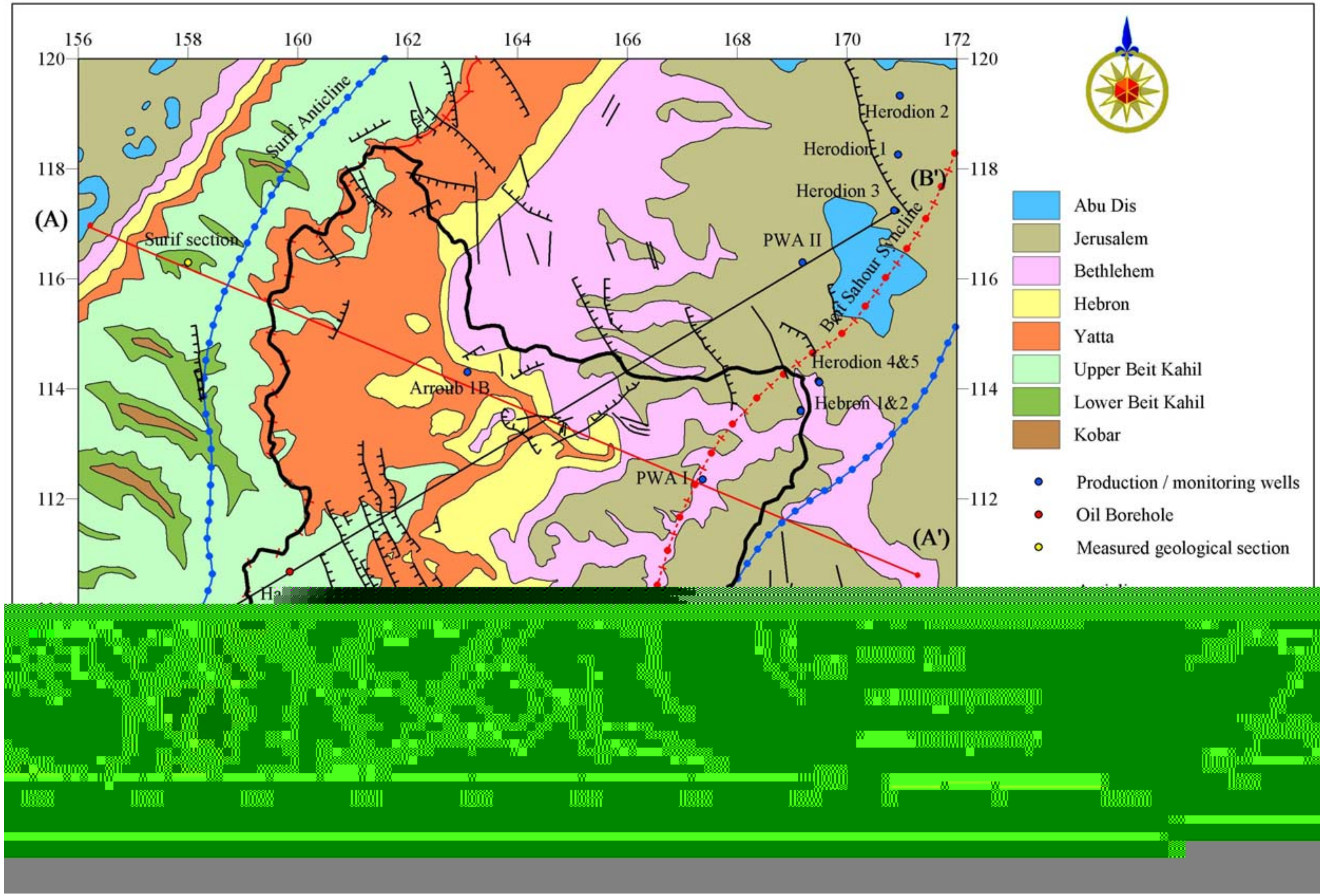


Fig. 4.3: A geological and structural map of Wadi Al Arroub drainage basin (modified after the Geological Survey of Israel 1999; Kolton 1972; Hirsch 1983; Hirsch 1997; and Rofe and Raffety 1963).

4.3.1 Cretaceous

4.3.1.1 Aptian-Albian – Kobar Formation

According to the Israeli nomenclature, this formation is made-up of five sub formations (Table 4.1): the Nabi Said, Ein Al Asad, Tammun, Ein Qiniya and Qatana. In the area of study only the formations of its upper part Ein Qiniya and Qatana are exposed. Ein Qiniya Formation is made-up of layers of thin gray to brown, thin to middle grained limestones which contains iron concretions and thin calcite veins. The limestone layers are inter-bedded with horizons of marl, rich in fossils (Shakhnai 1969 and Millennium Engineering Group et al. 2000). On the other hand the Qatana Formation is composed of yellowish-brown-gray limestone alternating with layers of yellow marls. Ein Qiniya and Qatana formations in this area are exposed only as very small strips in the floors of the wadis of Sheikh Yousef, Ar-Rashrash and Mazr'ah. The thickness of Ein Qiniya in these outcrops is about 15 m according to Hirsch (1983), whereas Qatana reaches a thickness of about 40 m (Hirsch 1983 and Millennium Engineering Group et al. 2000). The two formations are part of regional aquiclude, including the Tammun Formation below them.

4.3.1.2 Albian - Lower Beit Kahil Formation

This formation represents the lower part of the upper Albian (Braun and Hirsch 1994). It is exposed mainly at the crest of the anticline 2 km west of the study area. It is built of two sub formations, Kefira and Giva't Yearim. Kefira, the lower part of this formation, is made-up of limestone with thin layers of porous dolomite interchanging with marly limestone. Gray limestone layers alternating with layers of shale and marl, are typical for the lower part of the Kefira Formation (Guttman and Gotlieb 1996). On the other hand, Giv'at Yearim, the upper part of the Lower Beit Kahil Formation, is made-up of gray to brown dolomite with clayey and marly limestone. The marly uppermost part of Ein Yorqe'am is equivalent to Moza marl (Picard 1938). Generally, the Lower Beit Kahil is considered to be a moderate to good aquifer, forming the lower part of the Albian aquifer. Its vertical thickness ranges between 137 m in PWA1 and 215 in Hebron well 1. Kefira in all wells has 2-4 times greater thickness than Giva't Yearim Formation.

4.3.1.3 Albian Upper Beit Kahil Formation

This formation is regarded as the upper part of the upper Albian. It has two sub formations that are; Soreq and Kesalon. The lower part of this formation (Soreq) consists of porous dolomite, marly dolomite, marl and at times some chert. The occurrence of the marl in this formation reduces its water bearing capability. On the other hand, the upper part of this formation (Kesalon) mainly consists of brittle dolomite and brittle limestone rich in fossils. This formation usually appears as a cliff and some times as a rocky landscape. The vertical thickness of the Upper Beit Kahil Formation ranges between 66 m in Herodion well 4 and 145 m in the well of PWA I. This formation is considered to be the upper part of the lower aquifer.

4.3.1.4 Cenomanian - Yatta Formation

The Lower Cenomanian Yatta Formation (Beit Meir and Moza formations in Israeli literature) overlies the Upper Beit Kahil Formation. Beit Meir, 50-110 m thick, is composed of limestone, chalky limestone, dolomite, marl and greenish clay at the bottom. Moza, 10-20 m thick, is composed of yellowish marly limestone with traces of greenish marl at the bottom. Yatta Formation, 86 m thick in Herodion 4 and 128 m in Herodion 3, in general act as an aquiclude and separate the Cenomanian aquifer from the Albian aquifer underlying it. The dolomite of the upper part of Beit Meir shows some water bearing nature (Guttman and Gotlieb 1996). Sometimes the limestone near the top, officiates as a local perched aquifer, which explains why a few springs emerge 20 m below the contact of the Yatta Formation with the Hebron Formation (Rofe and Raffety 1963).

4.3.1.5 Cenomanian - Hebron Formation

The Middle Cenomanian Hebron Formation, Aminadav in the Israeli terminology, is composed of brittle karistified gray dolomite, dolomitic limestone and gray limestone. At its base it is formed of hard dolomite and dolomitic limestone with some silicification. The lithology is uniform since dolomite and dolomitic limestone are found throughout the sequence of Hebron Formation. The porosity of this Formation is mainly secondary because the rocks are well jointed and karstified. The Hebron Formation without doubt is the most important aquifer within the West Bank. Its Vertical thickness ranges between 70 in Herodion well 4 and 120 m in PWA I.

4.3.1.6 Cenomanian – Bethlehem Formation

The Upper Cenomanian Bethlehem Formation, is built of two formations: Weradim as its upper part and Kfar Shaul as its lower part. Kfar Shaul is made-up of limestone, chalky limestone and marl that act as a confining aquiclude for the Hebron Formation beneath. The Weradim Formation is made-up of hard dolomite with some limestone. Bethlehem Formation is frequently highly jointed and fractured making this formation a good aquifer. Its vertical thickness ranges between 88 m in PWA I and 260 m in Herodion well 4.

4.3.1.7 Turonian - Jerusalem Formation

This formation is of Turonian age. Its lithology is characterized by karstified limestone and dolomite with marl and clay mainly near the bottom. Sometimes occurrence of chalk is evident on the top of this formation. The Jerusalem Formation has a thickness of about 90-100 m as in Herodion wells 3 and 4. Due to fractures and joints of this formation turns out to be a good aquifer.

3.3.1.8 Senonian – Abu Dis Formation

This formation is part of Senonian age. It consists of chalk and chert, the chalk usually white but in some areas dark colored due to the presence of bituminous materials. In general chalk often appears to be a fracture flow aquifer but because of its clayey nature it is considered as an aquiclude. According to ARIJ (1995b) the thickness of this formation ranges between 40 and 150 m.

4.3.2 Quaternary

Alluvial formations are of Pleistocene to Recent age, consisting of unconsolidated, laminated marls, clay, silt, gravel and conglomerate. The deposits of this formation cover the floors of all wadis in the study area with thicknesses ranging from less than one meter to 33 meters at the Hebron well 2 (Guttman and Gotlieb 1996).

4.4 Structure of Wadi Al Arroub driange basin

4.4.1 Folding

There is a SW-NE structural trend of folds in that part of the Hebron area where the Wadi Al Arroub drainage basin is located. The dominant structures are the Surif (Hebron) anticline, Surif Monocline, Herodion (Beit Fajjar-Beit Sahour) syncline and the Bani Naim anticline (Fig. 4.1 and 4.3). Wadi Al Arroub drainage basin lies less than 1 km to the east of the axis of the main structure, the Surif anticline (Fig. 4.2). The Surif anticlinal axis, forming the Hebron Mountain Range, runs from the Hebron-Halhul area to Jerusalem in a general SW-NE direction and plunges in the direction of Jerusalem (Guttman 2000). The Surif monocline forming the western flank of the Surif anticline dips steeply (up to 40°) and then levels out in a matter of half a kilometer and become slightly synclinal (Tahal 1975). On the eastern flank of the Surif anticline dips are mainly gentle with a few marked exceptions, and there are a number of subsidiary NNE-SSW folds. The Beit Fajjar - Beit Sahour syncline is the first of shallow folds east of the main axis

The Herodion syncline begins in the Si'ir-Hebron area and dips in a N-NE direction towards Beit Sahour and Wadi An-Nar (Kidron Valley), then it gradually diminishing 2 km east of Abu Dis. In the area of Hebron wells 1 and 2 and Herodion boreholes 4 and 5 the young layers in the center of the syncline belong to Bina (Jerusalem) Formation of Turonian age. In the Teqou' area the younger strata belong to the Menuha Formation, of Santonian age, while to the east of Abu Dis the young strata in the center of the syncline belong to the Mishash and Ghareb formations, of Campanian and Maastrichtian ages. It is significant that the Hebron, Herodion and Beit Fajjar wells are located in this syncline (Guttman and Gotlieb 1996).

To the east of the Herodion syncline the Bani Naim anticline is situated, which forms the beginning of the eastern dip of the anticline in the Hebron area towards the Judean Desert and the Rift Valley (Tahal 1975). It begins north of Hebron trending SW-NE until it diminishes out near Abu Dis. It is running about 2 km to the east of the Herodion syncline and parallel to it. Further east the Sheikh Khalifa Anticline Which has a steep east limb. This anticline begins in the Yatta area and ends about 5 km to south of Mar Saba anticline (Fig. 4.1)

4.4.2 Joints

According to Rofe and Raffety (1963), the joints in the West Bank, part of which is Wadi Al Arroub drainage basin, are either a result of shrinking or the varying competency of individual beds within a formation. The shrinking joints are supposed to originate from the dolomitisation of limestone, reduces the volume by about 12 % (Pettijohn 1957 and Schlumberger 2002), that assist the occurrence of the fairly well develop joints in the dolomite limestone of the Lower Beit Kahil, Hebron and Jerusalem formations, all of which are wholly or partially dolomitic. On the other hand, brittle beds of Yatta, Bethlehem and Jerusalem formations are highly jointed, perhaps due to their brittleness, whereas the marly and chalky beds of these formations are less affected.

4.4.3 Faults

Most significant faults in the study area trend NNW-SSE, while N-S faults are less significant, whereas the NE-SW faults are of much less significance (Fig. 4.3). According to Baida and Zuckerman (1992), the majority of the faults in the area penetrate deeply at least crossing the lower Beit Kahil Formation. The throw of the major faults, 1-2 km to the east of Halhul Oil Borehole, as demonstrated by CH2M-HILL (2000) ranges between 20-70 m.

Two hydrogeological cross-sections, NW-SE and SW-NE, in the area of Wadi Al Arroub drainage basin are shown in Fig. 4.4 and 4.5. The two sections show the main folds in the area, the thickness of the geological formations as well as the ground water level. For the location of the section see Fig. 4.3. The thickness of the formations at Halhul borehole and the water tables were adopted after CH2M Hill (2000).

4.5 Karstification

Generally, limestones and other soluble rocks at or near the surface that have been modified by corrosive solution of limestone characterize karst regions. Surface sinks, sparse streams, subsurface caverns and deep water tables are typical features in such areas (Legrand and Stringfield 1973).

Karstification is a result of the widening of the joints and fractures, through the dissolution of the carbonate rocks, by CO_2- rich percolating water. As the solubility of the dolomite is less and slower than that of the limestone, karst is less developed in the dolomite than in limestone and only minor developed in marl (Milanovic 1981)

The dominance of the jointed and fractured carbonate rocks, limestone and dolomite, in the West Bank and the study area, suggests the possible existence of karst caves. According to Arkin (1980), fractures and karstification are common features of the West Bank.

In Wadi Al Arroub drainage basin there are several karst features to be seen. Caves are common in the mountains, particularly in the Hebron Formation. One example is the caves from which the spring of El Bas-West is flowing. Such caves are also common between the houses and they are used for animal keeping. The loss of drill fluid during drilling of wells is another examples of karstification phenomena. Loss of drill fluid occurred for a few meters in the wells Hebron 1 and Herodion 3, but for 250 meters in the Arroub well 1B. Loss of drill fluid may occur shallow or deep, in Arroub well 1B it happened between 250-500 m below the ground level. All these features and the deep water table of about 300-350 meters below the ground level proves that the area is intensively karstified.

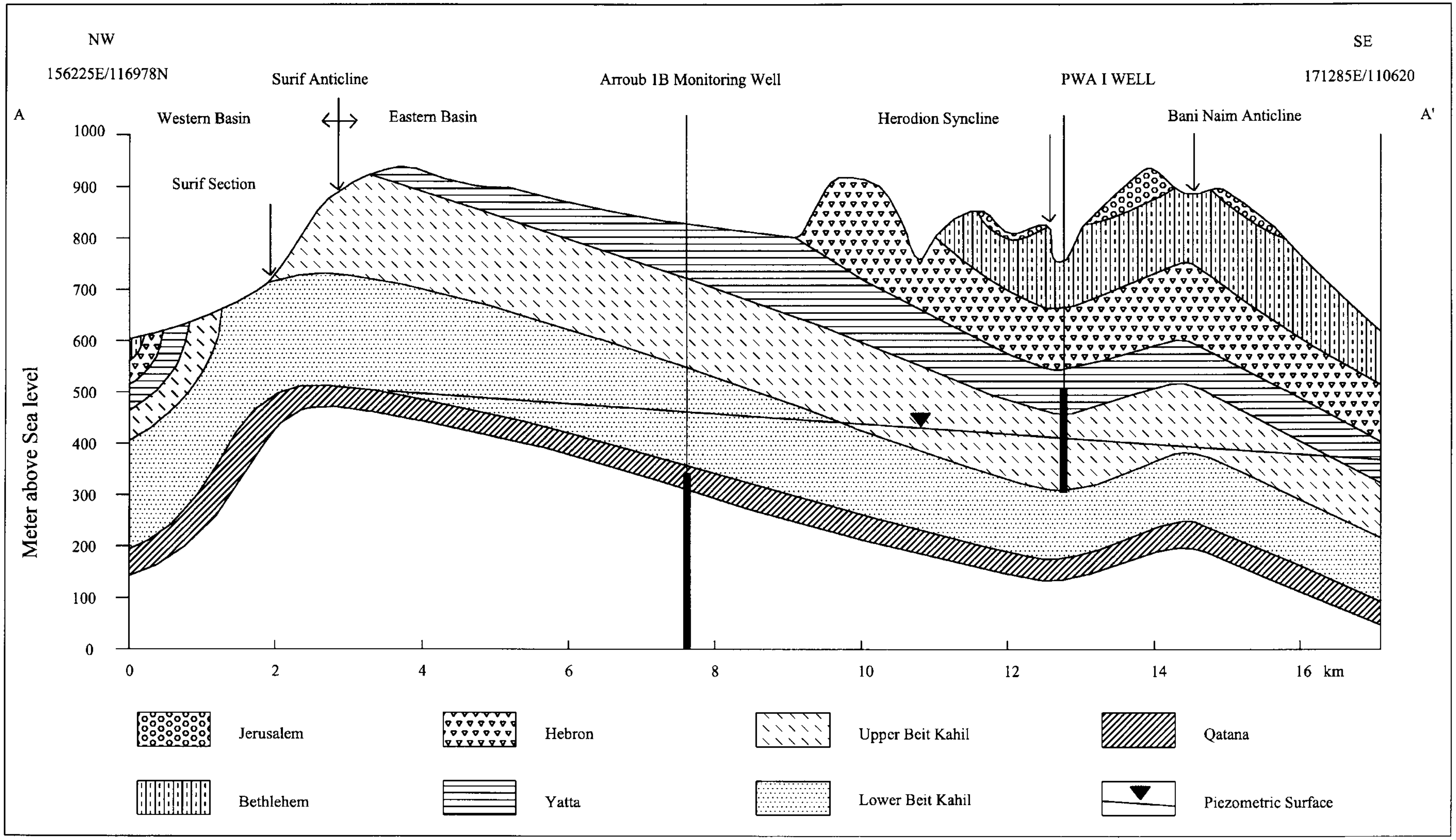


Fig. 4.4: A NW-SE hydrogeological section across Wadi Al Arroub driange basin.

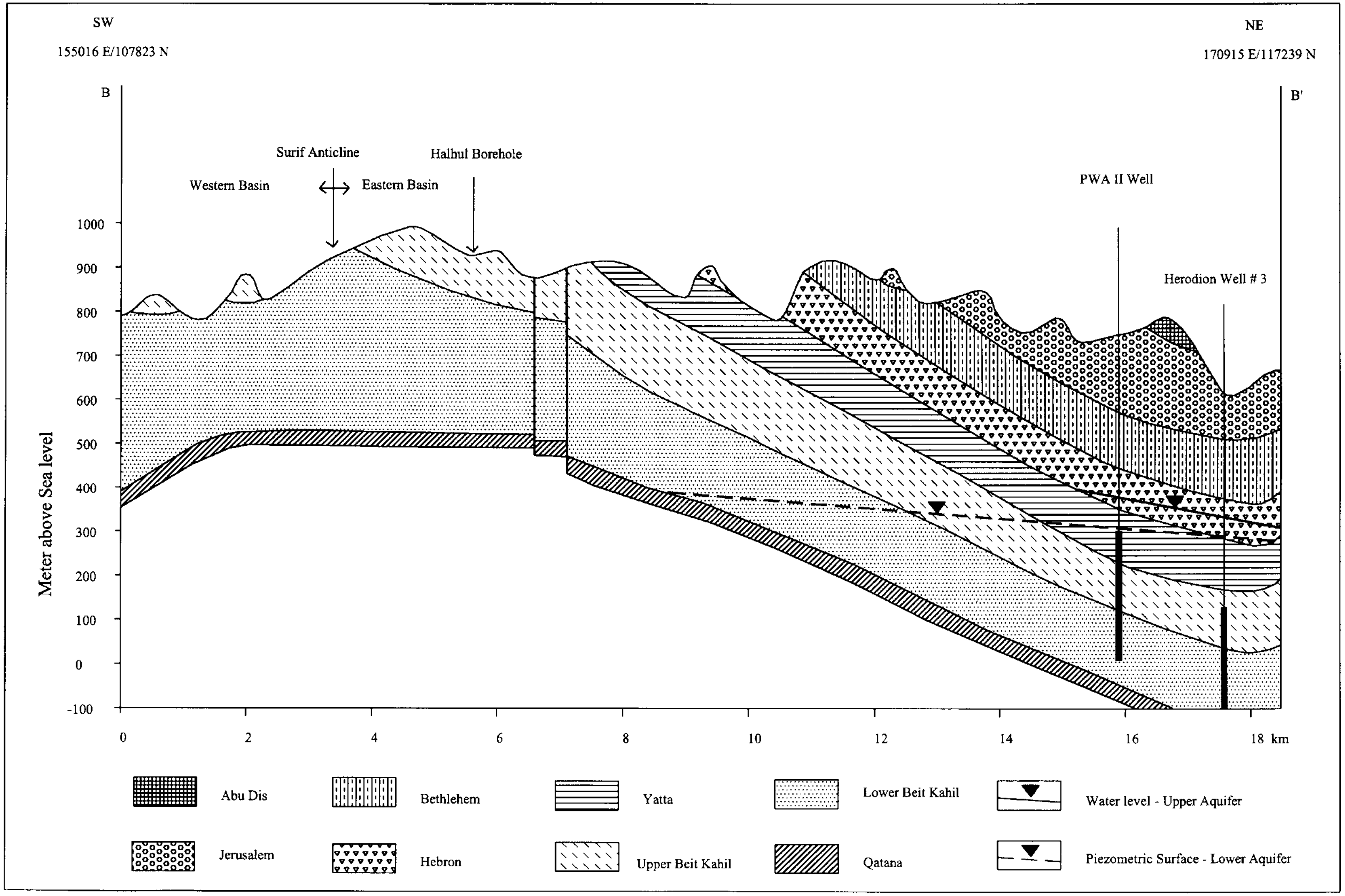


Fig. 4.5: A SW-NE hydrogeological section across Wadi Al Arroub driange basin.

5 GEOMORPHOLOGY

5.1 Introduction

Generally, the West Bank morphology is a result of folding, faulting and subsequent denudation. The dominant geomorphological features of the West bank are the Hebron Mountains, rising to an elevation of 1020 m, turning over northwards into the Jerusalem Mountains, Nablus Mountains and to the 300-400 m high Jenin Hills. Roughly parallel to this north-south trending line of hills the Rift Valley with the Jordan River flowing southwards into the Dead Sea terminal lake is the most significant and unique geomorphological feature. The bottom of the Jordan Valley in the West Bank falls from an elevation of 200 masl to 410 mbsl as it enters the Dead Sea (410 mbsl).

The hilly-mountains areas may be considered as four distinct units, as shown in Fig. 5.1; the Mountain Plateau, the Semi-Coastal Plain, the Western slopes, and the Eastern Slopes (MOPIC 1999). The three mountain blocks of Hebron, Jerusalem and Nablus are referred to as the Mountain Plateau, to the east of which the hills of the Eastern slopes descend including the Jerusalem Desert from a height of 600 m, at an average gradient of 1:20, to the western edge of the Rift Valley. The semi costal plain is a hilly area with an elevation of 50-300 m above sea level, 3-12 km wide and about 70 km long. It is an extension of the Palestinian Mediterranean coastal region, limited to the northwestern West Bank and comprises parts of Jenin and Tulkarm districts. The hilly transition zone between the Semi Coastal Plain and the Mountain Plateau is referred to as the Western Slopes that have an elevation of 300-600 masl and an average slope of 1:40. In the southern West Bank these slopes are sometimes referred to as the Jerusalem foothills.

Wadi Al Arroub is a sub-basin of the Jordan River Basin and drains part of the Hebron Mountains towards the Dead Sea. It is a tributary wadi to the Wadi Ghar, which it joins at the western edge of the Jerusalem Desert.

5.2 Drainage system

The Precambrian Shield forms the base of the Afro-Arabian Plate that did not become two distinct plates until the Miocene. During the Mesozoic, the West Bank area was part of the continental shelf of the Afro-Arabian Plate onto which mainly carbonate deposits were sedimented. At the end of the Cretaceous Period, these sediments were folded up above sea level into the Syrian Arc System (Krenkel 1924) and therefore were subjected to sub-aerial denudation. Because the Dead Sea Graben did not yet exist, the base level of erosion was the Mediterranean Sea to which the runoff water flow forming the young wadis.

Between the mid Miocene and Pliocene-recent phases a lateral strike-slip movement of the African and Arabian plates took place. This movement placed the West Bank in the Sinai sub-plate and led to the development of the rhomb-graben left lateral shear fault system along the line of the Dead Sea. This fault system had a vertical, stepped component, which led to the lowering of the base level for both the surface and phreatic ground water drainage (Rofe and Raffety 1963 and Andrew 2000). This new base level of erosion deflected the drainage system from flowing to the Mediterranean Sea to flow towards the Dead Sea. This deflection divided the West Bank into two major basins, Mediterranean and Dead Sea basin, divided by the ridge on the Mountain Plateau. This process as a whole leads to the formation of what is known as the Jordan River Basin. It is important to mention that the subsidence of the Rift area took place at a much faster rate than erosion and the whole area is now at a very immature stage of erosion cycle.

As a summary, the drainage system of the West Bank is mainly controlled by tectonics. It was initiated by the uplift of mountains through the folding of the Syrian Arc system and rejuvenated through the formation of the Jordan Rift Valley. The climate has a partial effect on the rejuvenation of the drainage system, as it was three or four times more humid than at present in the Pleistocene and the period immediately following (Rofe and Raffety 1963).

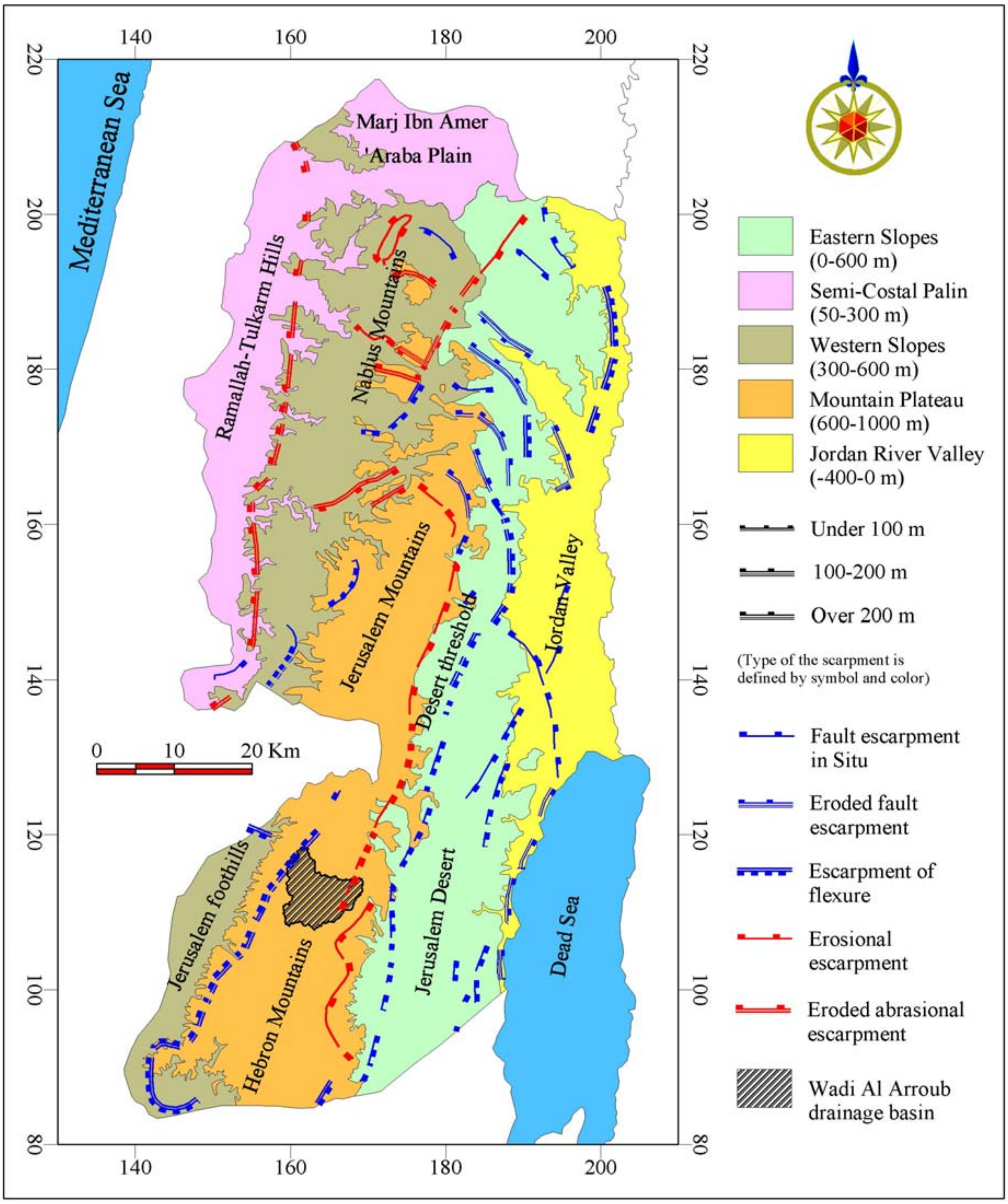


Fig. 5.1: Geomorphological map of the West Bank (modified after Benvenisti and Khayat 1988; Adler et al. 1985 and MOPIC 1999).

5.3 Wadi Al Arroub drainage basin

5.3.1 Basin area

It is important to point out that the area of investigation is a small sub-catchment of the Jordan River Basin, which is a trans-boundary basin draining parts of the West Bank, Israel, Jordan, Lebanon and Syria. For the purpose of this study Wadi Al Arroub drainage sub-basin will be referred to as a catchment or basin. Wadi Al Arroub drainage basin (Fig. 5.2) was identified in this study to be the catchment being drained by Wadi Al Arroub and Wadi Si'ir and their tributaries.

With the help of the GIS package (TNT-mips), the area of Wadi Al Arroub drainage basin was measured to be 61.3 km^2. This number represents the projected rather than the true surface area taking into consideration the surface slope. The average extent of this basin is 9-10 km from west to east and 5-6 km from north to south. The size of this basin is very small when compared to it mother basin, the Dead Sea - Jordan River, which covers an area of 42800 km^2 (Fig. 1.1).

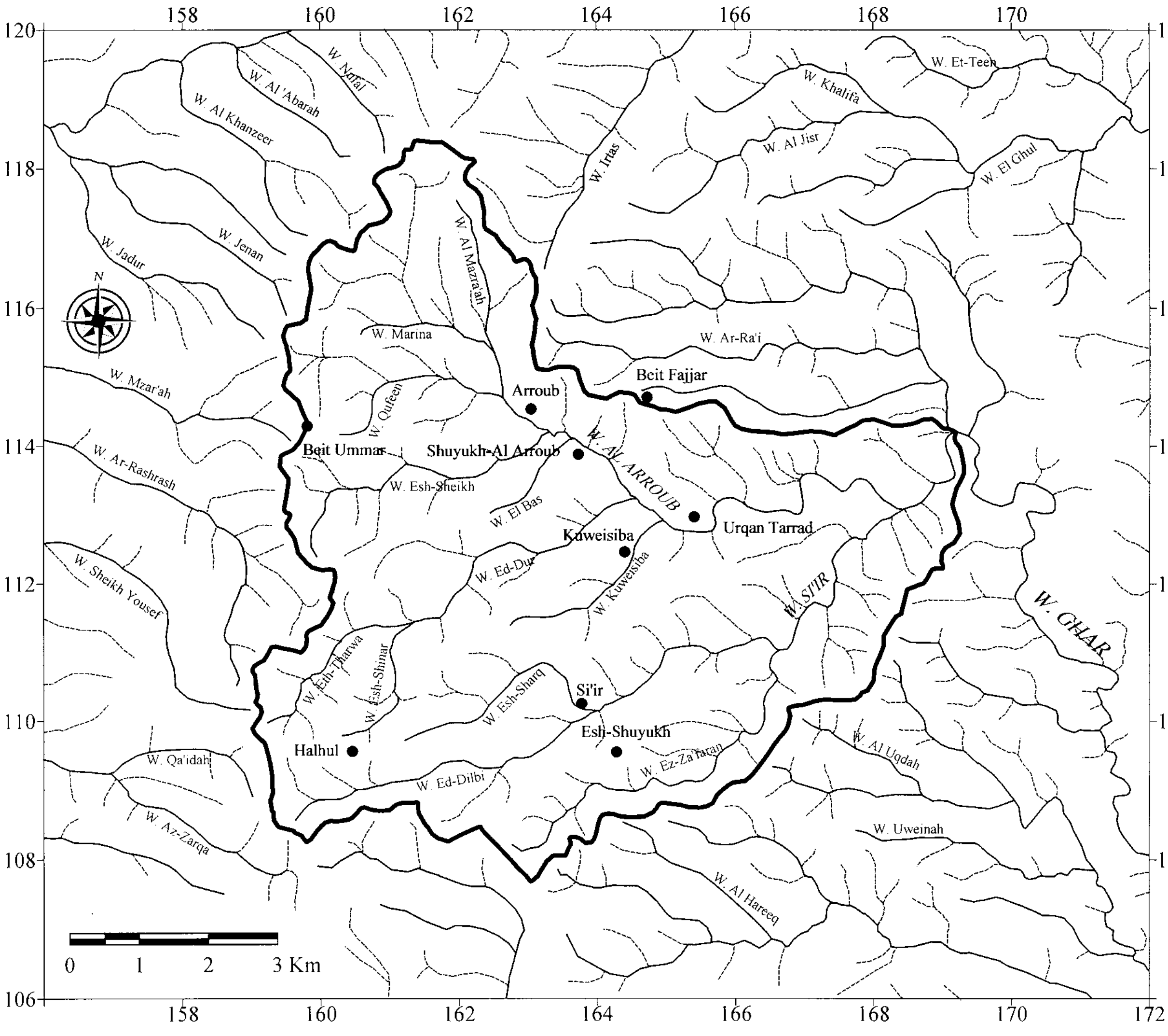


Fig. 5.2: A map showing the border of Wadi Al Arroub basin and its drainage system.

5.3.2 Topography and stream flow direction

The topography of Wadi Al Arroub drainage basin has an elevation difference of 320 m between its highest and the lowest points, with a slope of about 1:30 towards the east. The elevation attains it highest altitude, 1020 masl, at Jabal Halhul at the south-western edge of this catchment and drops to 700 masl at the eastern edge where Wadi Al Arroub joins the Wadi Ghar (Fig. 5.3).

Wadi Al Arroub, the main wadi discharging this catchment, being tributary of Wadi Ghar which discharges into the Dead Sea. This direction of flow within the catchment is being controlled by the dip (average 30 m per km) towards the east. As a main wadi, Wadi Al Arroub has its own tributaries, such as Wadi Al Mazra’ah, Wadi El Sheikh and Wadi El Dur, which collect the runoff water in winter from the areas south, west and northwest of Wadi Al Arroub. A few hundred meters before the draining point, Wadi Al Arroub joints Wadi Si’ir that collects with its tributaries, Wadi Esh-Sharq, Wadi Ed-Dilbi and Wadi Ez-Za’afaran, the runoff water from the south-east area of this catchment (Fig. 5.2).

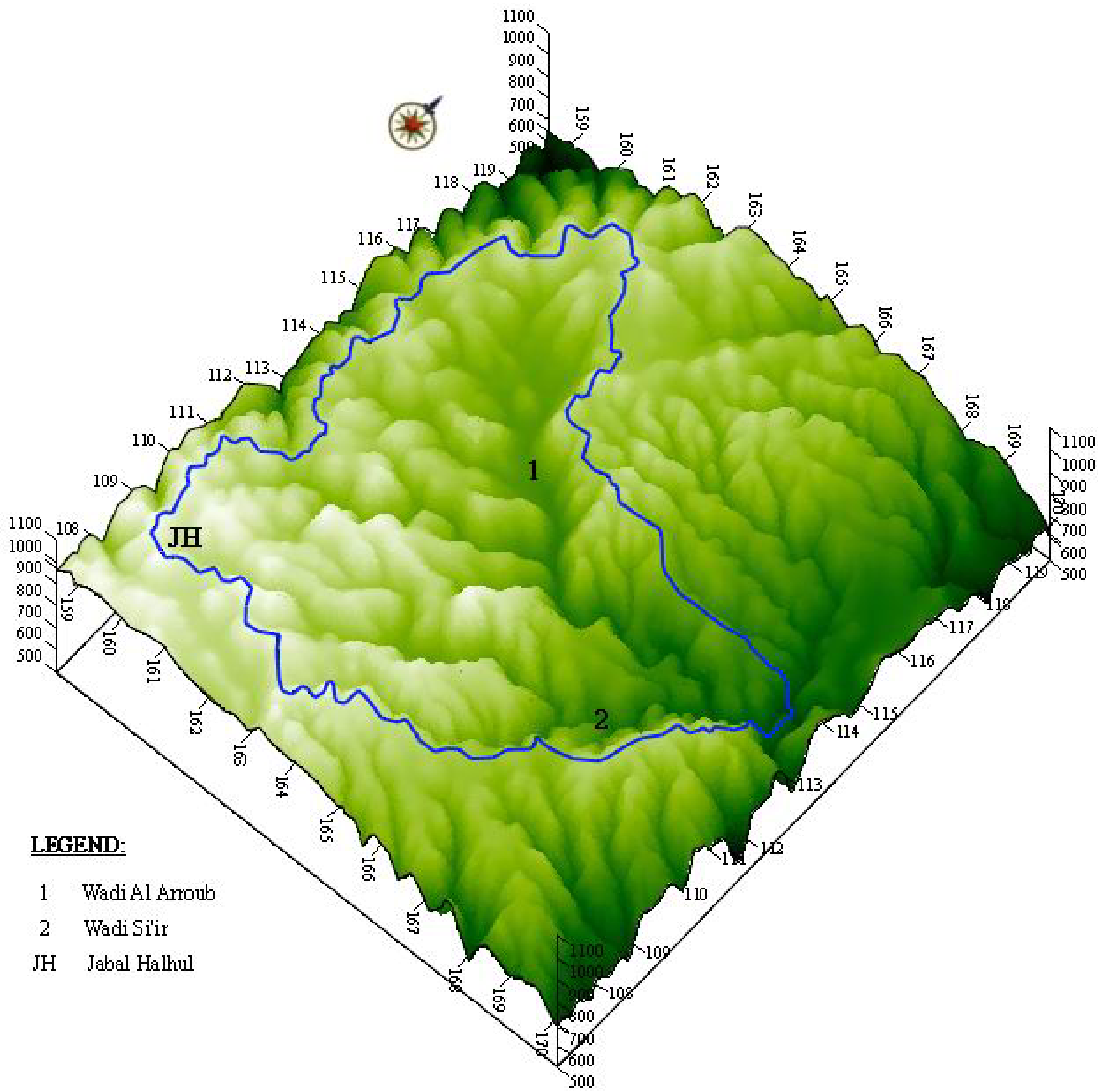


Fig. 5.3: A three-dimensional terrain model of the study area.

5.3.3 Drainage system and drainage lineation

Generally, the drainage system of a catchment area is controlled by climate, structure, lithology, soil properties, topography and landuse. This chapter tries to study the effect of the structure, topography and lithology on the drainage system in Wadi Al Arroub drainage basin as wells the characteristics of the basin and the drainage system. Lithology is supposed to be of minor impact since the same carbonate rocks cover the whole study area. In order, to study the effect of the local structure and topography on the drainage lineation, rose diagrams were plotted for both the stream segments and the structural parameters (Fig. 5.4).

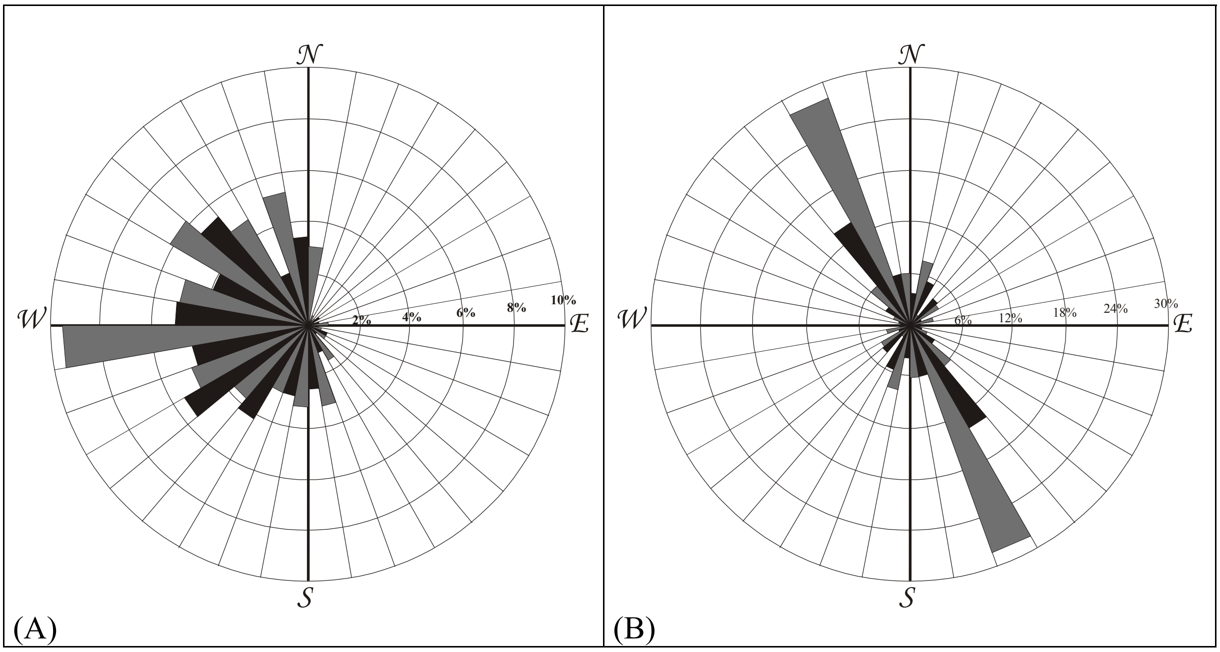


Fig. 5.4: Rose diagrams, (A) for the drainage lineaments length of the drainage system, (B) for lineaments length of the structural components in the study area.

The rose diagram (Fig. 5.4-A) shows that the study basin is mainly affected by W-E, NNW-SSE trends and to some extent by N-S trends. Comparing the two rose diagrams in Fig. 5.4 leads to the conclusion that the topography has more effect on the drainage lineation than the tectonical structure and direction of faults in the study area, and that the topography has its main effect in the W-E direction, while the effect of the structure (folds and faults) is mainly in the NNW-SSE direction and to some extent in the N-S direction. However, it is very important to keep in mind that the topography of the whole West Bank, part of which is this study area, is a result of the tectonic activity that took place in the late Cretaceous and uplifted the anticlines forming the West Bank mountains.

5.3.4 Quantitative geomorphology of the drainage basin

Six geomorphological parameters are studied and discussed in details to evaluate Wadi Al Arroub drainage basin in the following paragraphs.

5.3.4.1 Ordering of the stream network

Classifying stream networks is an important step in understanding their characteristics. Horton (1945) developed a system to describe the internal organization of stream networks that became know as Horton Stream Order System. Strahler (1957) introduced a few useful modifications, which were adopted and are used here. Horton (1945) and Strahler (1957) assumed that stream networks have a recognizable inherent hierarchical order; small creeks combine to become small streams which in turn combine to become rivers and so on.

The order of a system indicates the position of a particular stream section in the hierarchy of a stream network. An order number classifies every section of a stream network in the order system from its source to its drainage mouth. First order streams are those that flow from their source and have no tributaries. Second order streams are formed at the junction of two first order streams and third order streams are formed at the junction of second order streams and so on. A join of two streams having different orders does not change the stream order. Only when a stream joins another stream of the same order, the order number increases by a value of one. It is important here to clarify that the stream ordering as well as the other geomorphologic parameters are scale dependent. Large scale, detailed maps, show smaller streams and lead to the assignment of higher orders to the same river segment than maps of smaller and less detailed scale. Maps of 1:50 000 scale were used in this study. The stream of the highest order in a stream network characterizes the order of the entire network. The system is also applied to the catchment areas, where the catchment takes the same order of the stream draining it. Based on this criterion, the Wadi Al Arroub drainage basin is a fourth-order catchment as the dominant stream is a fourth order stream. This stream designation is illustrated in Table 5.1 and Fig. 5.5.

Table 5.1: Orders and numbers of the wadis building up the drainage system in the Wadi Al Arroub drainage basin.

Wadi	**Tributary**	**Order**			
		1°	**2°**	**3°**	**4°**
Wadi Al Arroub	W. Al Mazra'ah	3	1	0	0
	W. Marina	9	3	1	0
	W. Qufeen	11	3	1	0
	W. Esh-Shyeikh	1	3	1	0
	W. El Bas	1	0	0	0
	Wadi Ed-Dur	8	1	1	0
	W. Ash Shinar	4	1	0	0
	W. Eth-Tharwa	8	2	0	0
	W. Kuweisiba	3	1	0	0
	Other tributaries	18	2	0	1
Wadi Si'ir	W. Az-Za'faran	12	1	0	0
	W. Esh-Sharq	4	1	0	0
	W. Ed-Dilbi	6	1	0	0
	Others tributaries	21	2	1	0
Total		109	22	5	1

Horton (1945), showed that the streams orders are related to their corresponding streams numbers from one side and their streams average lengths from the other side by simple geometric relations; where plotting the logarithm of the number of the streams and the logarithm of the average streams lengths against their corresponding orders give straight lines. This means that the streams orders are inversely proportional with their numbers and direct proportional with their streams average lengths. Fig. 5.6 indicates the stream network relationships in the Wadi Al Arroub drainage basin

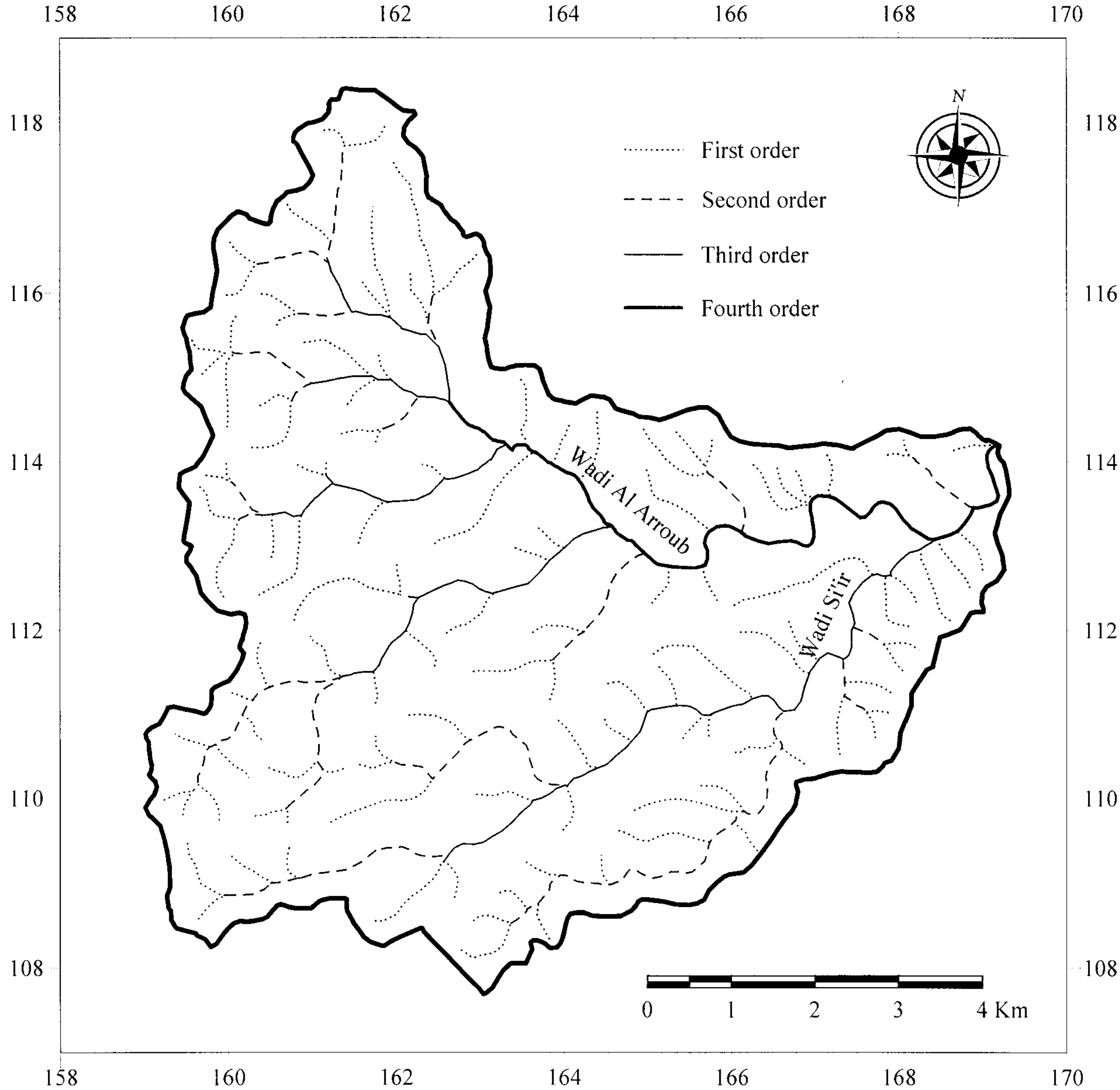


Fig. 5.5: The orders of the stream network of Wadi Al Arroub drainage basin.

5.3.4.2 Bifurcation ratio

The bifurcation ratio (R_b) is a parameter used to characterize the stream network. According to Horton (1945), it is the ratio of the stream numbers of any given order (N_u) to the number of the next higher order (N_{u+1}), as first order to the second order, second to the third etc. Where $R_b = N_u / N_{u+1}$. Strahler (1964) expresses the relationship between the bifurcation ratio and the streams numbers and orders as: log N_u = a-bk where the anti-log of (b) is the bifurcation ratio. This means that plotting the streams orders (u) against the logarithm of their corresponding streams numbers (log Nu) give a straight line, whose slope expresses the bifurcation ratio (Fig. 5.6-A).

Both Horton's mathematical method and Strahler's graphical method gave the same value (4.8) of bifurcation ratio for the stream network in Wadi Al Arroub drainage basin.

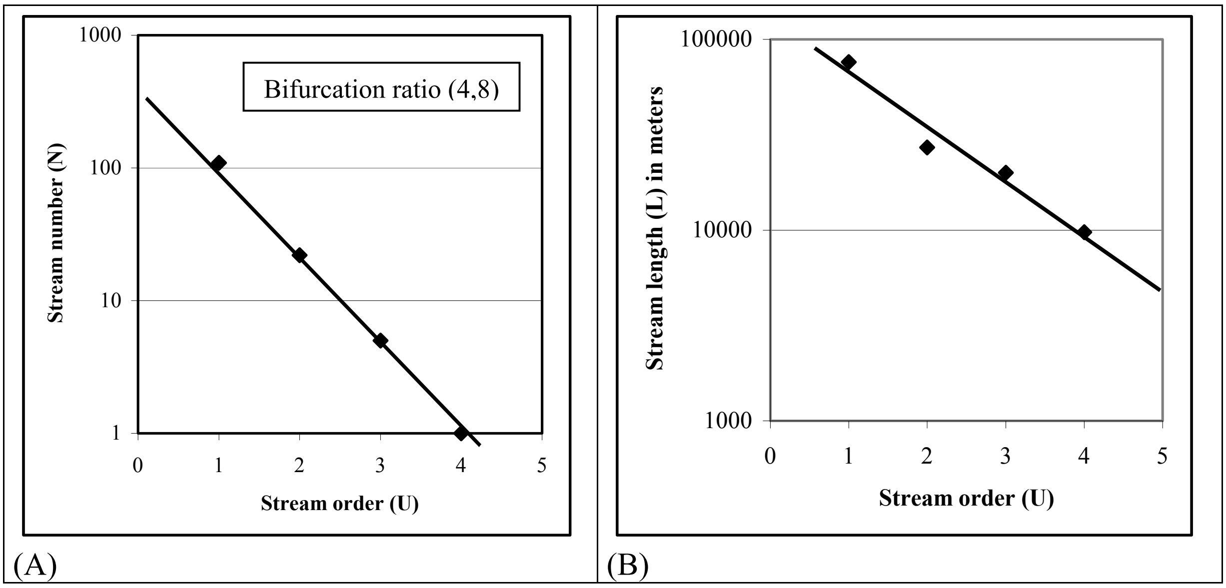


Fig. 5.6: Plots represent the geometric relations of the stream orders (a) with the streams numbers (b) with the average streams lengths.

According to Strahler (1964), McCullagh (1978) and Saad et al. (1980), basins of bifurcation ratios between 3.0-5.05 are characterized by minor or insignificant roles of the structure (folds and faults), whereas the effects of the structure increase with the increase of the bifurcation ratio. Not only, the bifurcation ratio is related to the structure of the area but also it is related to the geometric shape of the basin, elongation and circularity, and the rate of drained water, where basins of high bifurcation ratio are elongated in shape and permit the runoff of water over an extended period of time, thus giving more chance to feed the aquifers. While basins with low bifurcation ratios are circular in shape allowing the runoff to pass in a very short time thus forming readily flash floods.

5.3.4.3 Drainage density

Drainage density is defined as the total length of streams in a basin divided by its total area. It expresses the clossness of tributaries and reflects the topographic, lithologic, pedologic and vegetation controls. The last two are highly influenced by climatological inputs.

The drainage density is usually higher on clayey rock of low permeability than on sand or chalk with higher infiltration capacities. High values of drainage density indicate regions of large numbers and lengths of contributing tributaries, impermeable surface or rugged mountains relief (Strahler 1964). While basins with low drainage density numbers indicate regions of highly permeable or highly resistant subsoil material under dense vegetation. Basins with high drainage density numbers indicate appreciable local amount of rainfall but on the other hand high flood peaks and low contribution to the Ground water (Orbson 1970).
The total length of the streams and the drainage density in Wadi Al Arroub drainage basin were found to be 132.9 km and 2.20 km^{-1} respectively. Sakar and Kanungo (2002) classified the drainage density into three classes; high (> 10 km^{-1}), moderate (5-10 km^{-1}) and low (< 5 km^{-1}). Based on that the study area is a catchment of low drainage density.

5.3.4.4 Relief

The relief ratio is defined as the ratio between total basin relief, the maximum elevation difference within the catchment, and basin length, measured as the length of the line roughly parallel to the major drainage. Sometimes the basin length is measured as the longest dimension of the drainage basin (Schumm 1956). Because it is often difficult to measure the length of major drainage when the basin has a complex form, the relative relief is more commonly used than the relief ratio. The relative relief is the relief divided by the square root of the basin area. These two measures of relief serve as an indication of the overall slope of the catchment. In general, the flooding potentiality increases with the increase on the relief and the steepness of the hill slopes, as a result of the decrease in the time of the runoff concentration.

For Wadi Al Arroub basin the maximum basin length is 11350 m and the length of the major drainage is 14250 m. The relief, relief ratio (based on the maximum basin length) and the relative relief were calculated as 320 m, 2.82 % and 4.09 % respectively.

For comparative purposes the values of the three variables were also calculated for the Dead Sea-Jordan River Basin (area of 42800 km^2, 460 km maximum basin length and 3214 m maximum difference in elevation, +2814 m at Mt. Hermon area at the Lebanon-Syria border and –400 m at the dead Sea area) as 3214 m, 0.70 % and 1.55 % for the relief, relief ratio and the relative relief respectively. It is clear that the relief ratio and the relative relief of Wadi Al Arroub drainage basin is about 3-4 times higher than that of its mother basin (Dead Sea-Jordan River Basin) which proposes that the study area is among the sub-basin that contributes strongly to the flooding in the Dead Sea-Jordan River Basin.

5.3.4.5 Basin shape

The basin shape is another factor affecting the stream discharging characteristics. It ranges from nearly round to long and narrow and is a function of the underlying soils and geology. Circular basins produce larger floods than longitudinal watersheds if they are of similar sizes. That is mainly because a shorter time of accumulation of the flood is expected. Generally the shape of the basin is described by the elongation and circularity ratios. The elongation ratio (R_e) is defined as the ratio of the diameter of the circle of the same area as the basin to the maximum basin length (Schumm 1956). Values near to unity are typical for regions of very low relief and the basin shape is nearly circular. Whereas the circularity ratio (R_c), is the ratio of the basin area to the area of a circle having the same perimeter (Miller 1953). Clossness of the value of (R_c) to 1 indicates the clossness of the shape of the basin to the circular shape

With the help of the TNT-mips package, the perimeter of the study area was measured to be 40636 m. Based on that, the elongation and the circularity ratios of Wadi Al Arroub Basin were calculated to be 0.78 and 0.47 respectively.

Since the elongation ratio of the study area is closer to a circular catchment than to an elongated catchment, this suggests that high floods might readily occur.

5.3.4.6 Valley and stream network patterns

The valleys in Wadi Al Arroub drainage basin are V-shaped, in which the streams have the same orientation and length as the valleys. On the other hand this area is being discharged by a dendritic stream network. This indicates an area with uniformly dipping bedrock but no strong tectonical or lithographical controls. The dendritic pattern resembles the even branching of a tree and the streams are highly integrated so that they form large systems and are, therefore, relatively old. All the streams in this pattern flow towards bigger tributaries (Fig. 5.5).

Finally, this geomorphologic study of the Wadi Al Arroub drainage basin offers basic scientific data about the area and is also valuable for comparative studies. But in order to compare the drainage basins in a meaningful way, it is necessary to compare basins of the same order of magnitude.

6 CLIMATE, METEOROLOGY AND RECHARGE

6.1 Climate of the West Bank

The West Bank has a typical Mediterranean climate with two distinct seasons: dry hot season from June to October, and cold wet season from November to May. The predominantly low pressure area of the Mediterranean is centered between two air masses: the north Atlantic high pressure of north Africa and the Euro-Asian winter high pressure located over Russia. This is the primary cause of winter weather in the West Bank and the eastern Mediterranean in general (Husary et al. 1995).

In the West Bank, the dominant travel direction of air masses is from the Mediterranean Sea towards the east. Rainfall increases eastwards with elevation, with the heaviest rain falling near the ridge of the Central Highlands (800-1000 masl). Further, to east, there is a rapid decline in rainfall amounts as the air is heated, decreasing the relative humidity and establishing a rain-shadow, particularly in the Dead Sea area (410 mbsl) and the central Jordan Valley. Rainfall amounts also decline from north to south, particularly at the western ridge of the West Bank. The isohyetal map (Fig. 6.1) shows the long term annual average rainfall all over the West Bank of the period 1961-1990.

Since most of the rainstorms are related to the winter period, their seasonal distribution, amount of rainfall, intensity, span and intermittence vary considerably. The rainfall duration vary from less than few minutes to a few days with intensities of less than 1 mm to more than 100 mm in an event, and they vary in time span between each rain event from few days up to several weeks (Ayalon et al. 1998)

The rainfall is the only input parameter in the water budget of the West Bank, as it is the only source of recharge water for the distinct aquifers. The total amount of annual rainfall over the West Bank varies seasonally. In the season 1988/1989, it was estimated to be 87.5 Mill. m^3, while in the season 1991/1992 it was estimated to be 153.4 Mill. m^3 (GTZ 1995).

6.2 Climate of Wadi Al Arroub drainage basin

According to PNOMO (1998 and 1999) the area of Wadi Al Arroub as part of the West Bank has a warm-humid Mediterranean climate. The only climatological reference in the study area is Al Arroub Meteorological Station which is located on 162100 E/114700 N (PG) and at an elevation of 865 masl. Occasionally, the station failed to provide continuous records of the meteorological parameters, due to malfunctioning and lack of maintenance.

To replace missing meteorological values linear regression between the records of Al Arroub Meteorological Station and the Hebron Meteorological Station, which has more continuous and completed records was performed. The Hebron Meteorological Station lies 8 Km to the south of Al Arroub at of 159350 E / 107250 N at an elevation of 1005 masl.

6.2.1 Rainfall

Although the average annual rainfall recorded at Al Arroub Meteorological Station for the period 1953 –2001 is 607.1 mm, there are considerable variations in the quantity of the annual rainfall from year to year. The maximum recorded annual rainfall was 1200 mm in the 1991-1992 season, while the minimum was 212 mm in 1998-1999 (Fig. 6.2).

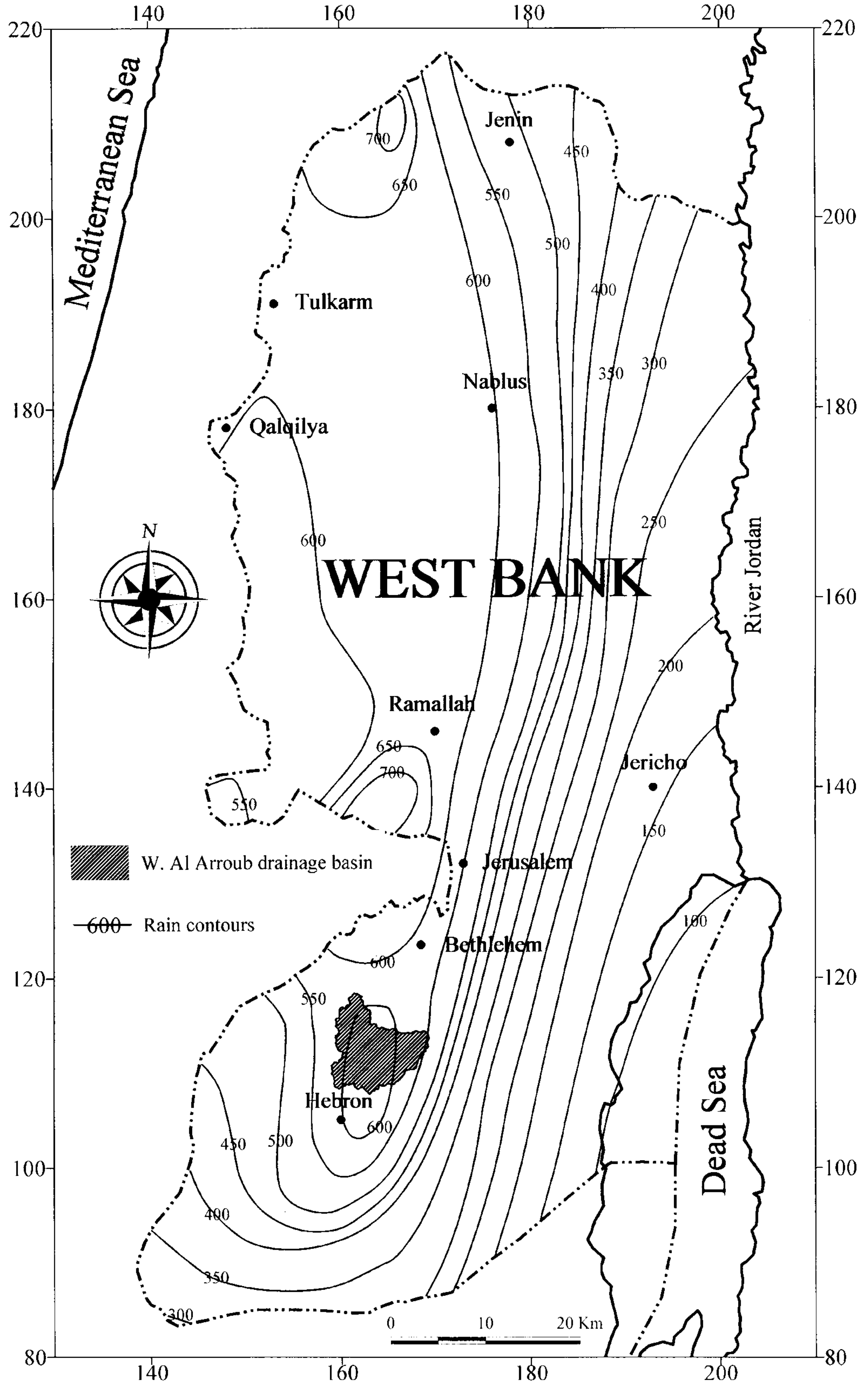


Fig. 6.1: Isohyetal contour map of the long term annual rainfall averages of the West Bank during the period 1961-1990 (modified after the Israeli Meteorological Service 1990).

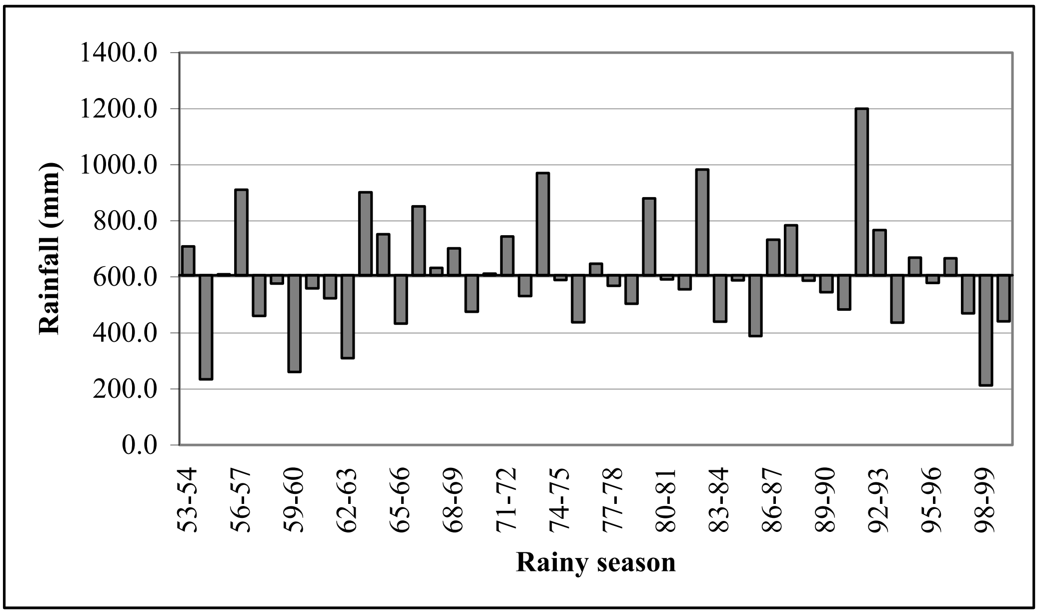


Fig. 6.2: The annual rainfall variations at the Arroub Meteorological Station during the period 1953-2001.

Generally, the wet season in the area of Wadi Al Arroub stretches over eight months (October to May). But most of the rain falls during the period November to April. About two thirds of the rainfall amount falls between December and February (Fig. 6.3). Not only 1959-1960 and 1961-1962 were very special seasons as the rain started in September, but also 1991-1992 was very special as June appeared to be the end of that rainy season.

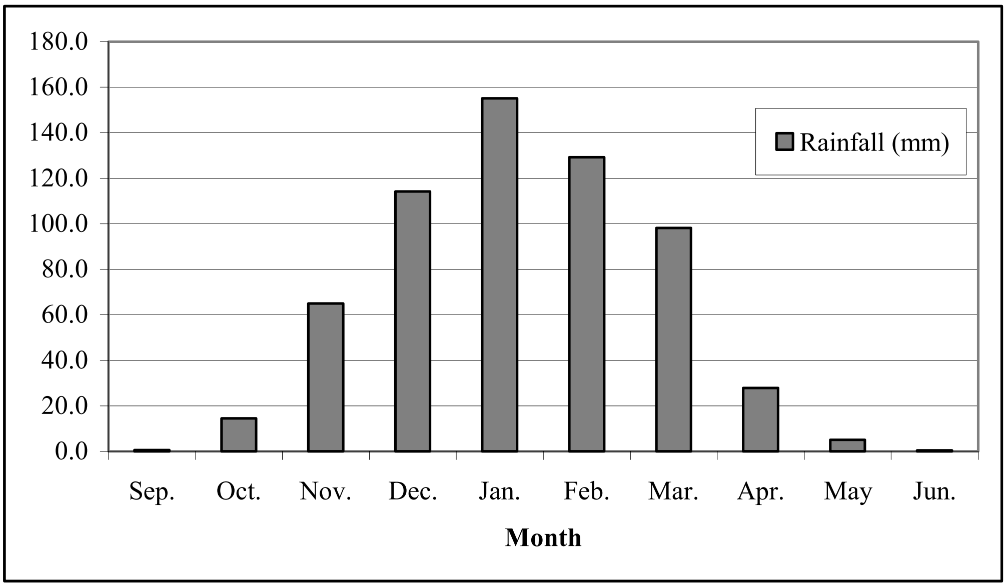


Fig. 6.3: The average monthly rainfall recorded at Al Arroub Meteorological Station for the period 1953-2001.

The average annual number of rainy days between 1953 and 2001 is 46 day, the maximum number of rainy days was recorded in 1987-1988 as 65, and the minimum as 22 in 1998-1999.

Rainfall intensity exceeding the 100 mm/day (during the period 1953 and 2001) was recorded only 12 times, 5 times in January, 4 times in February, 1 time in December and 2 times in November. The maximum recorded daily rainfall intensity was 148 mm/day and it was recorded in November, 19th 1953. The wettest month with a total record of 490.8 mm was January 1974. Generally, snow falls very seldom in the area of study and when it falls it melts within 2-3 days. Snow occurred three times during 1991/1992 rain season, which was a very special one.

6.2.2 Temperature

The average summer temperature, in the West Bank varies between 20 and 23 °C, reaching a maximum of 43 °C. The average long term winter temperature is 10 to 11 °C with a minimum of 3 °C. These variations are expected because of the differences in position, elevation, and distance from the coast and the environment around the stations (Ghanem 1999). The temperature increases from north to south and from west to east on contrary to the altitude. The summer daily temperatures are relatively constant whereas they fluctuate in winter hence, warm and nice days are quickly followed by cold cloudy ones.

In Wadi Al Arroub area, during the period (1965-1998), the long term average of the monthly mean temperature ranges between 7.5 °C in January and 22.6 °C in August. The average of the monthly maximum temperature varies between 11.6 °C in January and 29.6 °C in August, whereas the average monthly minimum temperature ranges between 3.4 in January and 15.7 °C in July. Fig. 6.4 shows clearly that January is the coldest month and August is the warmest.

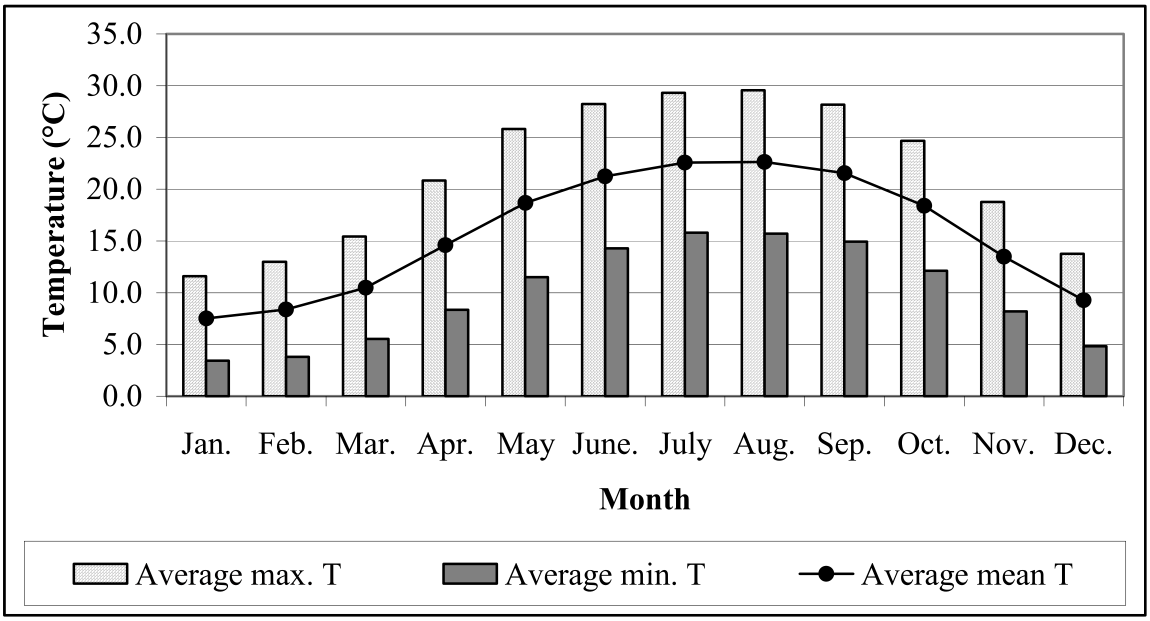


Fig. 6.4: Monthly averages of the mean, maximum and minimum temperatures at Al Arroub Meteorological Station (1965-1998).

6.2.3 Relative humidity

In the West Bank, temperature, the elevation as well as the distance from the coast are the main factors controlling the atmospheric moisture content e.g. expressed as relative humidity

(RH %). The driest locations are in the Jordan Valley, while a more temperate climate can be experienced at the highest summits of the mountain ridge. The Relative humidity in the West Bank varies from north to south. It ranges from 60-65 % in the north and 50 % in the south during summer. During winter it ranges from 65-70 % in the north and 70-75 % in the south (Ghanem 1999).

Fig. 6.5 represents the relative humidity averages (RH %) in Wadi Al Arroub drainage basin during the climatological period (1968-998). The extreme values of the average monthly RH % are 47.6 % in May and 75.7 % in January. The average monthly maximum RH % ranges between 61.6 % in June and 90.8 % in January. Whereas the minimum monthly RH % varies between 36.5 % in May and 59.8 % in February. The average annual RH is 61.8 %, whereas RH % in January represents the highest values and May of the lowest.

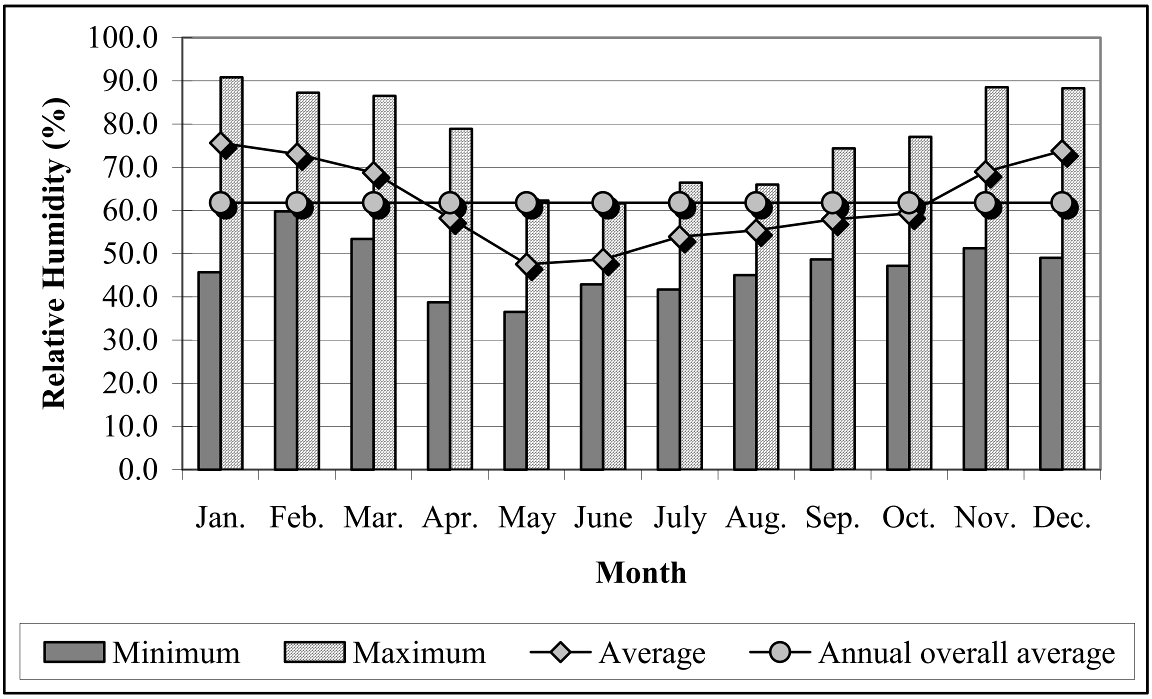


Fig. 6.5: Averages of monthly mean, maximum and minimum relative humidity at Al Arroub Meteorological Station (1968-1998).

6.2.4 Wind

Normally, during the months of autumn (early winter months) and spring (late winter months), Wadi Al Arroub drainage sub-basin as part of Hebron District experience western winds from the Mediterranean Sea. Humidity of these winds is the significant factor in determining the possibilities of rainfall occurrence. In summer (June, July and August), this area is prevailed by northwest winds, while in winter by southwest, west and occasionally northwest winds. From late April to mid-June the area is often affected by very hot dry, dusty winds (Khamaseen winds) which are blowing from the Arabian Desert.

In this area of investigation, the data about wind speed is not always available. Fig. 6.6 shows the average monthly wind speed during the meteorological period (1965-1969), which were calculated from daily records at Al Arroub Meteorological Station. These averages show that the average wind speed in the wet season is 9.5 km/h, while in the dry season it is 5.3 km/h.

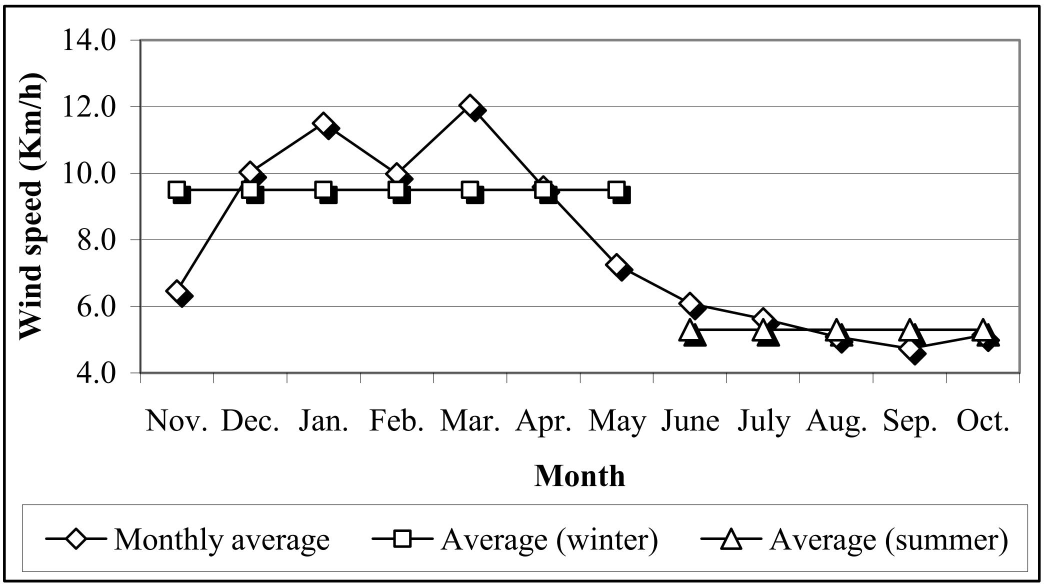


Fig. 6.6: Average monthly wind speed during the meteorological period (1965-1969) at Al Arroub Meteorological Station

6.2.5 Sun shine duration

The longest sun shine duration occurs in the summer months, which is almost cloudless. During winter, even in the rainy days few hours of sun shine can be recorded. According to PNAMO (1998 and 1999), the annual sun shine duration in the West Bank is ranging between 3000-3300 hours. The inhabitants of the West Bank are utilizing to a great extent solar energy for heating of domestic water. The overall daily average sun shine duration at Al Arroub Meteorological Station is 8.8 hour for the period 1961-1990 (PNAMO 1998) with a summer average of 10.6 h/day and 7.5 h/day during winter. The maximum monthly sun shine durations are 11.8 h/day recorded in June, while the minimum average is 6.2 h/day recorded in January and February (Fig. 6.7). The annual sun shine duration has a total of 3200 hour.

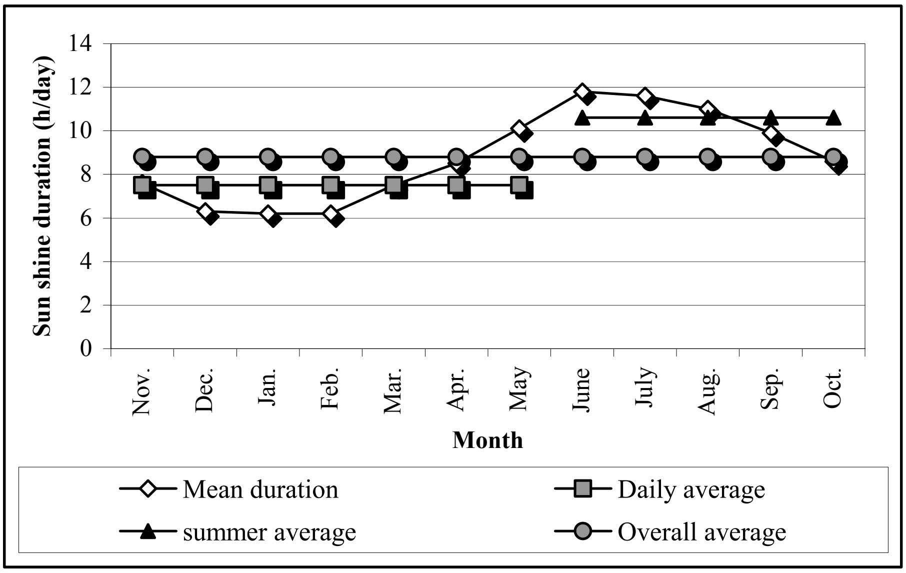


Fig. 6.7: Daily average sun shine duration at Al Arroub Meteorological Station (1961-1990)

6.2.6 Potential evaporation, class A-pan and mesh effect

The standard USA Weather Bureau Class-A pan Evaporation is the common method to measure the potential evaporation (PE) in the West Bank. These pans are unpainted circular galvanized iron containers with a diameter of 122 cm and 25.5 cm depth. The pans are usually filled with water to 5 cm below the rim, and being refilled when the level drops 2-2.5 cm from the initial filling level. The 1980-1989 potential evaporation contour map of the West Bank (Fig. 6.8) shows that the central highlands have the lowest potential evaporation records (1400-1800 mm/yr). Further, east, there is a rapid increase in potential evaporation, lower elevation, higher temperature, lower relative humidity particularly in Dead Sea area (2800 mm/yr). From north to south less evaporation variations could be noticed and that could be attributed to less variation in elevation. Also this map shows that Al Arroub drainage basin had the lowest potential evaporation (1400-1600 mm/yr) records in the West Bank. This is attributed to its high elevation (850 masl).

Correcting the Class-A pan evaporation records at Al Arroub Meteorological Station for the effect of the mesh leads to that the actual values are equal to 111 % of the recorded values. The monthly averages of the Class-A pan potential evaporation records at Al Arroub Meteorological Station between 1965-1998 as well as their corresponding corrected values (PE_c) are shown in Table 6.1. In the following sections the corrected values of the potential evaporation will replace its measured values.

Table 6.1: Descriptive statistics for the 1965-1998 Class-A pan potential evaporation records at Al Arroub Meteorological Station and their corresponding corrected values.

Month	Class-A-pan records					The mesh corrected values			
	Average	Max.	Min.	Std. dev.		Average	Max.	Min.	Std. dev.
January	48.4	68.2	31.0	11.6		53.8	75.8	34.4	12.8
February	55.3	90.3	31.4	14.7		61.5	100.4	34.9	16.3
March	85.4	157.0	48.0	24.5		94.9	174.4	53.3	27.2
April	113.3	151.7	73.6	20.1		125.9	168.5	81.8	22.4
May	162.1	203.8	126.5	20.2		180.2	226.5	140.6	22.4
June	195.6	230.4	144.8	19.7		217.3	256.0	160.9	21.8
July	193.0	239.0	166.4	19.5		214.4	265.6	184.9	21.6
August	172.8	219.0	137.2	24.8		192.0	243.3	152.4	27.6
September	137.9	162.2	98.8	16.8		153.2	180.2	109.8	18.7
October	105.0	137.1	70.3	19.2		116.7	152.3	78.1	21.4
November	77.8	180.9	40.3	32.2		86.4	201.0	44.8	35.8
December	50.1	85.8	31.2	13.8		55.7	95.3	34.7	15.3
Total	1396.8					1552.0			
Average	116.4	160.4	83.3	19.8		129.3	178.3	92.5	21.9

Table 6.1 shows that the average monthly potential evaporation varies between 53.3 mm in December and 217.3 mm in June. The overall annual average is 1552 mm.

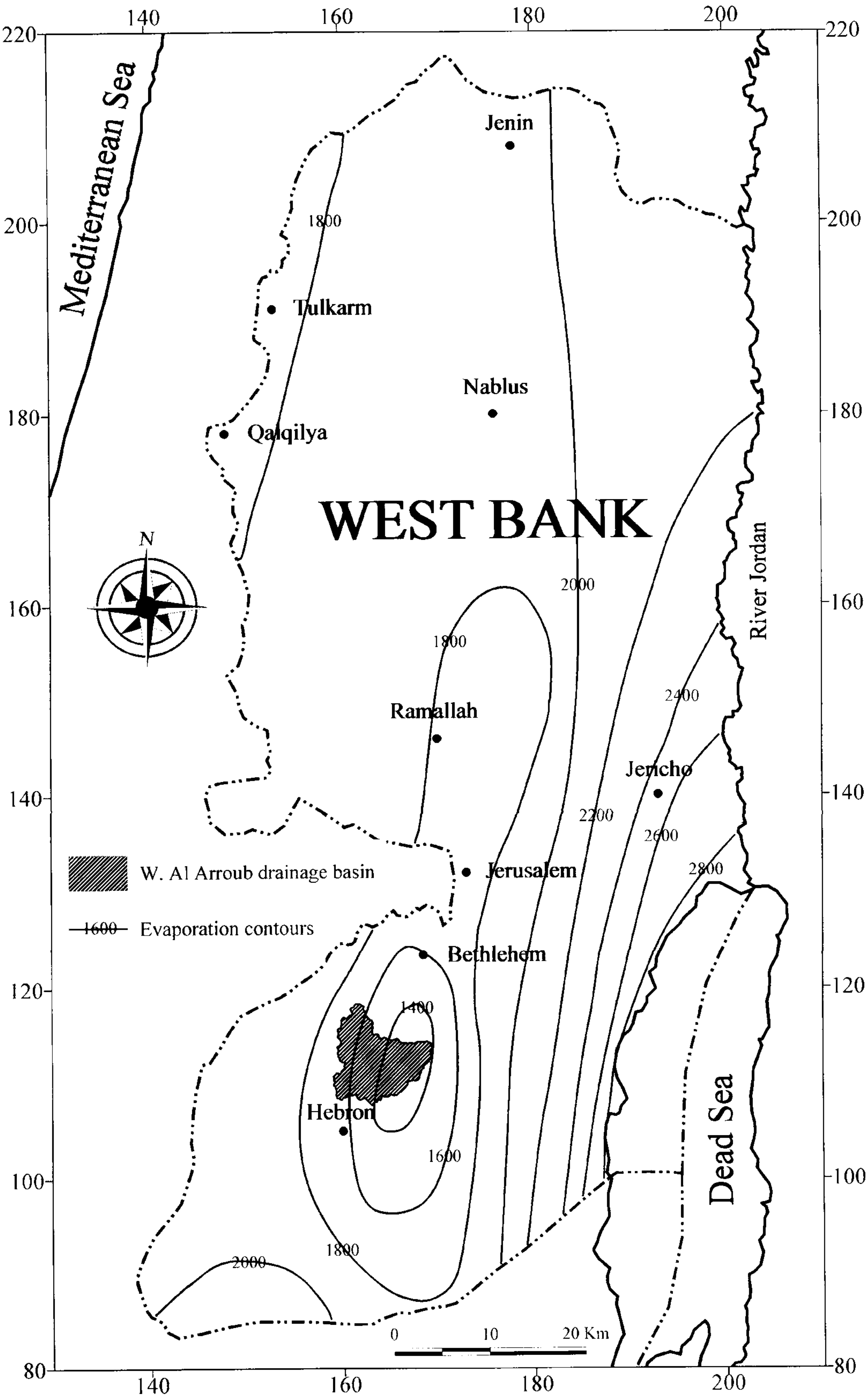


Fig. 6.8: 1980-1989 Class-A pan evaporation contours map for the West Bank (modified after the Israeli Meteorological Service 1990)

6.2.7 Potential evapotranspiration

Evaporation from the water bodies and soil surfaces together with the transpiration from vegetation is termed as evapotranspiration (PET). Because the pan evaporation is always higher than the evaporation from an adjacent lake or surrounding vegetation, it is important to accommodate this difference by using empirical pan coefficients.

6.2.7.1 Estimation of the pan coefficient

Based on the empirical pan coefficients, that were tabulated by Doorenbos and Pruitt (1977), with the assumption that Arroub is sited in cropped fields and that the average upward side distance of the green crops is 30 m, The overall average value of the pan coefficient for Arroub was calculated to be 0.72. The lowest coefficient value is 0.61, when the relative humidity is less than 40 %, while the maximum is 0.77, when the relative humidity is more than 70 %. In winter the average coefficient value is 0.74 and in summer 0.71. This proves that the relative humidity has the major effect on the values of the pan coefficient in Arroub area.

6.2.7.2 Calculation of the potential evapotranspiration

According to Maidment (1993), the relation between the potential evaporation, measured by the Class-A pan, and the potential evapotranspiration is expressed as (PET = PE * CP). Based on this equation the monthly average potential evapotranspiration at Arroub was calculated and presented with the potential evaporation in Fig. 6.9.

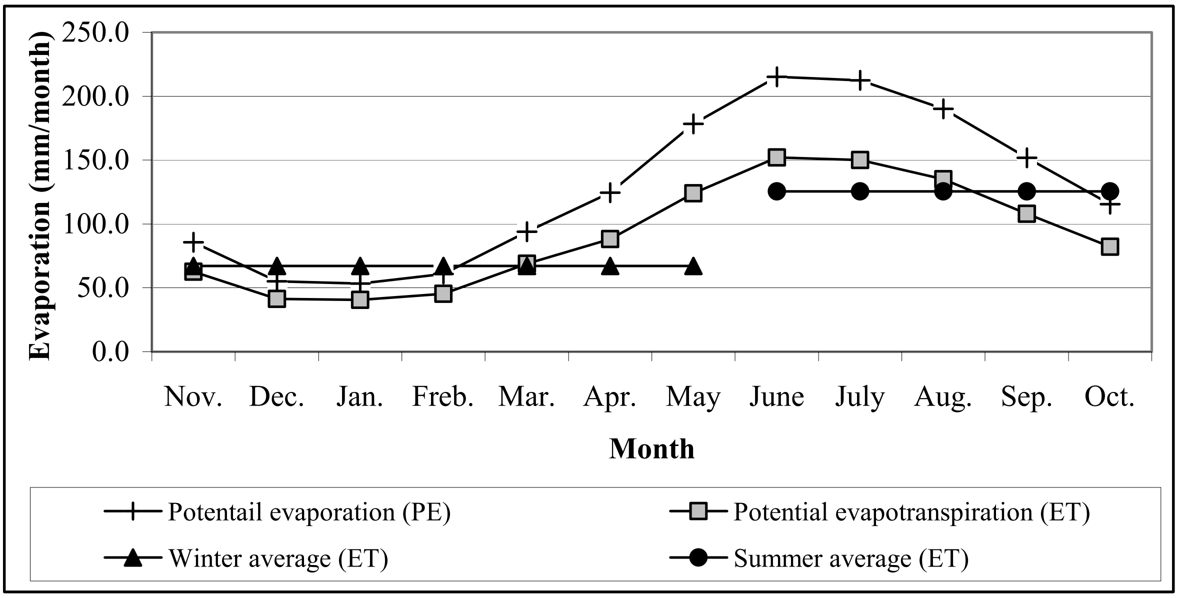


Fig. 6.9: Monthly averages of the potential evapotranspiration and potential evaporation at Al Arroub Meteorological Station between 1965 and 1998.

Fig. 6.9 shows that, the evapotranspiration has its highest value of 152 mm in June, and the lowest of 40.5 mm in January. In winter the average value is 125.5 mm/month and in summer is 67.5 mm/month. The annual average of the potential evapotranspiration at Arroub was found to be 1108 mm.

The potential evaporation in winter could represent the potential evapotranspiration much better than in summer, because winter is the rainy season, the relative humidity peaks at maximum and the temperatures peaks at minimum.

6.3 Aridity of the area

There are different definitions of the terms arid and semi arid found in the literature. Under different research problems and conditions different definitions may be appropriate. For example, in an agricultural context, the terms arid and semi-arid are applied to those areas where rainfall will not be sufficient for regular rain-fed farming (FAO 1981). Many other definitions have been developed based on climatological data, usually precipitation, evapotranspiration and temperature.

To evaluate the aridity of the study area the aridity index (X) of Murai and Hunda (1991), the ratio of P/PET (UNESCO 1979), and the PE index (Thornthwite 1931) were calculated and were found to be 24.2, 0.57, and 83.7 respectively. From this it can be concluded that Al Arroub drainage basin is a humid catchment. This could be attributed to the high rainfall average in the area (607 mm/yr), low potential evaporation average (1400-1600 mm/yr) and to the low annual temperature average (15.7 °C).

6.4 Water balance

Precipitation is the main input parameter in the water budget of the West Bank, whereas the actual evapotranspiration, recharge and runoff are its major output parameters. The interception, soil moisture and depression storage are of minor importance. Using the isohyetal method and the rainfall contour map in Fig. 6.1, the average rainfall over the West Bank was calculated to be 450 mm/yr giving a budget input volume of about 2600 Mill. m^3/yr.

An overall water balance conducted by Rofe and Raffety (1965) shows that the actual evapotranspiration, recharge and surface runoff represent 66.9 % , 26.8 % and 6.3 %, of the annual rainfall, respectively. It is also useful to mention that the actual evapotranspiration in the West Bank represents about 15.3 % of the annual potential evaporation, which was calculated to be 1970 mm using the isohyetal method and the map in Fig. 6.8.

6.5 Water balance of the Al Arroub drainage basin

6.5.1 Mean areal rainfall

The rainfall gauges represent only the sampling point of a storm distribution, whereas the hydrological analysis requires always the average depth of the rainfall over the study area. The mean rainfall could be represented by the isohyetal or the Theissen polygon method. In this study the isohyetal method was preferred over the Theissen method because there is only one station within the boundaries of the study area and the geographical distribution of the stations in the surrounding and their elevation are not appropriate to apply Theissen polygon method. Applying the isohyetal method provided the ability to compensate the elevation differences (orographic effect) of stations by the contour lines of the rainfall map of the West Bank (Fig. 6.1). Because the rainfall contour map of the West Bank presents the period 1961-1990 and this study concentrates on the period 1965-1994, the contour lines were corrected based on a geometric relation established between the rainfall averages for both periods at the available stations. The meteorological stations and the rain gauges which were used for constructing the isohyetal map for this area are shown in Table 6.2, whereas Fig. 6.10, shows the rainfall contour map of the study area for the period 1965-1994.

Table 6.2: The meteorological stations and the rainfall gauges, the records of which were used for constructing the rainfall contour map of the study area.

Station	Coordinates		Elevation	Average Rainfall		Available Data
	East	North	masl	1961-1990	1965-1994	
Arroub *	162100	114700	860	624.7	649	daily
Hebron*	159350	107250	1005	573.0	591	daily
Salisian	169450	123350	720	567.6	598	yearly
Rush Zurim	162000	119700	930	585.1	616	monthly
Cremisan	166400	126000	820	564.4	618	monthly
Beit Sahour	170750	123500	650	443.5	467	yearly

* meteorological station

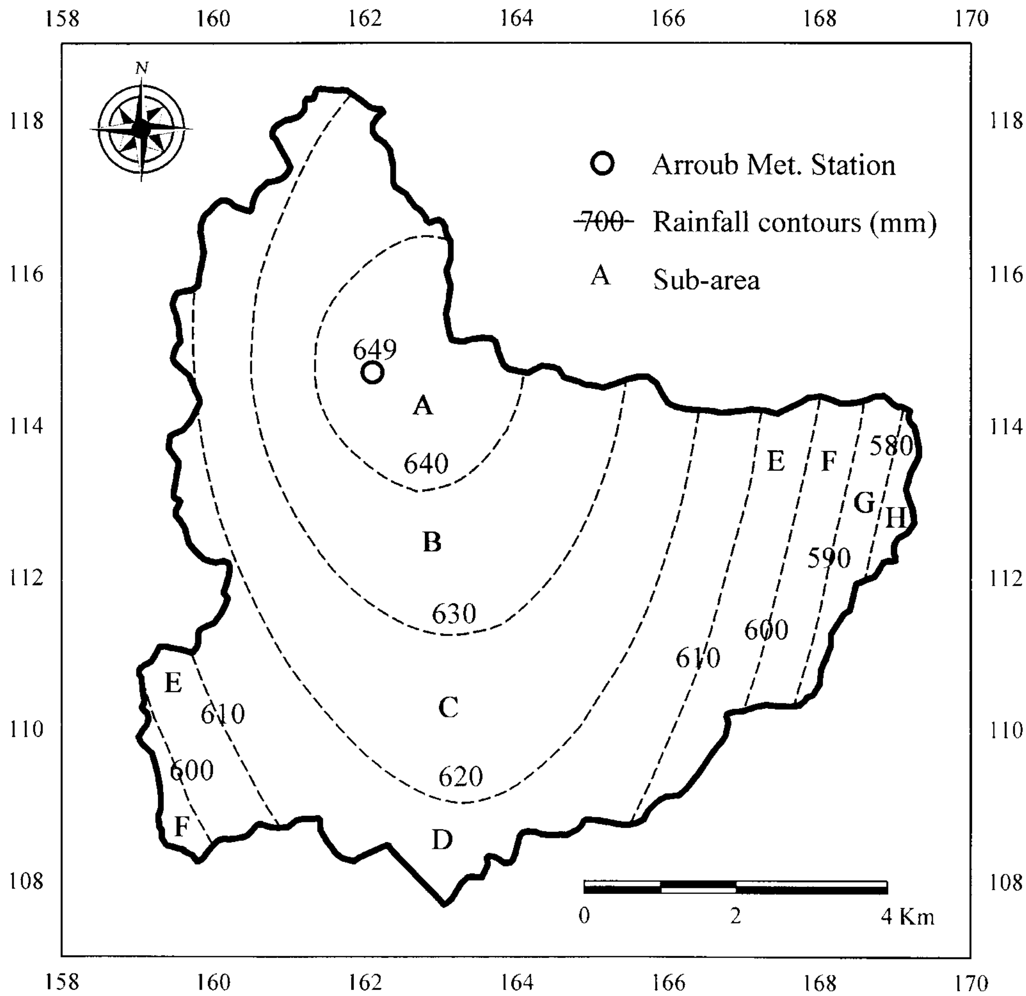


Fig. 6.10: The rainfall contour map of Wadi Al Arroub drainage basin, 1965-1994, showing the sub areas on which the calculation of the mean annual rainfall was based. Contour lines calculated by means of kriging girding method with the help of Surfer 7 software.

Based on the isohyetal method and with the help of the rainfall contour map (Fig. 6.10), the calculation were implemented and summarized in Table 6.3.

Table 6.3: The basic data used to calculate the mean annual rainfall.

Sub-area	Contour (1) P_1 (mm)	Contour (2) P_2 (mm)	Average ppt. P_i (mm)	Area A_i (m^2)	Pi * Ai
A	640	649	644.5	$6.00*10^6$	$3.87*10^9$
B	630	640	635	$1.36*10^7$	$8.65*10^9$
C	620	630	625	$1.72*10^7$	$1.08*10^{10}$
D	610	620	615	$1.32*10^7$	$8.10*10^9$
E	600	610	605	$5.82*10^6$	$3.52*10^9$
F	590	600	595	$3.15*10^6$	$1.88*10^9$
G	580	590	585	$1.70*10^6$	$9.94*10^8$
H	570	580	575	$6.51*10^5$	$3.7*10^8$
Total				$6.13*10^7$	$3.81*10^{10}$
P_m: Average depth of the rainfall in (mm)					621.9

Table 6.3, shows that the average depth of the rainfall over Wadi Al Arroub drainage basin during the period 1965-1994 is 621.9 mm/yr. Taking into consideration that P_m during the period 1965-1994, is 621.9 mm and that the Wadi Al Arroub drainage sub-basin has an area of 61.3 km^2, the annual volume of the rainfall over the area (P_v) will be 38.14 Mill. m^3.

6.5.2 Surface runoff

The surface runoff in the West Bank, which occurs on the dry riverbeds in winter after heavy rainfall, is sporadic. The rainfall intensity, duration of the rainfall storm, landuse, soils; elevation, surface slope and the shape of the catchment are the deciding factors. The non-existence of surface water bodies in the study area limits the runoff to the overland flow, therefore whenever the term runoff is used it referrers to the surface runoff.

The measurements of the runoff in the West Bank are very rare and the majority of the available data is only estimations, e.g. 7-14 % of the annual rainfall (Rofe and Raffety 1963), and 5 % (Gvirtzman 1994). None of the wadis in the study area was gauged; therefore to estimate the surface runoff Goldschmidt formula and the US Soil Conservation Service method (SCS) were applied.

Applying Goldschmidt formula for the period 1965-1994, leads to an estimated average annual runoff of 94.3 mm (5.73 Mill. m^3) which corresponds to about 14.5 % of the average annual rainfall.

In the SCS method a basic parameter to be calculated is the curve number (CN), the value of which depends mainly on the soil class, vegetation and dormancy, antecedent moisture class and landuse. For Wadi Al Arroub drainage basin these parameters are described below:

- Soil class: The study area was classified to have class C soil, slow infiltration, as the soils in this area are Terra Rossa, brown and Pale Rendzinas which are mainly clayey loam, and sandy clay (Dan et al. 1975)

- Vegetation and dormancy: About 95 % of the vegetation cover in the study area are vine and almond, peach, apricot and apple trees. According to the Head of Hebron Agricultural Department (personal communication 2001) the vine and fruit trees have an average vegetation period expanded between March and November.
- Antecedent moisture classes (AMC): based on the accumulative rainfall amount in five successive days the conditions were classified into three groups dry (AMCI), normal (AMCII) and wet (AMCIII) as show in Table 6.4.

Table 6.4: Classification of antecedent moisture classes (AMC) for the SCS method of rainfall abstraction (Chow et al. 1990 and Maniak 1993).

Total 5-days antecedent rainfall (mm)		
AMC group	**Dormant season**	**Vegetation season**
I	< 15	< 30
II	15 to 30	30 to 50
III	> 30	> 50

- Landuse: based on the landuse map of the area (Fig.1.2), and the tabulated CN-value by Maniak (1993), Maidment (1993) and Chow et al. (1990), CN-values (Table 6.5) were estimated for the different landuse activities within the study area.

Table 6.5: The different land use activities in the study area, their areas and their estimated curve numbers.

Landuse		**Area**		**CN**
		m^2	**%**	
Palestinian areas (Arroub) + pool	65 % impervious	$4.44*10^5$	0.72	90
Palestinian areas (All others)	30 % impervious	$1.16*10^7$	18.91	81
Israel	25 % impervious	$1.93*10^6$	3.14	80
Forest	middle	$1.19*10^6$	1.94	73
Trees	50 % grapes	$2.44*10^7$	19.93	79
	50 % stone fruits		19.93	73
Non-vegetated		$2.05*10^7$	33.41	91
Crops		$5.30*10^5$	0.86	78
Stone factories		$1.04*10^5$	0.17	91
Cemeteries		$3.08*10^4$	0.05	83
Quarries		$2.79*10^5$	0.45	71
Dumps		$8.32*10^4$	0.14	91
Tree-land / housing		$2.06*10^5$	0.34	79
CN Weighted (CNII) = $\sum$(CN * Area %) / 100				82.18

As a result of the calculations, based on the SCS method, it was found that the average annual surface runoff rate for the period 1965-1994 in Wadi Al Arroub drainage basin is equal to 122 mm (7.4 Mill. m^3), which represents 19.6 % of the annual rainfall.

According to Goldschmidt formula and the SCS method, the runoff in Wadi Al Arroub drainage basin represents 14.5 % to 19.6 % of the annual rainfall. In order to calculate the other parameters of the water balance 17.05 % (106.1 mm/yr, 6.44 Mill. m^3/yr), the average between these two values, will be used to represent the average annual surface runoff in this area. Fig. 6.11 shows a runoff event in the floor of Wadi Al Arroub.

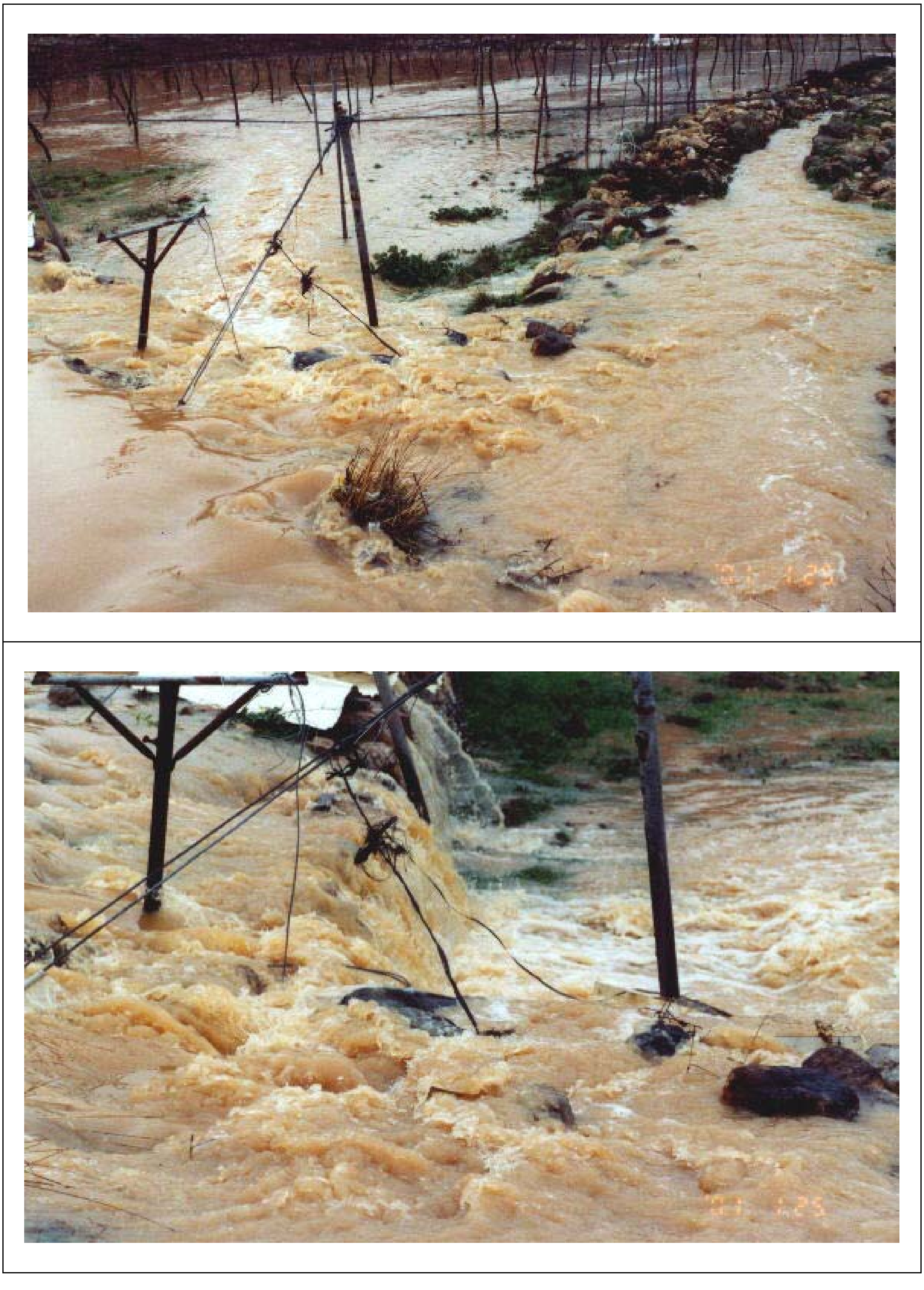


Fig. 6.11: A view in front of Shuyukh Al Arroub showing the surface runoff in the floor of the wadi in the morning of January, 25, 2001.

6.5.3 Infiltration and recharge

The rate and quantity of water that infiltrates into the subsurface is a function of soil type, slope, soil moisture, permeability, ground cover, and duration of rainfall. As the rainfall hits the soil surface part of it seeps into the soil. This movement of water through the soil surface is known as infiltration, which is the primary step of ground recharge. The infiltrated water may be stored in the soil, consumed by vegetation or evaporation, or may penetrate to deeper parts and replenish the ground water.

The most important number required as a basis for sustainable aquifer management is the recharge rate. In the West Bank the main source of the ground water recharge is the direct infiltration of rainfall through the fractured rocks. The annual renewable water in the eastern basin, part of which is the study area, has been estimated to be 125 Mill. m^3 (Guttman and Zuckerman 1995).

In the study area there are no direct infiltration measurements available (e.g. with lysimeters). Therefore to estimate the recharge in the study area, the SCS method, the chloride mass-balance method as well as the Goldschmidt and Jacobs formula were applied.

Using the SCS method, the infiltration rate was calculated to be 147 mm/yr, which represents 23.6 % of the average annual rainfall, in the study area.

In the calculation of the infiltration using the chloride-mass balance method, because only few data about the rainfall water quality in this area are available, the weighted average, 5.56 mg/L, of long term analysis, 1980-1990, of rain in surrounding areas, such as Teqou (172000E / 118000N), Hebrew University -Jerusalem (169000E / 131000N) and Har Gillo (166000E / 126000N) were used to represent the chloride concentration in rain (Herut 1992). Rain water samples over the study area, which were analyzed between 1998-2000, were in good accordance with above weighted average. On the other hand, the analysis of the spring water of El Bas-West, Dilbi and Wadi Ed-Dur in the last ten years showed variation in the chloride concentrations between 16.5 and 23 mg/L and in few samples 25 mg/L. Therefore, an average of 20 mg/L was assumed to represent the chloride in the ground water. Taking into consideration that the mean rainfall over the area is 622.5 mm/yr and the average runoff is 106 mm/yr, the average recharge in the study area according to this method was calculated to be 145 mm/yr, that represents 23.2 % of the annual rainfall.

Applying Goldschmidt and Jacobs formula for the period 1965-1994, gives an average annual recharge of 225.8 mm (13.73 Mill. m^3), which is about 36.3 % of the average annual rainfall.

From the above calculations, it was found that the SCS and chloride-mass balance method gave approximately the same recharge rate (146 mm/yr), while the Goldschmidt formula gives a recharge rate of 225.8 mm/yr, which is a much higher value. This big difference may be attributed to the fact that the Goldschmidt equation is an empirical formula resulted from a study conducted in Wadi Al Qilt, which has similarities with Wadi Al Arroub drainage basin in the geology but on the other hand has differences in the hydro-meteorological parameters and therefore in the water balance components. Based on this and the fact that both the SCS method and the chloride mass-balance method utilized data from the study area, the recharge rate resulted from the Goldschmidt formula will be excluded and the average of the other two methods will be used to represent the recharge rate in the area. This average is 146 mm/yr (8.87 Mill. m^3/yr) representing 23.4 % of the annual rainfall.

6.5.4 Soil moisture

The main factors controlling the soil moisture (ΔM) are the soil texture and thickness as well as the type, density and the root depth of the vegetation. Also, the amount of soil moisture depends on its consumption during dry seasons by evaporation and transpiration, which varies widely from place to place in the West Bank.

The soil in Wadi Al Arroub drainage basin is of clayey loam texture, with has a high water capacity, storing large amounts of water that plant may use. The soil moisture in the study area is consumed by the surface evaporation especially during the summer dry months and by transpiration, where 38 % of the area is covered by trees (Table 6.5).

6.5.5 Interception and sealed areas

Interception loss (I) accounts for precipitation that is retained by plant leaves and immediately evaporated. A similar effect can be seen at sealed areas, where rain water may not infiltrate but evaporate readily. Since trees cover 38 % of Wadi Al Arroub drainage basin and 23 % of it is covered by built-up areas it is supposed that these two processes have a significant impact on the water balance.

5.5.6 Depression storage

The depression storage (ΔS) is the water that is held in natural depressions in the land surface therefore not contributing to surface runoff. Its amount is directly proportional to the perviousness of the surface and inversely proportional to its slope. Although Wadi Al Arroub drainage basin is hilly and its clayey soil are of low permeability, this parameter is supposed to have significant impact on the water balance because all the wadis in the study area are terraced. Not only in the study area but also in the whole West Banks there are no data available about the soil moisture, interception and depression storage that could be used for this work. To get a reliable values for the soil moisture it is very important to have at least monthly measurements at representative locations and depths, which was not possible because my field trips were limited to 2-3 months a year, which was mainly January to March.

6.5.7 Actual evapotranspiration

The actual evapotranspiration (AET) represents the actual amounts of transpiration and evaporation. In order to evaluate the actual evapotranspiration not only the meteorological parameters are important but also many others such as the soil type, soil saturation, water table and vegetation type. Actual evapotranspiration may be directly determined in the field by means of lysimeters. However, no such device was available in the study area. Thus the actual evapotranspiration was calculated using the hydrometeorological method and the Penman-Gridley model. It was calculated also using some empirical formulas for comparative purposes and for checking the validity of theses formulas in the study area.

Using the hydrometeorological method and taking into consideration that P, Q and R equal to 622.5 mm/yr, 106 mm/yr and 146 mm/yr, respectively. 370 mm/yr will represent the actual evapotranspiration, interception, depression storage and change in the soil moisture. Assuming that ΔM, ΔS and I are equal to zero, 370 mm as the maximum possible annual actual evapotranspiration (59.4 % of the annual rainfall) is resulting from the balance equation.

Using Penman-Gridley approach the actual evapotranspiration was found to equal 266 mm/yr, which represents about 43 % of the average annual rainfall. The problem with this approach is that evaporation and transpiration in summer without rain are not considered. Based on the hydrometeorological method AET + ΔM + I + ΔS is equal to 370 mm/yr. meaning that the difference between Penman and Griddel model and the hydrometeorological method is 104 mm/yr representing 16.7 % of the annual rainfall. This 16.7 % represent not only ΔM + I + ΔS but also the evapotranspiration in the summer months. Taking into consideration that the soil in the area is of clayey loam texture with a high available water capacity, 38 % of the area is covered by fruit tree, i.e. almond and vine, that has its vegetation period in the summer months. 23 % is covered by congested built up areas and also about half of the year is represented by dry summer months with high potential evaporation values, It was assumed that, the change in soil moisture is negligible according to Arad and Michaeli (1967), soil moisture is a factor that may influence the water balance calculations for a single storm event or in exceptional cases, even for a whole season. For long-term calculations, this factor can be neglected. The interception, depression storage and the actual evapotranspiration in the summer months cannot be neglected, therefore it was assumed that they have equal impacts on the water balance. According to these assumptions total actual evapotranspiration sums up to be 301 mm/yr (48.4 % of the rainfall). Assuming interception and depression storage to be equal 70 mm/yr, this represents 11 % of the annual rainfall.

Examples of the empirical formulas are those of Turc and Wundt, where the actual evapotranspiration (AET) is represented as function of annual values of precipitation (P), mean annual temperature (t) and annual potential evapotranspiration (PET). The results of the calculations based on the three empirical equations are summarized in Table 6.6.

Table 6.6: The actual evapotranspiration based on empirical formulas according to Turc and Wundt.

Parameter	**Period of average**	**Turc 1 (P , T)**		**Wundt (P , T)**		**Turc 2 (P, T, ETP)**	
		mm/yr	**%**	**mm/yr**	**%**	**mm/yr**	**%**
P	Whole year	622.5		622.5		622.5	
	Rainy month (Oct.-May)	622.5		622.5		622.5	
T (°C)	Whole year	15.7		15.7		15.7	
	Rainy month (Oct.-May)	12.6		12.6		12.6	
ETP	Whole year					1087	
	Rainy month (Oct.-May)					553	
ETA	Whole year	551	88.5	517	83.1	562	90.3
	Rainy month (Oct.-May)	505	81.1	439	70.5	423	67.9

The evapotranspiration calculated based on the empirical formulas are much higher than its maximum possible value based on the hydrometeorological and Penman-Gridley model, therefore the results of calculations based on these formulas were not considered in this study. As a conclusion, these empirical formulas are not suitable for implementation in the study area.

7 HYDROGEOLOGY

7.1 General

Ground water, derived from the shallow and deep water bearing formations of the Mountain Aquifer, represents the main source of domestic water in the entire West Bank. Based on the direction of hydraulic drainage of the Mountain Aquifer, it was divided and named to three main ground water basins; Western, North-Eastern and Eastern Basin. The approximate boundaries between the three basins is shown are Fig. 7.1. Only the Eastern Basin lies entirely in the West Bank while the other two basins are shared with Israel. About 80-90 % of the recharge areas for the North-Eastern and Western basins lie within the West Bank (WWS 2002 and Libiszewski 1995), but the ground water flows westwards towards the Mediterranean and northwards towards Bisan and Marj Ibn Amer.

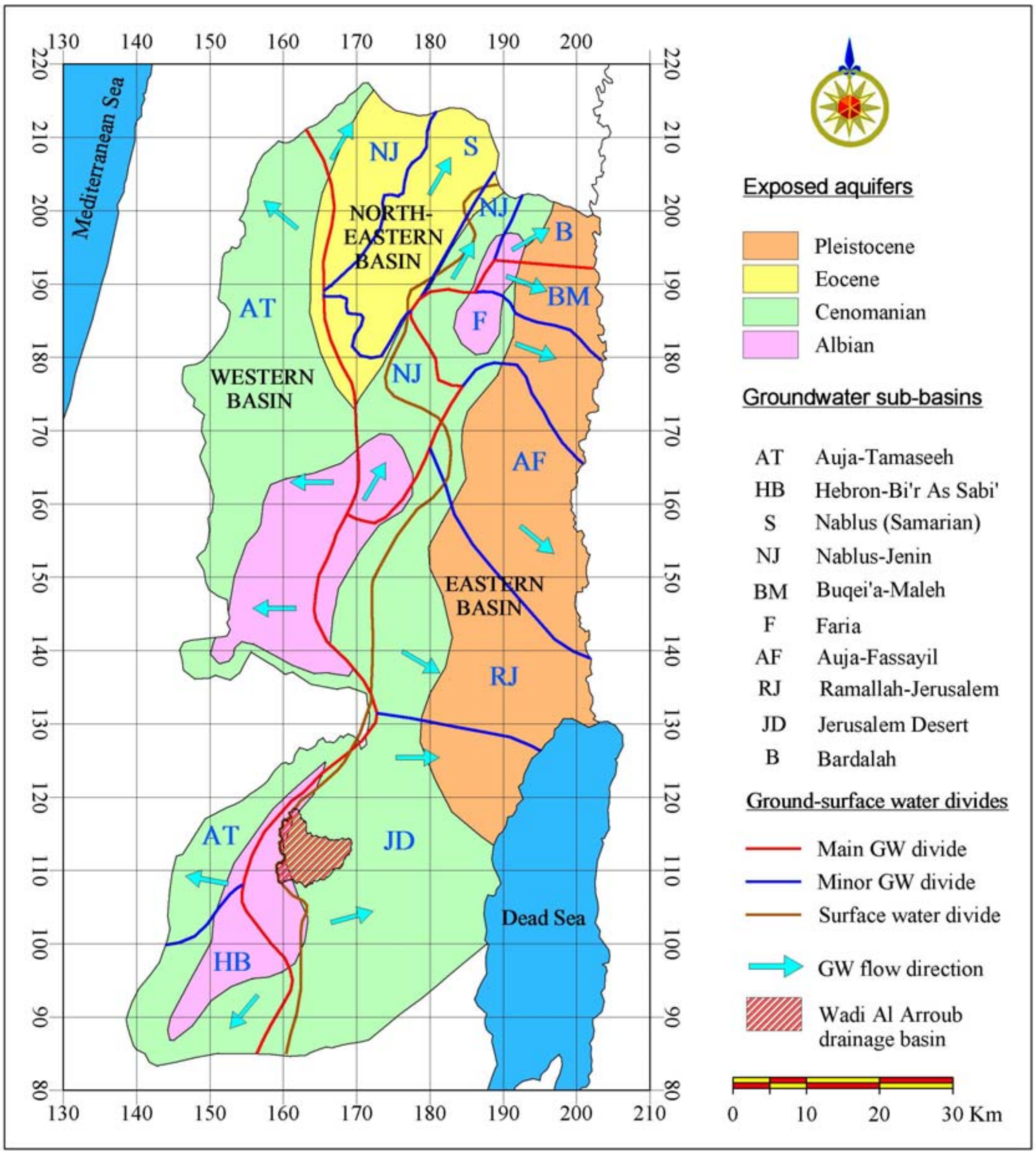


Fig. 7.1: Ground water basins and exposed aquifers in the West Bank / Palestine (modified after ARIJ 1995a; ARIJ 1995b and Husary et al. 1996)

7.1.1 North-Eastern Basin

There are several estimates for the recharge and storage capacity of this basin. According to Sturm et al. (1996) this basin has a total area of 700 km^2 out of which 650 km^2 are within the boundaries of the West Bank, while Elmusa (1996) estimated 500-590 km^2. The dominant direction of water movement is northeastwards along the plunge of Nablus-syncline. Different estimations for the safe yield of this basin are assumed to be 130 Mill. m^3/yr (Schwarz 1982), 140 Mill m^3/yr (Gvirtzman 1994 and Wolf 1995), and 145 Mill. m^3/yr according to Oslo 2 Accords (1995). Out of this yield the Palestinians use 25 Mill. m^3/yr around Jenin and 17 Mill. m^3/yr from east Nablus springs, the rest is being utilized by the Israelis (Oslo 2 Accords 1995).

7.1.2 Western Basin (Yarkon-Taninim in Israel)

This basin has a recharge area of 1800 km^2 of which 1400 km^2 are in the West Bank, whereas its storage area, about 2500 km^2, lies almost completely in Israel (Sturm et al. 1996). Gvirtzman (1994) and Oslo 2 Accords (1995) estimated the potential yield of this basin to be 360 Mill. m^3/yr, while Wolf (1995) estimated it by 320 Mill. m^3/yr. According to Oslo 2 Accord (1995), the Palestinians use 20 Mill. m^3/yr from wells in addition to 2 Mill. m^3/yr from springs near Nablus, while the rest is utilized by the Israelis. The flow direction in this basin is westward towards the Mediterranean Sea. Ground water from this basin is discharged by the springs of Ras Al-Ayin (Rosh Ha'ayen), which feeds Al-Auja (Yarqun) River and Al-Timsah (Tanninim) springs.

7.1.3 Eastern Basin

The direction of the water flow of this basin is eastwards toward the Jordan River and the Dead Sea. Naturally this basin is drained by several groups of springs in the West Bank, whereas a small fraction of its water discharges into the Jordan River and the Dead Sea and a negligible amount leaks to Israel. The recharge area of this basin encompasses over 2200 km^2 and the storage area over 2000 km^2 (Gvirtzman 1994). This basin lies almost entirely in the West Bank. Estimates of the safe yield (or extraction potential) of this basin are not well determined; 100 Mill. m^3/yr (Elmusa 1996 and Gvirtzman 1994), 125 Mill. m^3/yr (Wolf 1995) and 172 Mill. m^3/yr (Oslo 2 Accords 1995). According to Oslo 2 Accords (1995), the 172 Mill. m^3/yr are shared as follows: 24 Mill. m^3/yr utilized by the Palestinians from wells, 30 Mill. m^3/yr utilized by the Palestinians from springs, 40 Mill. m^3/yr used by the Israelis and 78 Mill. m^3/yr to be developed in the future.

According to the surface and subsurface hydrological divisions of the West Bank, Wadi Al Arroub area is part of the Jerusalem Desert sub-basin and accordingly part of the Eastern Basin (Fig. 7.1).

7.2 Hydrogeology of Wadi Al Arroub driange basin

7.2.1 Aquifers and aquicludes

The aquifer potentiality of the geological formations of the southern part of the Eastern Basin of the Mountain Aquifer part of which is Wadi Al Arroub drainage basin is represented in Table 7.1. The formations thickness and lithology presented in Table 7.1 are based on the geological log of the wells of Hebron 1 and 2, Arroub 1B, Herodion 3 and 4, PWA I and II.

Table 7.1: Hydrogeological formations at Wadi Al Arroub drainage basin and its surrounding area (Millennium Engineering Group et al. 2000; Guttman and Zuckerman 1995; Tahal 1975; Guttman and Gotlieb 1996 and Guttman 2000).

<table>
<tr><th colspan="3">Formation name</th><th>Thickness (m)</th><th>Simplified Lithology</th><th>classification</th></tr>
<tr><th>Palestinian</th><th colspan="2">Israel</th><th></th><th></th><th></th></tr>
<tr><td>Jerusalem</td><td colspan="2">Bina</td><td>90-130</td><td>hard limestone, some dolomite and marl.</td><td>Aquifer</td></tr>
<tr><td rowspan="2">Bethlehem</td><td colspan="2">Weradim</td><td>70-200</td><td>Dolomite and some limestone</td><td>Aquifer</td></tr>
<tr><td colspan="2">Kfar Shaul</td><td>10-70</td><td>Soft limestone, chalky limestone and marl</td><td>Aquitard</td></tr>
<tr><td>Hebron</td><td colspan="2">Aminadav</td><td>20-120</td><td>Dolomite and dolomitic limestone</td><td>Aquifer</td></tr>
<tr><td rowspan="3">Yatta</td><td>Moza</td><td>Upper</td><td>10-20</td><td>Limestone, marly limestone, marl and clay at the bottom,</td><td>Aquiclude</td></tr>
<tr><td rowspan="2">Beit Meir</td><td>Upper</td><td>40-110</td><td>Limestone, dolomite and</td><td>Aquifer</td></tr>
<tr><td>Lower</td><td></td><td>Marl at bottom</td><td>Aquiclude</td></tr>
<tr><td rowspan="2">Upper Beit Kahil</td><td colspan="2">Kesalon</td><td>10-80</td><td>Limestone, dolomite</td><td>Aquifer</td></tr>
<tr><td colspan="2">Soreq</td><td>30-140</td><td>Dolomite with marl</td><td>Aquifer</td></tr>
<tr><td rowspan="2">Lower Beit Kahil</td><td colspan="2">Givat Yearim</td><td>20-80</td><td>Limestone, dolomite</td><td>Aquifer</td></tr>
<tr><td colspan="2">Kefira</td><td>100-200</td><td>Limestone and marls</td><td>Aquifer</td></tr>
<tr><td>Kobar</td><td colspan="2">Qatana</td><td>30-50</td><td>Marl and clay</td><td>Aquiclude</td></tr>
</table>

7.2.2 Regional aquifers

The major regional aquifers exposed in Wadi Al Arroub drainage basin and its surrounding area, are the Albian and the Cenomanian-Turonian aquifers, referred to as the Lower and Upper aquifer respectively (Fig. 7.1). Based on the studies of Millennium Engineering Group et al. (2000), Guttman (2000), Guttman and Gotlieb (1996), Guttman and Zuckerman (1995) and Tahal (1975) as well as the geological log of the wells of Hebron 1 and 2, Arroub 1B, Herodion 3 and 4, PWA I and PWA II, the hydrogeological characteristics of these aquifers are summarized in the following.

7.2.2.1 The Albian aquifer

The Albian aquifer is built-up of limestones and dolomites of both the Upper and Lower Beit Kahil formations. This aquifer owes its high water bearing capacity and productivity to its great thickness (275-330 m). According to Guttman and Zuckerman (1995), the geological formations of this aquifer are characterized by a steep gradient of 4-5 % (40-50 m / km) towards the east. Rainfall and infiltration on the outcropping aquifer formations is the major source of recharge. Wadi Al Arroub drainage basin contributes to this recharge through the outcrops of the upper Beit Kahil Formation in its Western part. Despite its limited outcrops, most of the ground water abstraction in the area is from this aquifer, which could be attributed to additional feeding of this aquifer from the overlying Cenomanian–Turonian aquifer, mainly along the fault zones and fractures. Examples of the wells discharging this aquifer are the wells of Hebron 1, PAW I and II, Herodion 2, 3, and 4 as well as the Hundaza and Bani Naim wells. The strata of this aquifer are exposed for recharge at the western parts of the basin dipping eastwards beneath younger impermeable strata (Yatta Formation) thus becoming confined.

7.2.2.2 The Cenomanian-Turonian aquifer

Jerusalem, Bethlehem and Hebron formations are the water bearing formations of the Cenomanian –Turonian (Cen.-Tur.) aquifer (Millennium Engineering Group et al. 2000; Guttman and Zuckerman 1995 and CDM 1997), with a thickness ranging between 320 and 350 m. Generally, the formations of this aquifer are eroded at the Surif Anticline that forms the crest of the Hebron Mountains in this area, but they outcrop east and west of it. The eastern part of Wadi Al Arroub drainage basin acts as a recharge area for this aquifer through the outcrops of the Jerusalem, Bethlehem and Hebron formations. This aquifer is phreatic and therefore exposed to surface-derived pollution such as waste water infiltrating from the sewage conduit in Wadi Al Arroub and widespread poorly designed cesspits. The principal wells extracting water from this aquifer are the wells of Hebron 2, Herodion 1 and 5 and Beit Fajjar 3.

7.2.2.3 Hydraulic separation between the two aquifers

The major regional aquiclude that separates the Albian and the Cenomanian-Turonian aquifers is the marl, clay and chalk of the Yatta Formation. The separation is manifested in the difference of the regional water levels in the two aquifers. The water level in the Cenomanian-Turonian aquifer is at about 50-80 m higher than that in the Albian aquifer indicated from data derived from the wells of Herodion 4 and 5 (Guttman and Zuckerman 1995) and at about 40 m from the wells of Hebron 1 and 2 (PWA 2002). Fig. 7.2 shows a hydrogeological cross section of the regional aquifers and aquicludes, the dip of the strata as well as the elevation of regional water tables in the study area and its surrounding.

7.2.3 Local perched aquifers

Springs, shallow and deep wells in Wadi Al Arroub drainage basin show great changes in the ground water levels. This suggests that the occurrence of low permeable layers, i.e. marl, clay, shale or even hard dolomite in which there is no secondary porosity either from fracturing or karstification in the different geological formations create local perched ground water tables. For the purpose of this study these perched water tables will be referred to as aquifers. In the following are the perched aquifers that were distinguished in the area are described.

7.2.3.1 The perched water tables of the Albian aquifer

The springs of Eth-Tharwa and Misleh are among many springs in Halhul area in the southwestern part of the study area, that discharge a perched water table in the upper part of the Soreq Formation, Israeli terminology for the lower part of the Upper Beit Kahil Formation. The perched water table, 900-940 masl, is about 550-600 meters higher than the regional water table of the Lower aquifer at the Hebron well 1, 9 km to the northeast of these springs. This perched aquifer will be referred to as the Albian upper perched aquifer (AUPA). Another perched aquifer supported by the underlying aquiclude of Qatana Formation is expected in the Giv'at Yerim and Kefira Formation, but no well or spring was identified to discharge this perched aquifer in the study area. This aquifer will be referred to as the Albian lower perched aquifer (ALPA) Thus the Albian regional water table is a result of two perched water tables.

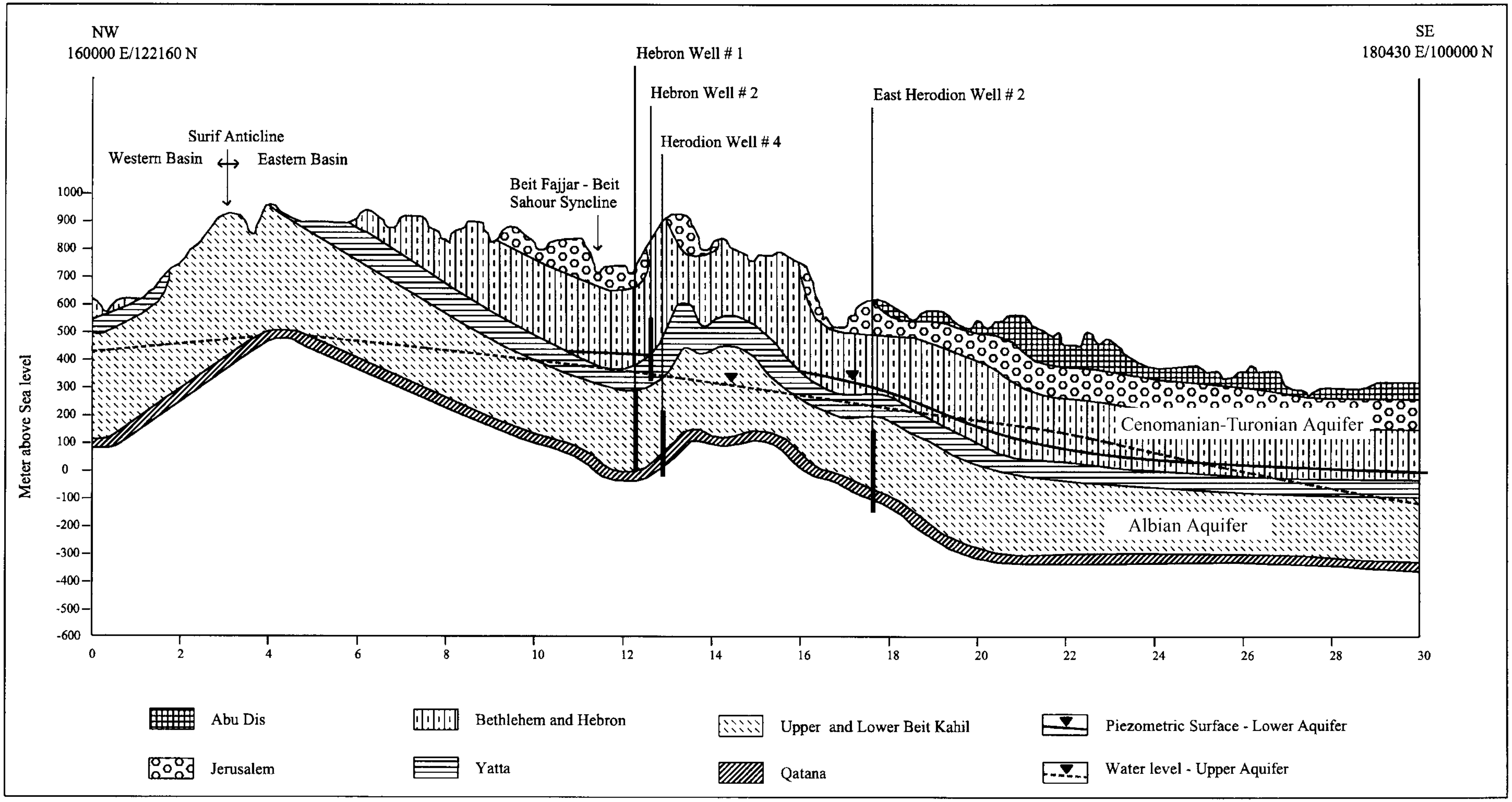


Fig. 7.2: NW-SE hydrogeological cross section showing the regional aquifers and aquicludes in the study area and its surrounding (after Millennium Engineering Group et al. 2000)

7.2.3.2 Perched water tables of the Cenomanian-Turonian aquifer

The data about the water levels at the Hebron wells 1 and 2, the Herodion well 3, and at the dug wells show that the regional water table of the Cenomanian-Turonian aquifer in the study area is built-up of three local perched water tables.

The marls and chalky limestones of the lower part of Bethlehem Formation (Kfar Shaul Formation in Israeli Terminology) act as a local aquiclude and divide the Turonian-Cenomanian aquifer into two perched aquifers: the Turonian aquifer, including both Upper Bethlehem Formation (Weradim in Israeli terminology) and Jerusalem Formation, and Cenomanian aquifer in the Hebron Formation. This is proved by the 18 m drop in the water table across Kfar Shaul Formation in Hebron well 1; the water table was measured to be 667 masl on top of Kfar Shaul Formation and after penetrating it the water level was measured to be 649 masl (Guttman and Gotlieb 1996).

On the other hand, the water level at the same well drops to 612 masl after penetrating the middle part of Hebron Formation indicating two perched water tables in the Hebron Formation (Guttman and Gotlieb 1996). The upper of which will be referred to as the Cenomanian upper perched aquifer (CenUPA) and the lower will be referred to as the Cenomanian lower perched aquifer (CenLPA). Examples of springs discharging these perched water tables are the springs of Kuweisiba 1 and 2 and Si'ir. The water level in these springs is about 830-860 masl, which is about 450 m higher than the regional water table of the Cenomanian –Turonian aquifer at Hebron well 2, 6 km northeast of these springs. The springs of Kuweisiba discharge the upper perched aquifer, while the spring of Si'ir discharges the lower perched aquifer.

Similar perched water tables were recorded during the drilling of the Herodion well 3 (Baida and Zuckerman 1992). The borehole establishes a link in between the perched water tables, and the final water level reached after penetrating all the formations of the aquifer is the regional water level. This means that in the study area the regional water table of the Turonian –Cenomanian aquifer is the water table achieved after the well fully penetrates the Jerusalem, Bethlehem and Hebron formations.

7.2.3.3 The perched aquifer/s of Wadi Al Arroub

Generally, Yatta Formation is said to be the regional aquiclude of the West Bank, but a closer study of this formation will show that, mainly the middle of this formation is of higher permeability than its top and bottom parts. According to the Israeli terminology Yatta Formation is divided into two smaller formations (Moza overlying Beit Meir). In this section the Israeli terminology will be used for simplicity. The bluish-greenish clay, marl and chalk of Moza and that of the lower Beit Meir are the actual parts of Yatta Formation that act as aquicludes. Dolomite and limestones of the upper-mid part of the Beit Meir are of higher permeability, which could assign this part as local perched aquifer.

A close study of the springs and dug wells in the Wadi Al Arroub drainage basin supports the fact that Yatta Formation is characterized by two perched water tables. The first is 5-15 meters below the contact between the Yatta and Hebron Formation and the second water table in the Beit Meir Formation. These perched water tables will be referred to as the Arroub upper perched aquifer (ArrUPA) and Arroub lower perched aquifer (ArrLPA), respectively.

7.2.3.3.1 Arroub upper perched aquifer

Based on the lithology of the dug-wells in the floor of Wadi Al Arroub and its tributaries, this aquifer is built-up from the clays and gravels of the alluvium deposits in the floor of the wadi as well as the underlying limestones, marly limestones and even marls of the upper-Moza. The bluish-greenish clays marls at the bottom of Moza act as the aquiclude supporting this perched water table. The variability in lithology of the uppermost part of the Yatta Formation (Moza Formation in Israeli terminology) is revealed in different dug wells. It consists of hard limestones, marls, and marly limestones. The lithology of the Moza Formation is variable, sometimes the whole depth of the dug-well is penetrating hard limestone, at other sites penetrating marly limestones and sometimes marls.

The local lithology of the dug-well, the cracks and fissures in the walls of the dug wells are the main factors determining its yield. The thickness of this aquifer ranges between 10 and 15 meters. The depth to ground water in this aquifer in winter ranges between 0-4 meter below ground level (mbgl), whereas in summer 0-11 mbgl. Examples of springs and dug wells discharging this perched water table are those of El Bas, Ed-Dilbi, Haj Hamid, Eid, Arroub, Ed-Diwan and Ayish. 55 spring and dug wells are discharging this ground water table which is characterized by a variable water table with a 2-5 m increase and a 2 to 3 fold yield during winter.

Because there is no detailed geological map of the area available that shows the boundaries of the Moza Formation, and it was not possible to identify the boundary in the field due to the alluvial cover, it was estimated by subtracting two surface models of the top Yatta Formation and the topography. First of all, a 10 m contour structural map for the top of Yatta was drawn, based on the outcrops, well logs, cross sections, and the structural map, bottom of Moza, prepared by Hirsch (1983) which, however, reaches only to line 160000 East.

Based on the data available from the logs of the wells of PWAI, PWA II, Hebron 1 and the geological maps of Kolton (1972) and Hirsch (1983) for the area around the study area, and based on the depth of the dug wells, the thickness of the Moza was assumed to be 15 meters. Areas included within the contour line of 15 meters below the top of Yatta were assigned to the Moza Formation, and this contour line was assumed to be the extent of the Moza outcropping on the surface. This work was done with the help of the GIS TNT-mips (Microimages Inc. 2001) and with the help of (Surfer-7) scientific graphics software (Golden software Inc. 1999). The border assigned to the Moza Formation is only estimated, so further field studies are necessary.

7.2.3.3.2 Arroub lower perched aquifer

Where Moza Formation is eroded as in the case of the western part of Al Arroub drainage basin, this perched aquifer is built-up from the alluvium deposits and the underlying dolomites and limestones of Beit Meir. Where Moza is present this perched aquifer is built-up from the Beit Meir dolomite and limestones only. The marls and clays and shale at the bottom of Beit Meir are the aquicludes supporting this perched water table. Examples of springs and dug wells discharging this aquifer are Beit Ummar El-Balad (Qufeen), Marina, the wells of Al Arroub Nursery ,and Arroub Agricultural School. Due to erosion the thickness of this aquifer is variable. Fig. 7.3 shows the regional as well as the local perched aquifers exposed in Wadi

Al Arroub drainage basin. Fig. 7.4 and Fig. 7.5 are cross section through springs and wells discharging perched water tables.

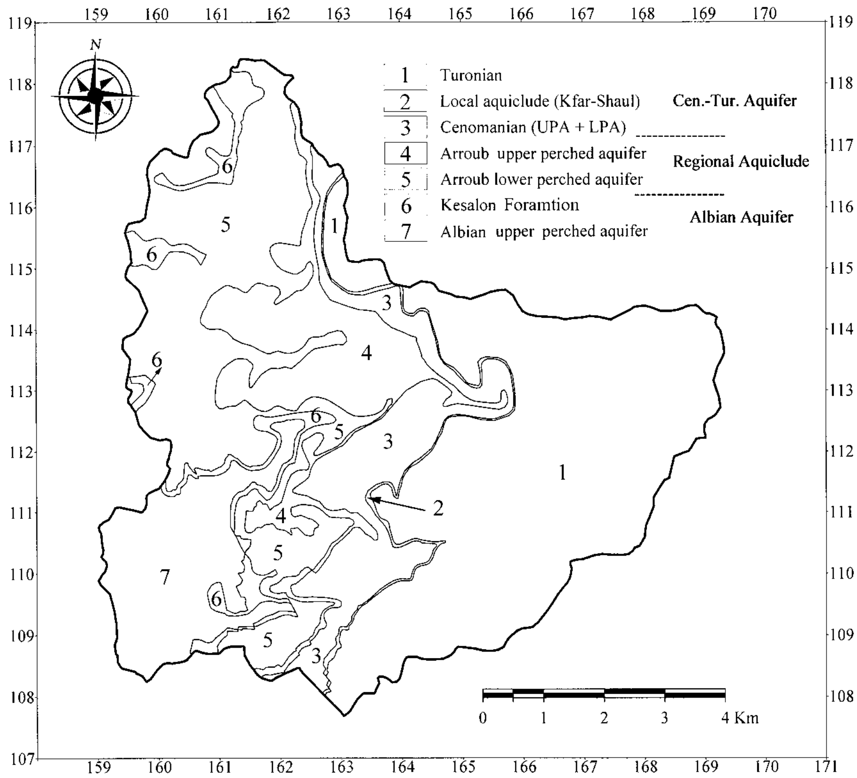


Fig. 7.3: Regional and local aquicludes and aquifers in Wadi Al Arroub drainage basin and its surroundings.

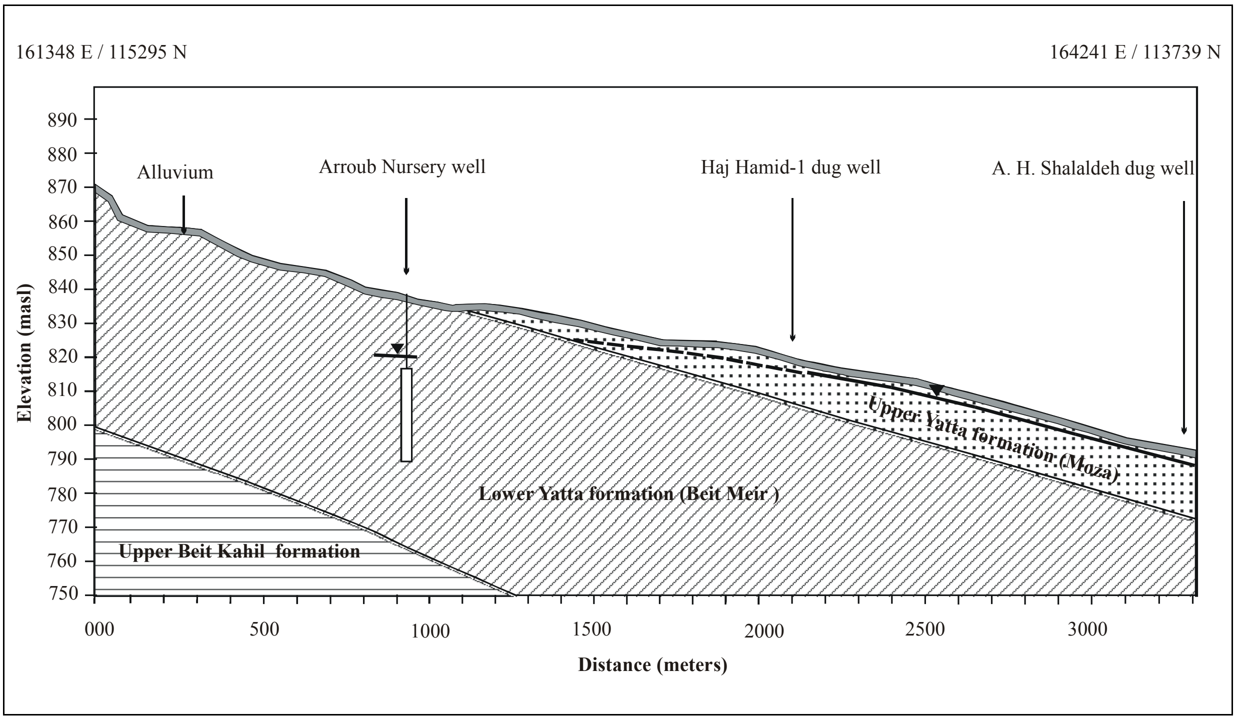


Fig. 7.4: Cross section through the well of Arroub Nursery and the dug wells of Haj Hamid-1 and Abdel Hamid Shalaldeh.

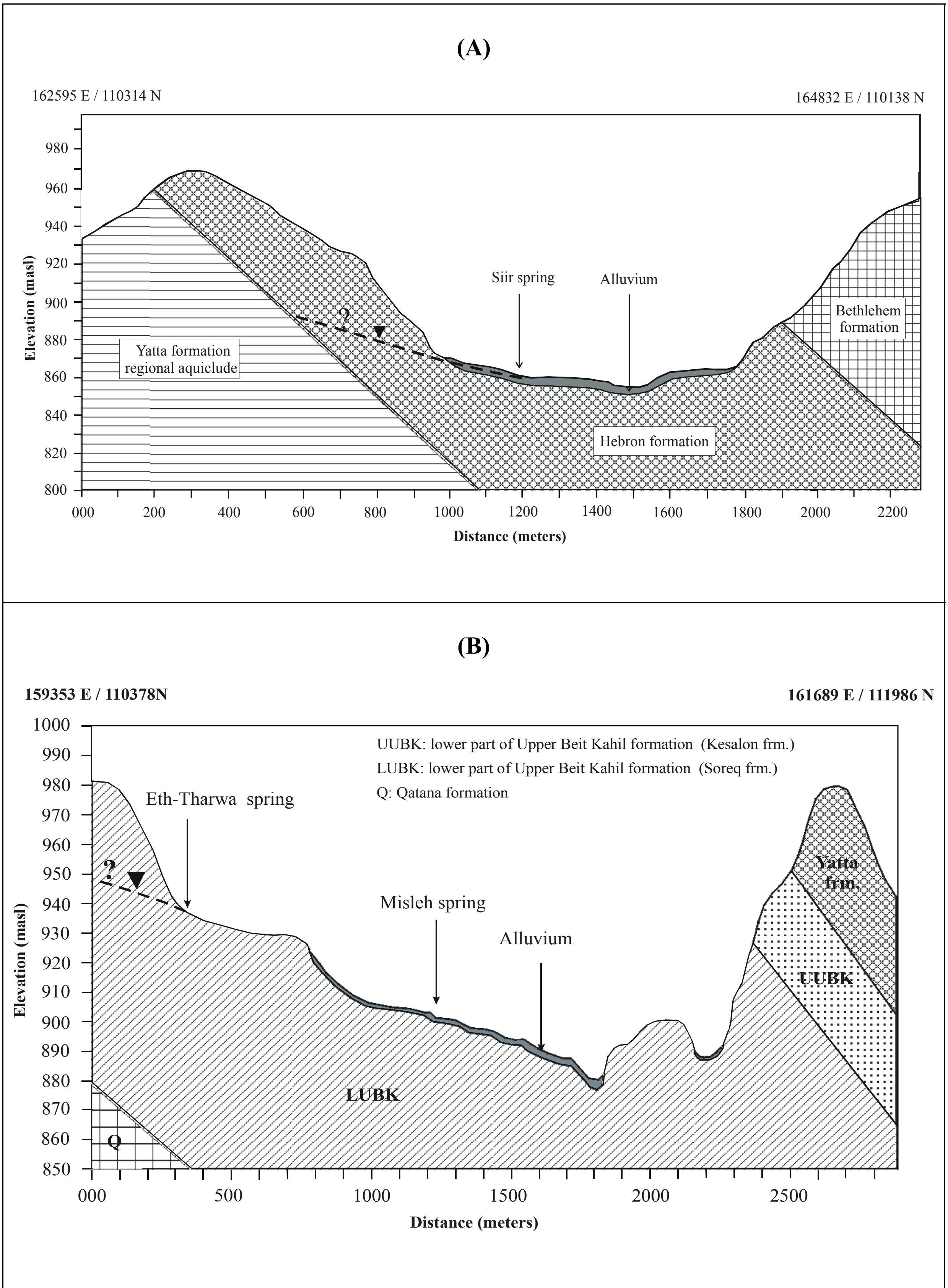


Fig. 7.5: Cross section through the springs of (A) Si'ir (B) Eth-Tharwa and Misleh.

7.3 Surface and ground water flow direction

7.3.1 Surface water flow direction

The flow direction of the surface water in the main streams of Wadi Al Arroub drainage basin is at most towards the northeast and to less extent towards the east and southeast, while in the secondary creeks it is mainly eastwards. Wadi Al Arroub, the main wadi discharging this catchment, is a tributary of Wadi Ghar that flows southeast towards the Dead Sea (see Fig. 5.2).

7.3.2 Ground water flow direction

Generally, the 400-450 masl water table along the axis of Surif anticline descends eastwards to an elevation of about 410 mbsl at the western shores of the Dead Sea. Assuming uniform gradient, this 800-850 m difference in the ground water heads over a 25-30 km of horizontal distance leads to a steep flow gradient. According to Guttman (2000) and Guttman and Zuckerman (1995), the water levels in the southern West Bank does not reveal a uniform W-E flow gradient. Herodion area, was identified to have relatively moderate flow gradients compared to a steeper gradient in the areas around the wells of Jerusalem 5 and Azzariya 1. Based on that, it was assumed that the ground water flow is influenced by transmissivity barriers (low transmissivity zones). As a result of bypassing these zones of low transmissivity the direction of the flow in Herodion area is towards the northeast and subsequently east.

7.4 Overexploitation of the ground water resources

The aquifers of this area, especially in the Herodion well field, are being heavily overexploited indicated by the serious drop in the static water levels overall the area (Table 7.2). Table 7.2 shows that the existing pumping scheme is causing a continuous drop in the water tables of the aquifers. Continuing this withdrawal policy and sinking more wells in the area has to be considered as ground water mining. Aliewi and Jarrar (2000) quoted from a modeling study delivered to the PWA by the CDM that, if the newly drilled wells are put in operation, which already happens, then the simulated draw-down is about 120 m over a four year period in the Herodion field, and this will significantly dewater the utilized aquifers.

Table 7.2: The drop in the static water level of selected wells in the study area and its surroundings (after PWA 2002).

Well	Well code	Aquifer	The static water level in meters asl				Drop in WL (m)
			Date	WL	Date	WL	
Beit Fajjar (substitute)	16-11/001A	Cen.-Tur.	15.04.87	582.8	20.11.1988	571.2	11.6
Herodion 5	16-11/007	Cen.	28.01.1997	430.0	09.11.1998	426.6	3.4
Herodion 4	16-11/006	Albian	10.08.1986	363.5	07.11.1999	292.1	71.4
PWA II	16-11/011	Albian	12.05.1999	335.6	26.11.1999	325.5	10.1
PWA I	16-11/010	Albian+Cen.	12.05.1999	450.4	20.12.1999	446.6	3.8
Herodion 2	17-11/002	Albian	27.12.1972	416.2	08.12.1999	370.3	45.9
Herodion 2a	17-11/001A	Cen.	28.01.1997	346.0	07.12.1999	339.5	6.4
Herodion 3	17-11/003	Albian	04.11.1981	400.2	21.08.1997	314.9	85.3
Hebron 1	16-11/008	Albian	15.02.1998	359.0	15.07.2001	325.5	33.5

7.5 Ground water resources

7.5.1 Ground water wells

The wells of Hebron 1 and 2, and PWAI are the only deep production wells within the boundaries of Wadi Al Arroub drainage basin, but these wells are part of a well field, the Herodion-Beit Fajjar well field, extending for a few kilometers to the northeast of this area. These wells are the main water resource not only for this area but also for about 50 % of the southern West Bank. The water of these wells is being pumped to the area of Wadi Al Arroub through a network of pipes. The major characteristics of the Herodion wells are summarized in Table 7.3.

Table 7.3: The deep wells. supplying the area of Wadi Al Arroub and about 50 % of the southern West Bank with tap water (Guttman and Zuckerman 1995 and CDM 1997).

Well	Coordination (E/N)	Aquifer	Altitude of well head (masl)	Depth (m)	Pump. rate (m^3/hr)
Hebron 1	169156/113619	Albian	696	704	300
Hebron 2	169161/113597	Cen.-Tur.	696	350	70
PWA I	167424/112301	Cen.-Tur. and Albian	746	600	250
PWA II	169186/116304	Albian	752	752	250
Beit Fajjar 1A	169696/115208	Cen.-Tur.	736	305	230
Herodion 1	170772/118220	Cen.-Tur.	580	351	128
Herodion 2	170958/119332	Albian	560	770	340
Herodion3	170857/117241	Albian	610	743	400
Herodion 4	169485/114160	Albian	686	691.5	240
Herodion 5	169464/114148	Cen.-Tur.	690	326	65

7.5.2 Springs and dug wells, names and codes

Until the year 1992 the springs of Wadi Al Arroub drainage basin especially Ein El Fawwar and Ein El Baradah represented a main source of drinking water during the whole year. As a result of the dryness of these two major springs and the usage of the floor of the Wadi for the waste water disposal, a great degradation of agricultural landuse can be seen especially in front of Al Arroub Camp and Shuyukh Al Arroub.

The dryness of these two springs and the decrease in the flow rate of other springs such as that of the El Bas-West and El Bas-East could be attributed to the dry climate that generally dominates the area since 1993. Expansion of the housing over the local surrounding of the springs reducing their recharge areas as well as the growing number of the agricultural dug wells (open pits) could be additional factors that kept these springs dry even in the good rainy season of 1994-1995 and 2000-2001. The number of the shallow agricultural wells (open pits) was increased by about 400 % in the last ten years. especially on properties owned by the inhabitants of Kuweisiba and Urqan Tarrad who depend to 90 % on farming.

Until the year 2001 the water of many of these springs and shallow wells was used for domestic purposes, especially in the case of interrupted tap water supply. Springs such as Kuweisiba-1 and El Bas-West are always used for domestic purposes. The spring of Wadi El

Dur is used for drinking purposes only by the farmers and sometimes by the people who pass by. More details about springs and dug wells in this area are given in Appendix 7.1.

Because in the study area several dug wells / springs have been identified by the inhabitants by more than one name, the majority of the springs and wells are private properties, thus changing the ownership changes the name of the wells or springs, and for simplicity, three-suffixed codes were given to the different springs and wells in the area (Appendix 7.1). In the following two examples are given.

WA-Sp-1
WA-Dw-1

The first suffix (WA) refers to the wadi in which the spring or well is located. The second distinguishes the springs (Sp) from the dug wells (Dw) and the third is a serial number counting from upstream towards downstream.

8 HYDROCHEMISTRY

This part of work was written primarily to provide information on the characteristics, water types, genesis and suitability of the water resources in the study area for domestic and agricultural purposes. Also the waste water will be characterized. The different types of pollutants, possible sources and impacts on the ground water resources will be highlighted. To achieve these purposes representative samples from the springs, dug wells, deep wells, rain water and waste water conduit (Fig. 8.1 and 8.2) from the study area were collected and analyzed between 1999 and 2001. Tap water samples from Al Arroub Camp were also collected during this study. All the samples were analyzed for the major and minor ions, trace elements, fecal and total coliform bacteria. The waste water samples were also analyzed for TS, BOD_5 and COD. Six samples from selected springs and dug wells as well as a waste water sample were analyzed for the volatile organic chemicals (VOC's). The EC, pH, Temp, and DO were measured for all the samples.

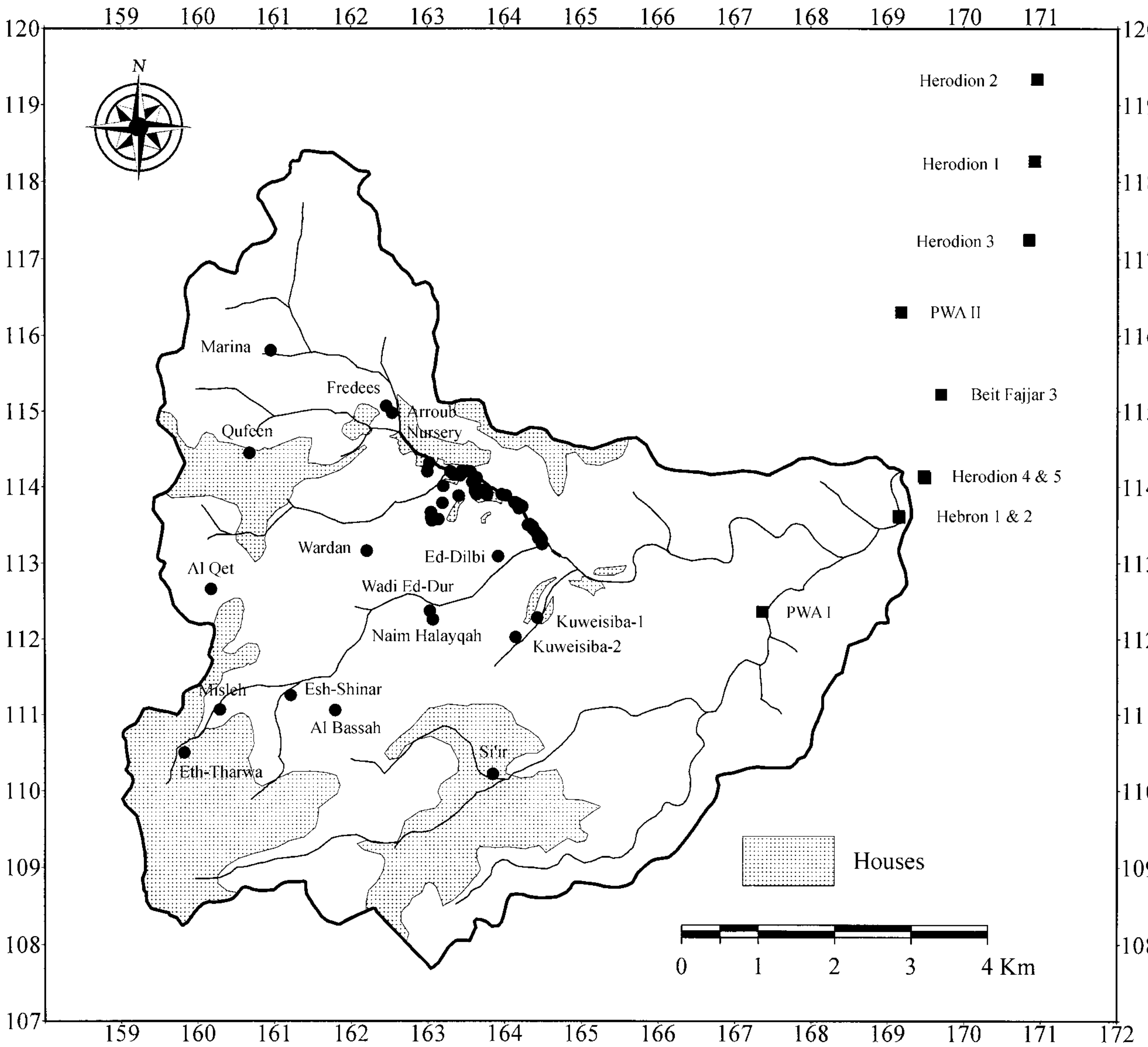


Fig. 8.1: Location map of the deep wells, dug wells and springs of Wadi Al Arroub drainage basin an its surrounding.

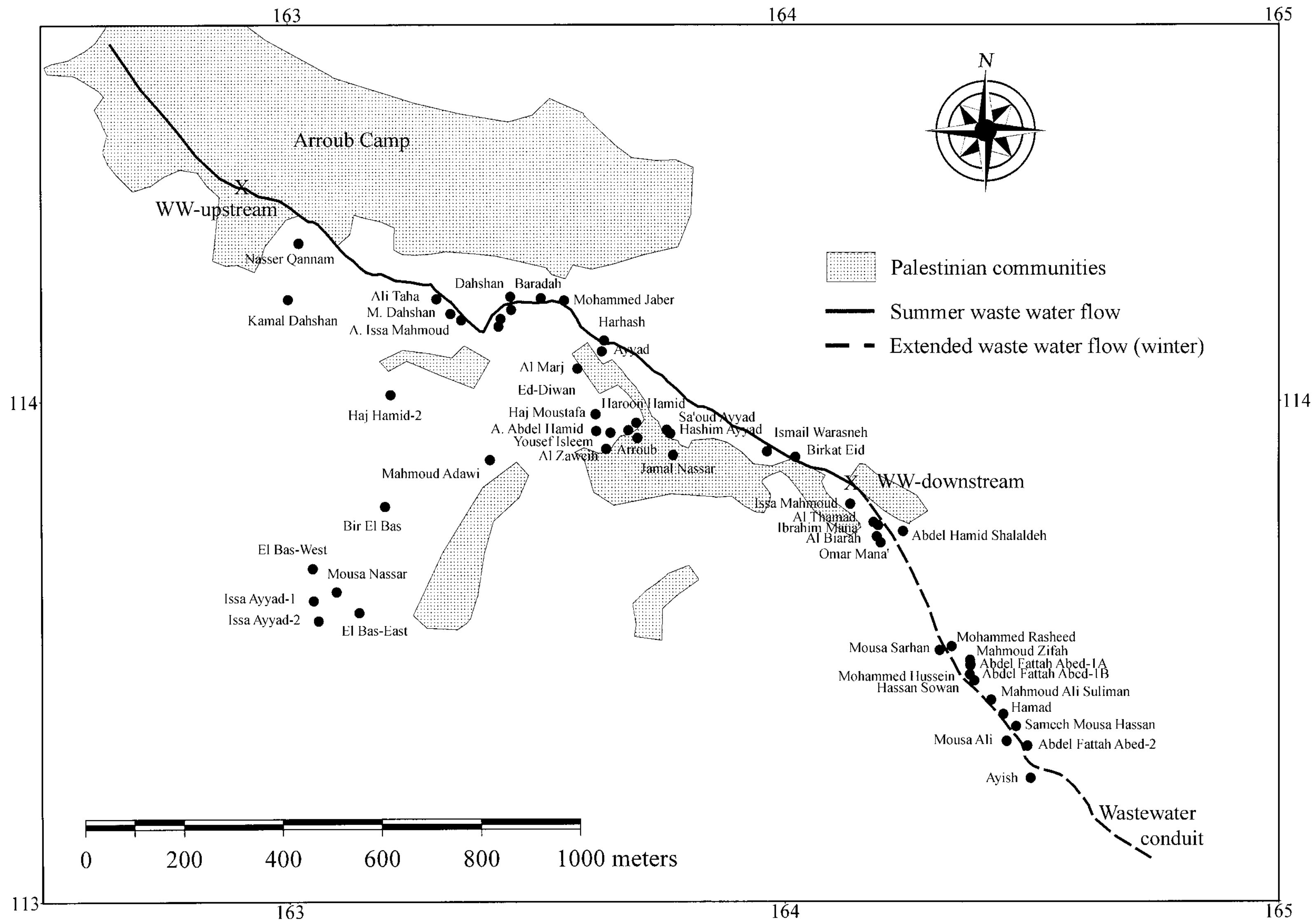


Fig. 8.2: Location map of the springs and dug wells in the floor of Wadi Al Arroub and Wadi El Bas.

8.1 Results and interpretation

Because of the very difficult political situation in the West Bank since 1998, it was not possible to sample some of the wells and springs proposed for this study, therefore previous analyses done by the author himself during the period 1996-1997 (Qannam 1997) of these sites were used in this study so as to offer a better geographical distribution of samples. The results of common sampling sites in the author's study in 1996-1997 and the present study were also used to give a better presentation of the sampling sites. All data about the dug and deep wells as well as the spring used in this study are show in Appendix 8.1. The data of rain water, networks and waste water are shown in Appendix 8.2, 8.3 and 8.4 respectively. The results of the VOC'S are shown in Appendix 8.5.

8.1.1 Total dissolved solids

Total dissolved solids (TDS) comprise inorganic salts, principally calcium, magnesium, potassium, sodium, bicarbonates, chlorides and sulfates and some small amounts of organic matter that are dissolved in water. The TDS concentration is a secondary drinking water standard and is regulated because of its esthetic effect rather than a health hazard. Elevated TDS indicate that the dissolved ions may cause the water to be corrosive, of salty or brackish taste, resulting in scale formation, and interfere and decreased efficiency of hot water heaters. It may also indicate that water may contain elevated levels of ions that are above the primary or secondary drinking water standards, such as: elevated levels of nitrate, arsenic, aluminium, copper, lead, etc. A general classification of ground water according to the TDS is shown in Table 8.1.

Table 8.1: General classification of ground water according to TDS (Carroll 1962).

Category of water	**TDS (mg/L)**
Fresh	0 - 1000
Brackish	1000 – 10000
Saline	10000 - 100000
Brine	> 100000

There was no measurements or analysis for the TDS during this study, therefore it was calculated using the equation of Freeze and Cherry (1979)

$$\text{TDS mg/L} = Ca^{2+} + Mg^{2+} + Na^{+} + K^{+} + SO_4^{2-} + Cl^{-} + NO_3^{-} + 0.5\ HCO_3^{-} \text{ (all in mg/L)}$$

The results of the calculations are tabulated in Appendix 8.1. From the results it is clear that all the collected samples of rain water, deep wells, tap water, springs and dug are of fresh water type with TDS values of 28-31 mg/L in the rain water, 240-400 mg/L in the deep wells and tap water, 160-300 mg/L in the springs and 300-1000 mg/L in the dug wells. Values between 1000-1200 mg/L and only in summer were recorder in the dug wells of Haj Omar and Haj Hamid, which are vary close to the sewage conduit. The sewage water showed a brackish water type with TDS values of 1000-1100 mg/L in winter and 1800-2100 mg/L in summer.

8.1.2 Electrical conductivity

The electrical conductivity (EC) is a measure of the total salt content of water based on the flow of electrical current through the sample. The higher the salt content, the greater the flow of electrical current. EC is the reciprocal of resistivity (R) and is reported in mS/cm or µS/cm. The measurements conducted during this study, showed that the EC values ranged between 49-80 µS/cm in the rain water, 400-700 µS/cm in the tap water and deep wells, 380-750 in the springs, while in the dug wells the values ranges between 500-2000 µS/cm. The highest values in the dug wells, 1500-2000 µS/cm, were recorded in the wells of Haj Hamid and Haj Omar in summer and in the well of Abed-2 in winter. The waste water showed EC values between 1500-1700 µS/cm in summer and values between 2800-3300 µS/cm in winter.

Since the EC and TDS are measurements of the total salt content, they must be directly proportional. The correlation between these two parameters for the analyzed samples in this study was plotted in Fig. 8.3, which showed a linear correlation with a mathematical approximation of (TDS mg/L = 0.55 EC µS/cm).

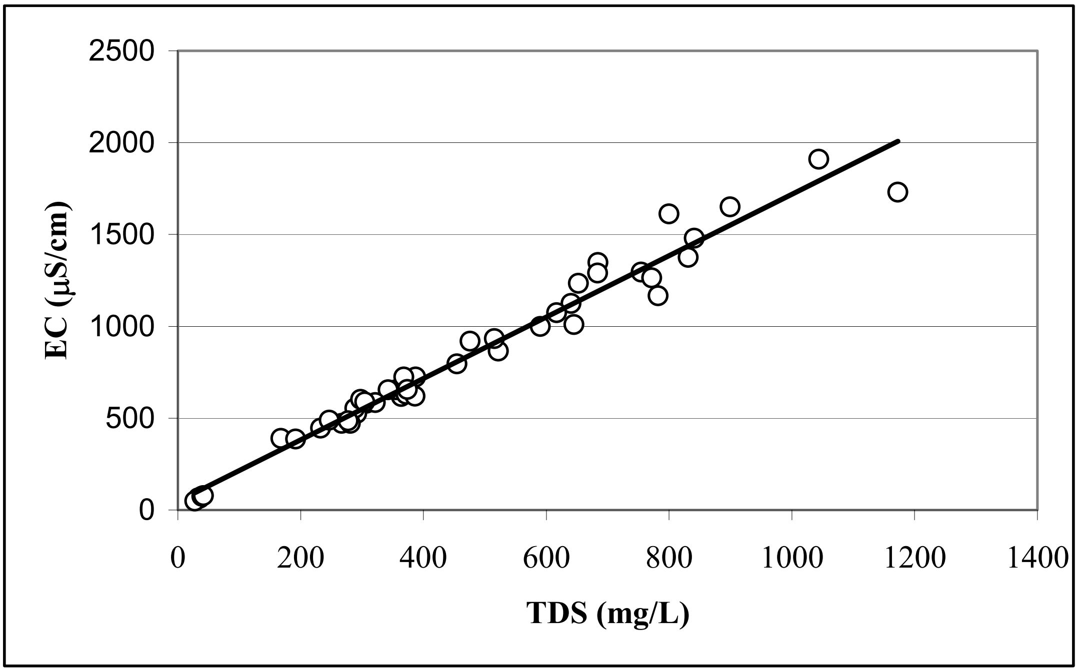


Fig. 8.3: Plot presenting the relation between the EC and the TDS values of the samples analyzed during this study

8.1.3 Classification of the ground water samples

Classification of waters provide a basis for grouping samples with similar characteristics. Most of the classification systems developed to date have considered only the major inorganic constituents and have ignored the organic and the minor and trace inorganic constituents. In this section graphical and statistical methodologies were used to classify the water samples into homogeneous groups. These include the diagrams of Piper, Durov, Schoeller, Collins and Icon (Chernoff) faces as well as the Q-mode cluster analysis and Mann–Whitney and Kruskal-Wallis tests.

8.1.3.1 Classification of water types using Piper and Durov diagrams

Using the software HYDROWIN 3 (Calmbach 1995), the results of the analyzed samples were plotted on Piper diagrams as presented in Fig. 8.4, 8.5, 8.6, 8.7 and 8.8.

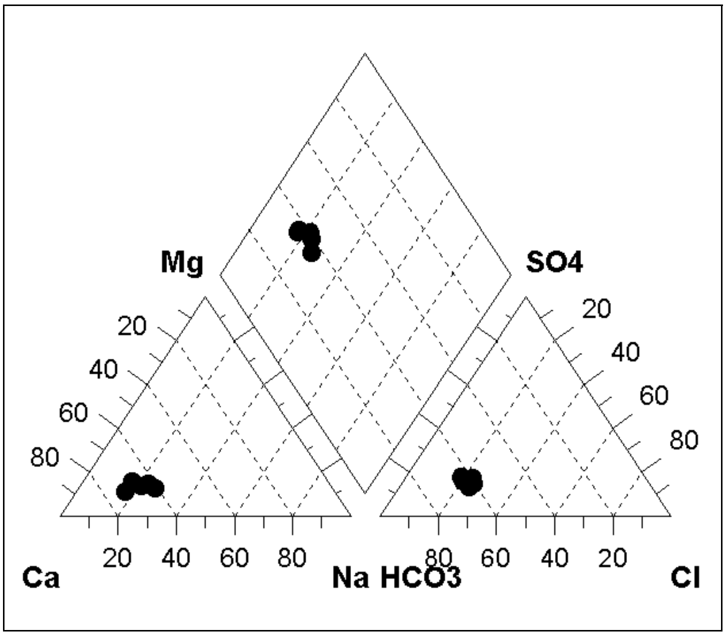


Fig. 8.4: Piper diagram illustrating the results of the rain water analyzed samples.

Fig. 8.4 shows that the rain water, which represent the only source for recharge in the study area is of Ca-Na-HCO_3-Cl water type. The water of the deep wells (Figure 8.5-A), tap water (Fig. 8.5-B), Arroub lower perched aquifer (Fig 8.6-A) and the majority of the springs and wells of Arroub upper perched aquifer (Fig. 8.6-B), Cenomanian upper and lower perched aquifers (Fig. 8.7-A), Albian upper perched aquifer (Fig. 8.7-B) are of Ca-Mg-HCO_3 water type.

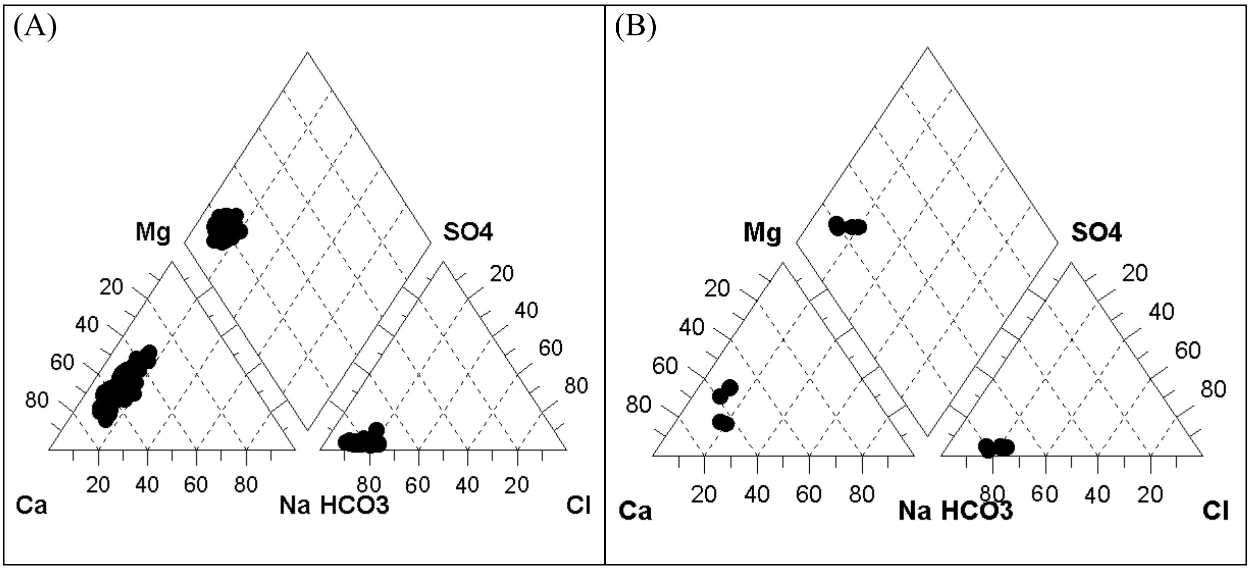


Fig. 8.5: Piper diagram illustrating the results of the analyzed samples of (A) deep wells and (B) tap water.

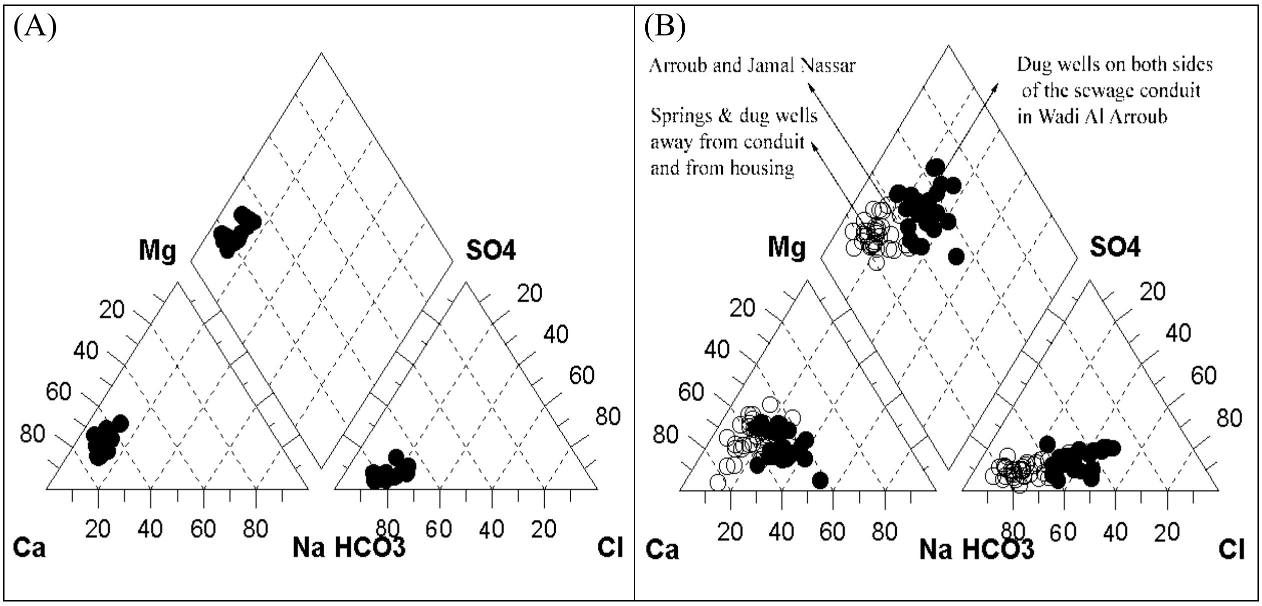


Fig. 8.6: Piper diagram illustrating the results of the analyzed samples of (A) Arroub lower perched aquifer (B) Arroub upper perched aquifer.

Mixing with the waste water leaking from the poorly designed cesspits is responsible for the increased concentrations of alkalis, chloride and sulfate in the springs and dug wells of Arroub and Jamal Nassar (Fig. 8.6-B), Si'ir (Fig. 8.7-A) and Eth-Tharwa (Fig. 8.7-B). The infiltration of the leachates from washing the piles of animals dung, collected for agricultural purposes or for generation of energy, by the rainfall in winter could be another factor responsible for such modifications. Mixing with the waste water leaking from the conduit in the floor of Wadi Al Arroub is the main factor responsible for such modifications in the water of the wells of Al Arroub upper perched aquifer, represented by the wells of Haj Hamid-1, Ayyad, Birkat Eid, Sowan and Abed-2. Wells that are far from the conduit in this perched aquifer are of Ca-Mg-HCO_3 water type (Fig. 8.6-B)

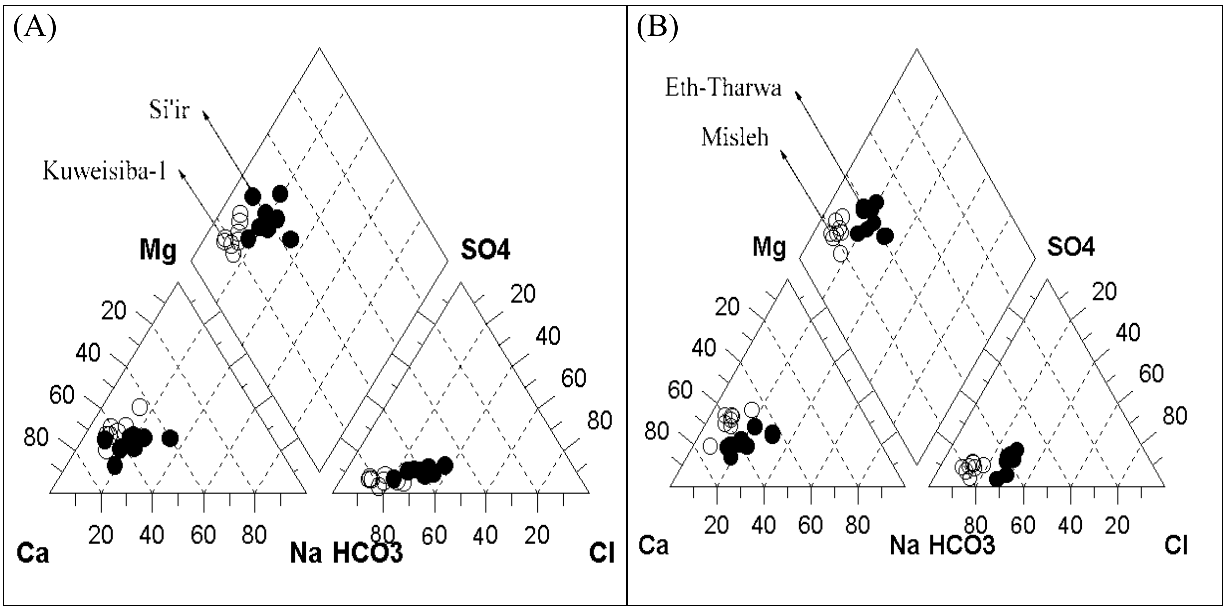


Fig. 8.7: Piper diagram illustrating the results of the analyzed samples of (A) Cenomanian upper and lower perched aquifers (B) Albian upper perched aquifer.

In summer the waste water is an alkaline water with prevailing chloride and sulfate, while in winter it is an earth alkaline water with prevailing chloride and sulfate as a result of its dilution with runoff water (Fig. 8.8).

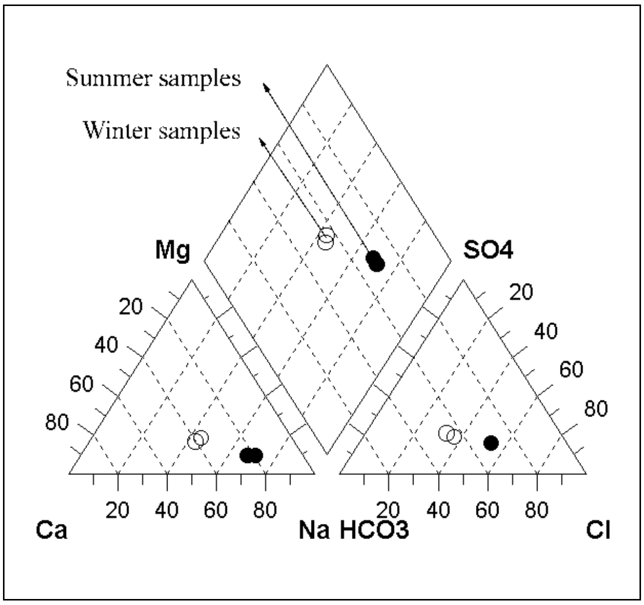


Fig. 8.8: Piper diagram illustrating the results of the analyzed waste water samples.

Another method of data presentation is the Durov diagram. The advantage of this diagram over that of Piper is that this diagram displays some possible geochemical processes that could affect the water genesis (Lloyd and Heathcoat 1985). Durov diagrams for samples analyzed in this study are illustrated in Fig. 8.9 and 8.10. The plot of the springs of Si'ir, Eth-Tharwa, Arroub, and the wells of Haj Hamid-1, Haj Omar, Ayyad, Birkat Eid, Sowan and Abed-2 in field 5 in Durov diagram (Fig. 8.9) along the mixing line supports the above proposed explanations concerning their water types.

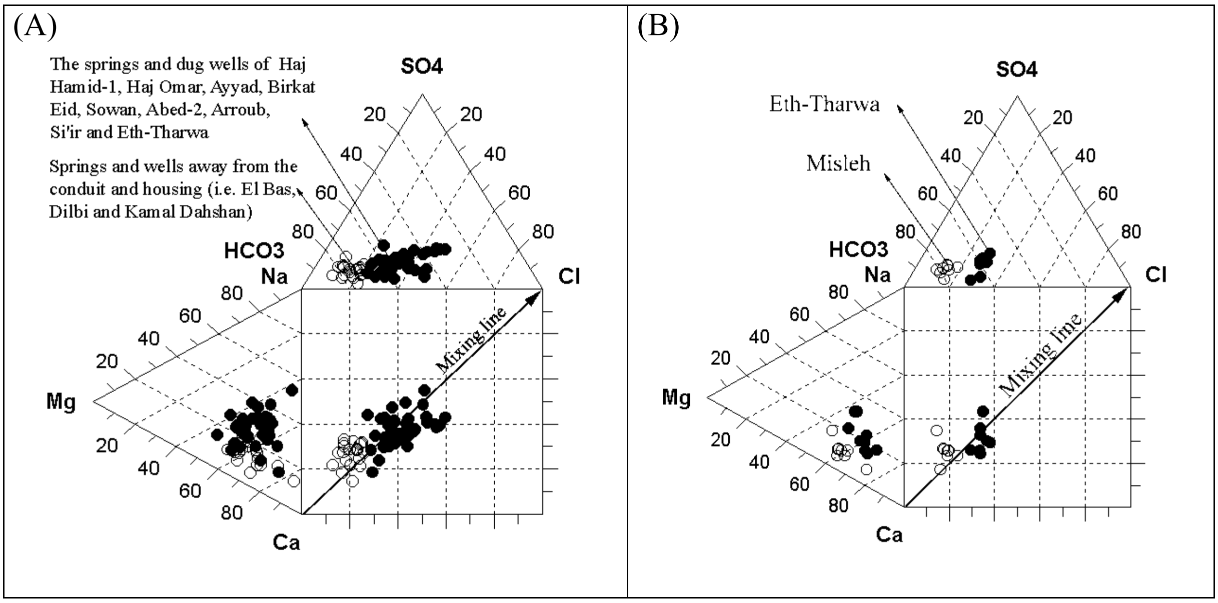


Fig. 8.9: Plot of wells and spring sampled during this study in Durov diagram (A) Arroub upper perched aquifer (B) Albian upper perched aquifer.

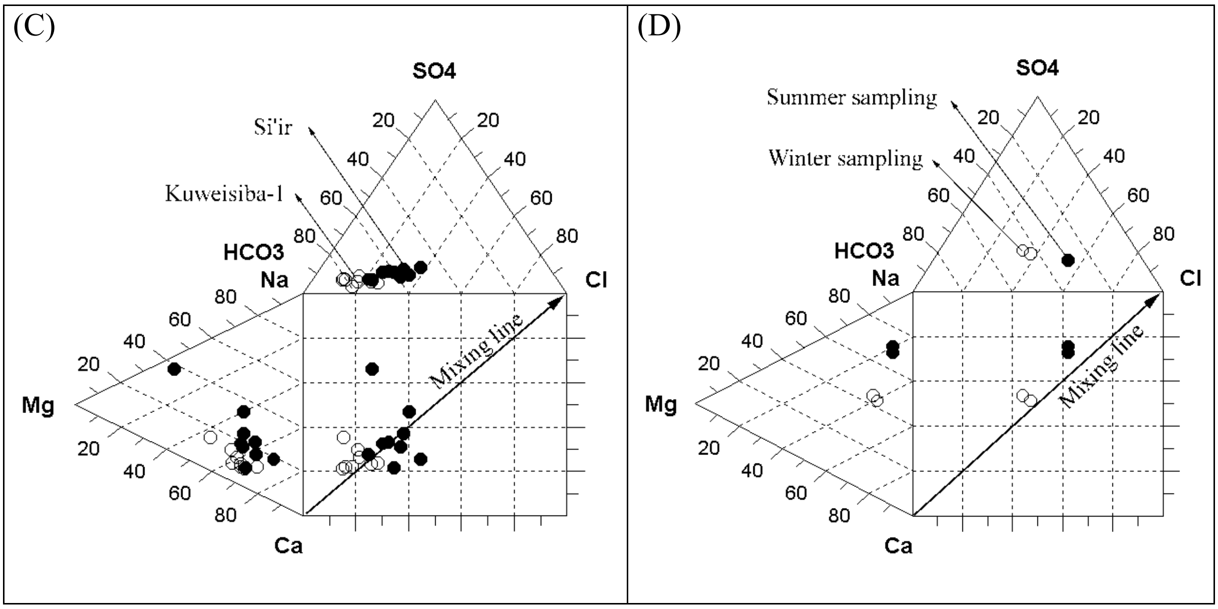


Fig. 8.10: Plot of wells and spring sampled during this study in Durov diagram (C) Cenomanian upper and lower perched aquifers and (D) Waste water.

8.1.3.2 Seasonal variation in the water quality

Due to the fact that the rainfall is limited to winter and is the only source of ground water recharge, seasonal variation could be noticed in the water quality of the different springs and wells. Three types of variations were noticed during this study between the water quality of the samples collected in winter and those collected in summer. The samples collected from the springs of Dilbi, Wadi Ed-Dur, El Bas-East and the well of Arroub Nursery showed that winter samples are diluted samples of summer (Appendix 8.1). Comparing the results of the samples collected in summer with that collected in winter from the wells of Sowan (Fig. 8.11) and Abed-2 showed that in winter the samples have higher concentrations of Na, K, Cl, NO_3 and SO_4 as well as higher EC. This could be attributed to mixing with the waste water of the the conduit, where the mixing possibility is at maximum when the flow of the conduit is high as in winter and at minimum when the flow is low or not existent as in summer.

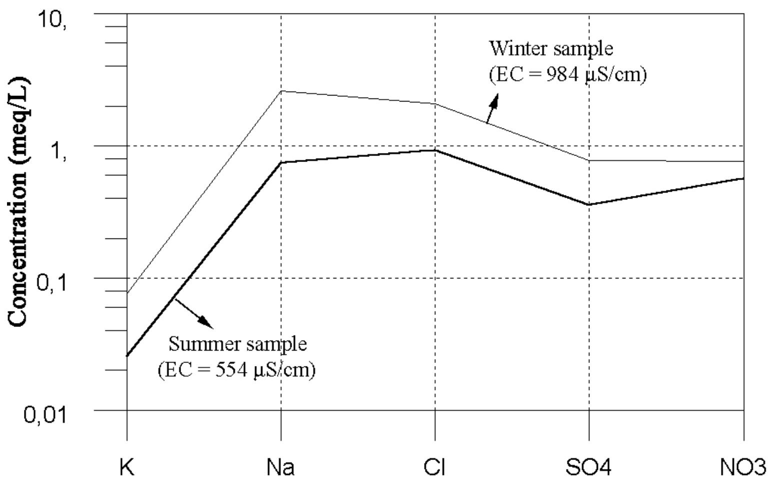


Fig. 8.11: Plot of the samples collected in summer and winter from the dug well of Sowan in Schoeller diagram.

The opposite case was recorded in the wells of Hamid-1 (Fig. 8.12), Ayyad, Birkat Eid and Haj Omar, where the water of the wells had lower concentrations of these elements in winter than in summer. This is due to the rainfall, infiltration and ground water recharge during winter and a more or less constant amount of waste water during the whole year. The results of the waste water showed that the concentrations of the different elements and the EC are less than that in summer, which is due to the dilution of the waste water by runoff water. A down stream increase was found in the waste water for BOD, COD, EC, Na and Cl caused by evaporation and thus decreasing the discharge of the waste conduit gradually until it dries up completely. On the contrary a decrease of sulfate and nitrate concentrations was noticed which can be explained by gaseous loss as ammonia and hydrogen sulfide as well as sorption by plants.

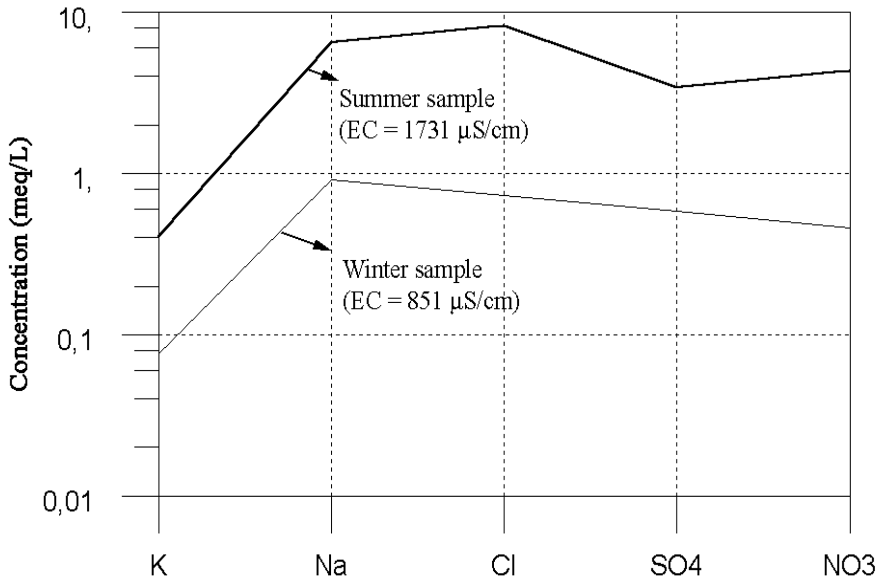


Fig. 8.12: Plot of the samples collected in summer and winter from the dug well of Haj Hamid-1 in Schoeller diagram.

8.1.4 Statistical analysis

Statistical calculations were conducted using the statistical software packages SPSS 10 for windows (1999) and STATISTICA 5 for windows (1995). Appendix 8.6 shows the descriptive statistics (minimum, maximum, mean and standard deviation) of the samples collected from the regional and local aquifers exposed in Wadi Al Arroub drainage basin.

The frequency histograms (Fig. 8.13-A and 8.13-B) and the results of the Kolmogorov-Smirnov (K-S) for normality (Appendix 8.7), show a normal distribution for Ca, Mg, HCO_3 and T and a asymmetrical distribution for EC, TDS, pH, DO, Na, K, Cl, SO_4, NO_3, F, PO_4, SiO_2, Fe, Cu, Mn, Pb, Cd, Zn, FC and TC.

For testing the correlation between the different variables the nonparametric Spearman's rank correlation coefficient was used since most of the variables are not normal distributed. The correlation matrix between the different variables is shown in Appendix 8.8. A summary of the positive ($+_{(0.01)}$) and negative ($-_{(0.01)}$) significant correlations at α = 0.01 and the positive ($+_{(0.05)}$) and negative ($-_{(0.05)}$) significant correlations at α = 0.05 is shown in Table 8.2.

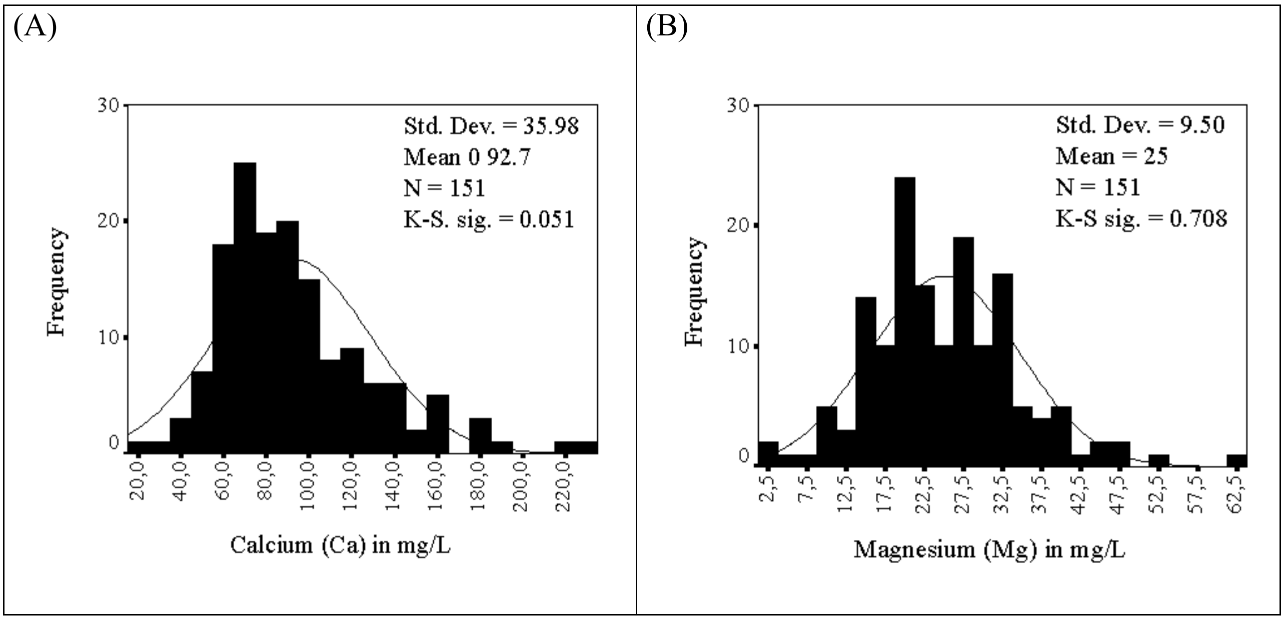


Fig. 8.13-A: Normal frequency histograms of calcium (A) and of magnesium (B).

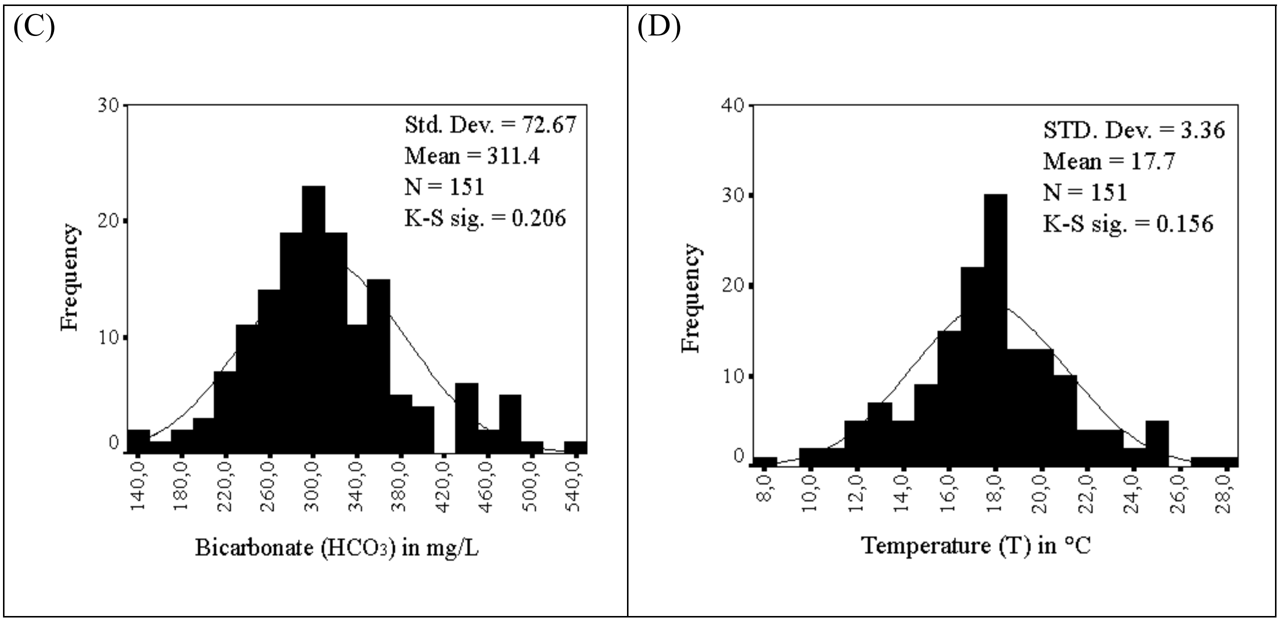


Fig. 8.13-B: Normal frequency histograms of bicarbonate (C) and of temperature (D).

Samples were collected in two different seasons, summer and winter, therefore it was very important to check whether there are significant differences in the mean concentrations of the different parameters between the two seasons. For this purpose and because the majority of the variable are not normal distributed, the nonparametric Mann-Whitney test was conducted. According to the fact that an error of 5 % is acceptable, a calculated significance higher than the significance level ($\alpha = 0.05$) indicates no significant difference between the means of the two seasons for the parameters studied. The results of this test tabulated in Appendix 8.9 showed that there are no significant differences between the mean concentration of all the studied parameters except the temperature and Zn. Based on this result, the available data of all springs and wells will be averaged regardless the season for further statistical analysis.

Table 8.2: Significant correlations at $\alpha = 0.01$ and $\alpha = 0.05$.

	EC	**TDS**	**Ca**	**Mg**	**Na**	**K**	**HCO_3**	**Cl**	**SO_4**	**NO_3**	**SiO_2**	**PO_4**
EC												
TDS	$+_{(0.01)}$											
Ca	$+_{(0.01)}$	$+_{(0.01)}$										
Mg	$+_{(0.01)}$	$+_{(0.01)}$	$+_{(0.01)}$									
Na	$+_{(0.01)}$	$+_{(0.01)}$	$+_{(0.01)}$	$+_{(0.01)}$								
K	$+_{(0.01)}$	$+_{(0.01)}$	$+_{(0.01)}$	$+_{(0.01)}$	$+_{(0.01)}$							
HCO_3	$+_{(0.01)}$	$+_{(0.01)}$	$+_{(0.01)}$	$+_{(0.01)}$	$+_{(0.01)}$	$+_{(0.05)}$						
Cl	$+_{(0.01)}$	$+_{(0.01)}$	$+_{(0.01)}$	$+_{(0.01)}$	$+_{(0.01)}$	$+_{(0.01)}$	$+_{(0.01)}$					
SO_4	$+_{(0.01)}$	$+_{(0.01)}$	$+_{(0.01)}$	$+_{(0.01)}$	$+_{(0.01)}$	$+_{(0.01)}$	$+_{(0.01)}$	$+_{(0.01)}$				
NO_3	$+_{(0.01)}$	$+_{(0.01)}$	$+_{(0.01)}$	$+_{(0.01)}$	$+_{(0.01)}$	$+_{(0.01)}$	$+_{(0.01)}$	$+_{(0.01)}$	$+_{(0.01)}$			
SiO_2												
PO_4	$+_{(0.05)}$	$+_{(0.05)}$				$+_{(0.05)}$	$+_{(0.05)}$			$+_{(0.01)}$	$-_{(0.05)}$	
Fe										$+_{(0.05)}$		$+_{(0.05)}$
Cu												
Mn		$+_{(0.05)}$			$+_{(0.05)}$	$+_{(0.01)}$	$+_{(0.05)}$			$+_{(0.01)}$		$+_{(0.01)}$
Pb				$-_{(0.01)}$			$-_{(0.05)}$					

8.1.4.1 Cluster analysis

The cluster analysis was conducted using the statistical package (STATISTICA 5 for windows 1995). The Euclidean distance as similarity measurement together with Ward's method for linkage were found to produce the most distinctive groups where each member within the group is more similar to its fellow members than to any member from outside the group. A dendrogram of Q-mode cluster analysis (Fig. 8.14) presenting the grouping of the wells and springs in the study area shows that the sampled springs and wells in the study area are mainly divided into two group at a low clustering level (level 1), group A and group B. At a higher clustering level (level 2), group A is divided into two minor groups (group A_1 and group A_2) and at a higher clustering level (level 3) group A_2 is divided into two minor groups (group A_{2a} and group A_{2b}). The similarities between the members of the groups and the groups themselves increases towards higher clustering levels. Interpretation of the four groups is summarized below:

Group A_1: this group includes the springs and dug wells that are located between the houses and are subject to contamination by waste water leaking from the widespread poorly designed cesspits. The dug well of Marina, and the springs of Misleh and El Bas-West are not located between houses, but their clustering in this group could be attributed to their contamination by the animal manure used as fertilizer in the nearby fields. This group is characterized by degraded water quality compared to the two subgroups (A_{2a} and A_{2b})

Group A_{2a}: this group includes the deep wells of Herodion Beit Fajjar well field which is characterized by good water quality.

Group 2_{Ab}: includes all the springs and wells that are separated from the waste water conduit and the housing and also of a good water quality.

Group B: includes all the dug wells close to the waste water conduit having lowest water quality of all wells and springs sampled in this study.

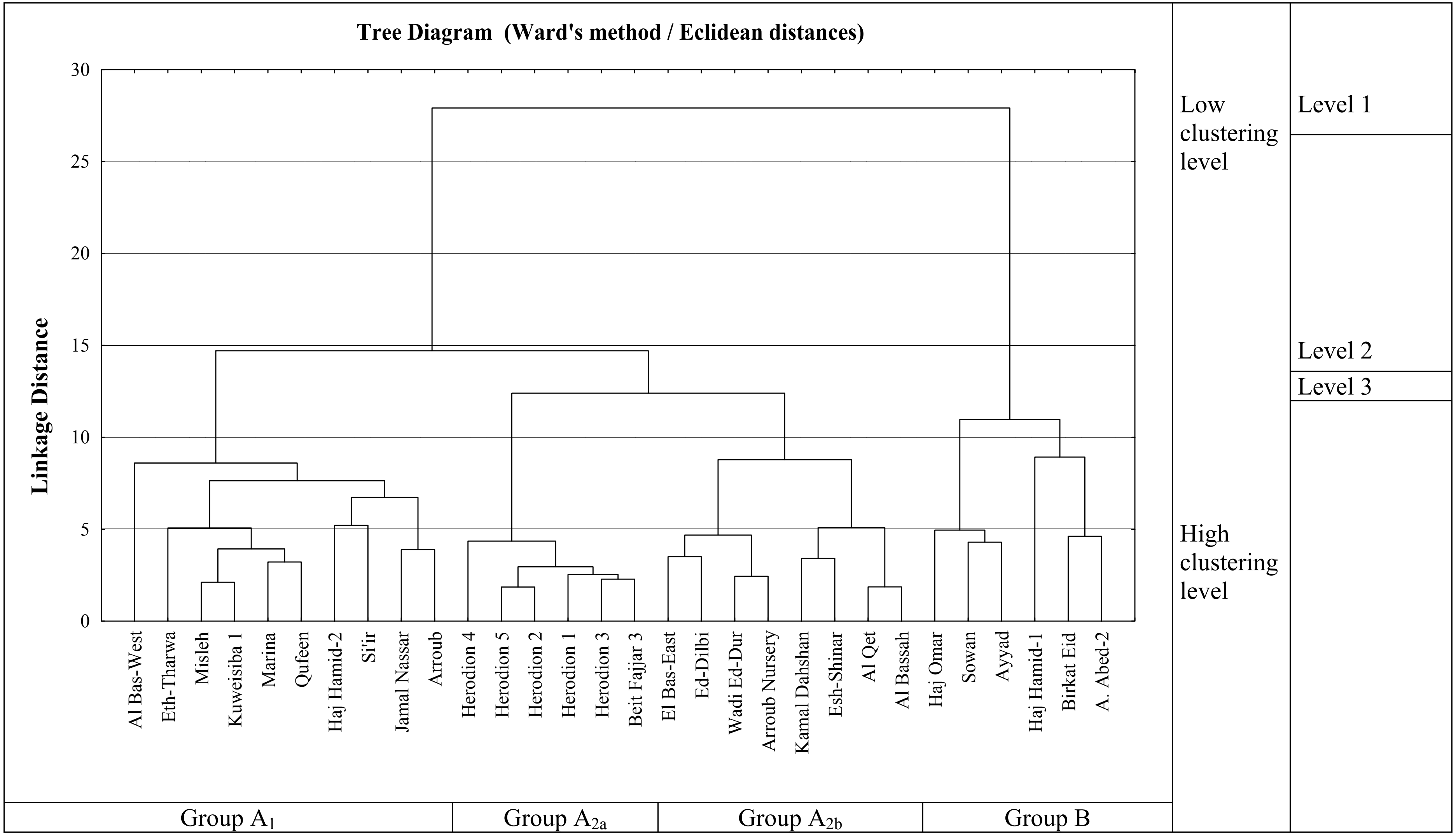


Fig. 8.14: Tree diagram (Dendrogram) of Q-mode cluster analysis showing the grouping of the wells and springs in the study area.

Results of descriptive statistics of the four groups are shown in Appendix 8.10. Collins bar diagram (Fig. 10.15) and Chernoff faces (Fig. 10.16) represent graphically the group means of the cluster analysis in meq/L - meq/L % and actual data respectively.

Supporting the results of the cluster analysis, Fig. 10.15 and Fig. 10.16 show that group A_{2a} and group A_{2b} have the maximum similarities between the four groups and that groups A_{2a} and A_{2b} have more similarities with group A1 than with group B.

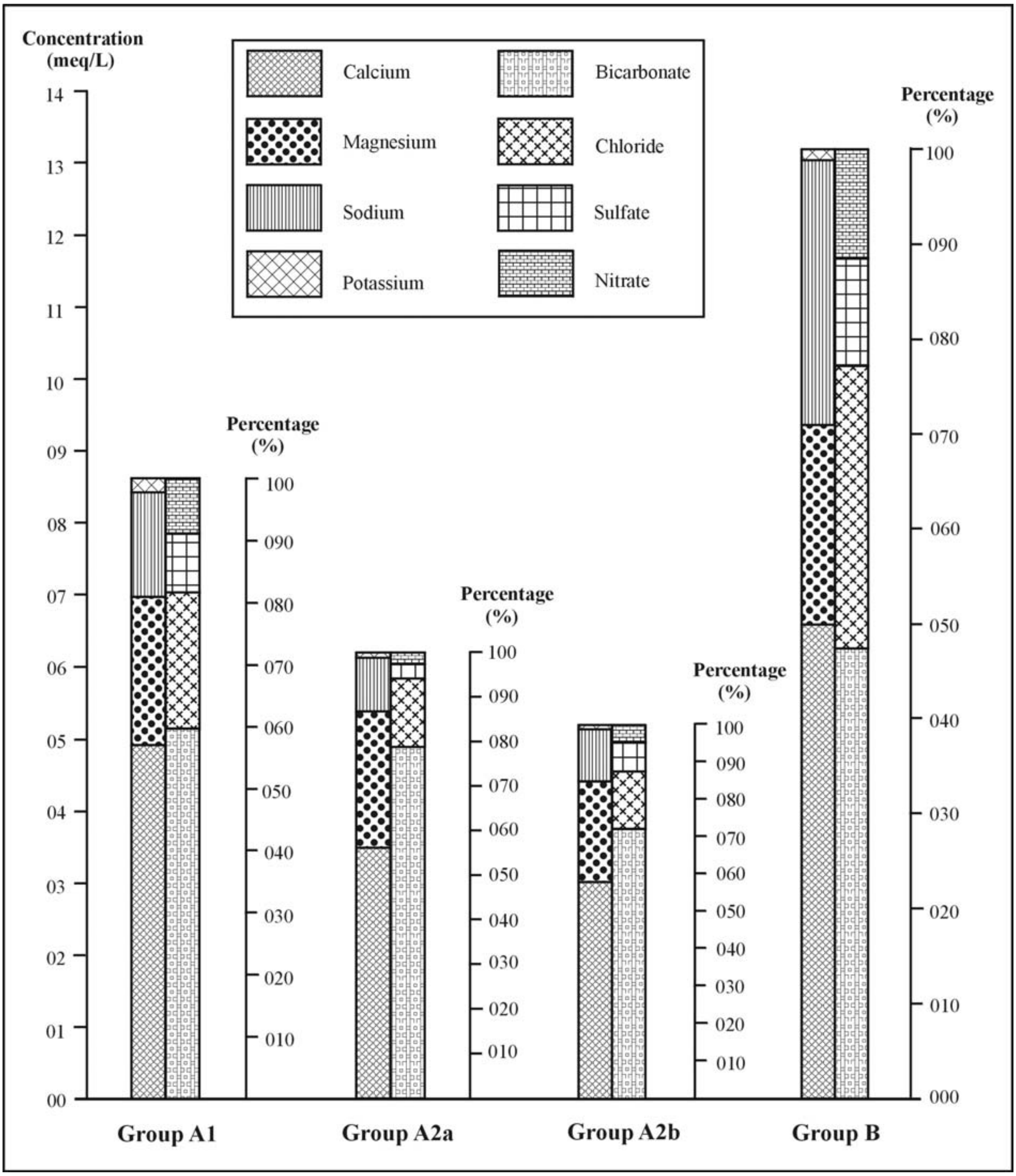
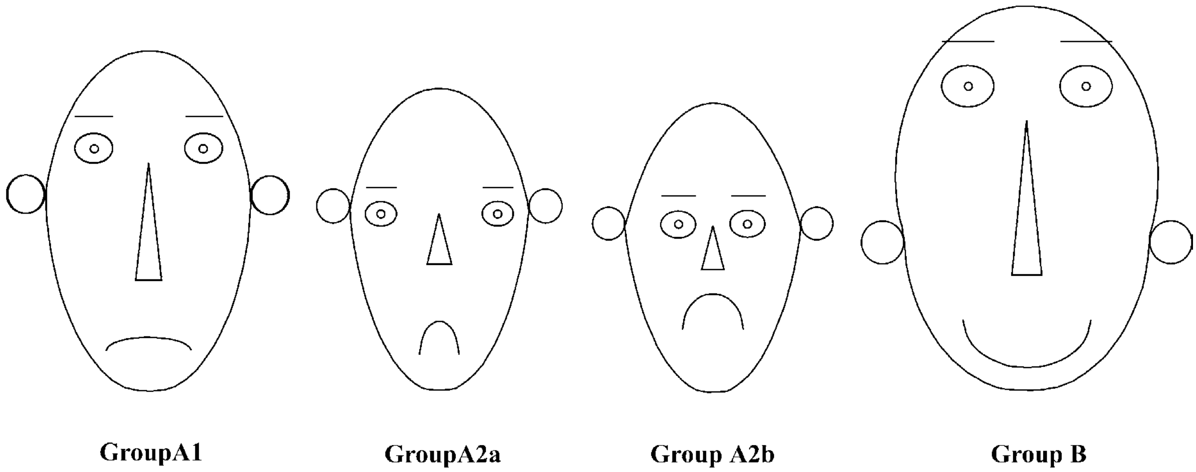


Fig. 8..15: Collins bar diagram for the major characteristics of the four groups.



Face width: EC, ear level: pH, half face height: Ca, upper face eccentricity: Mg, lower face eccentricity: Na, nose length: K, mouth center: HCO_3, mouth curvature: Cl, mouth length: SO_4, eyes height: NO_3 and eyes separation: SiO_2.

Fig 8..16: Chernoff faces presenting the main characteristics of the four groups.

8.1.4.2 Kruskal-Wallis and Mann-Whitney tests

In order to prove the differences between the four groups, the nonparametric Kruskal-Wallis test and the Mann-Whitney test were conducted using SPSS 10 for windows (1999). The results of both tests are summarized in Appendix 8.11 and 8.12.

The results of this test show that at least the mean of one group is different from the means of the other groups for all the studied parameters except for T, F, PO_4, Cu and Zn where the means of all the groups for these parameters are the similar. Because the Kruskal-Wallis test detects only for which parameters there is difference in the means between the groups and does not show between which groups, Mann-Whitney test was used to distinguish between the means of any two groups

The results of the Mann-Whitney test (Appendix 8.12) show that group (B) differs significantly, from all others. This is in concordance with the early separation within the dendrogram of cluster analysis. Differences between group (A) and group (A_{2a}) and (A_{2b}) are less significant. The least differences are between group (A_{2a}) and group (A_{2b}), which explains their clustering together at the highest clustering level.

8.2 Water quality evaluation

Water quality refers to the water chemical, biological and physical characteristics. The use of water (drinking, irrigation …etc.) is the main factor in determining the required water quality. Water is said to be good or acceptable for a special use, if its characteristics meet the standards for that use. A standard is the concentration of the constituent that does not result in significant risks (negative impact) to the health (balance) of the consumer (consuming system) over the lifetime of consumption. Short-term exceeding of deviations above the standards values do not necessarily mean that the water is unusable for consumption. The amount by which and the period for which any standard value can be exceeded without affecting public health depends upon the specific substance involved (WHO 1995). In this chapter the water quality of the springs wells, network sampled from the area of Wadi Al Arroub drainage basin will be evaluated for both domestic and agricultural purposes and the waste water will be evaluated for the agricultural purposes only.

8.2.1 Evaluation of water for domestic use

Drinking water standards respectively MCL's (Maximum contamination levels) differ due to different scientific knowledge, different techniques to calculate risk, economical issues (how much money is a available in a community), availability of water resources, nature of the water resource, and the political situation. Therefore variations between the WHO guideline and national standards are common. The 2001 Palestinian standards (PWA 2001) and the WHO (1996) guidelines that are shown in Appendix 8.13 will be used as guides for the water quality evaluation of using the water of the studied resources for domestic purposes.

8.2.1.1 Biological quality evaluation

Waterborne pathogens that cause disease fall into three general classes: bacteria (i.e. Salmonella, Shigella, Eschericia coli and coliform bacteria, Vibrio), viruses (i.e. Reovirus, Hepatitis A, Norwalk-like) and parasitic protozoa (i.e. Giarda Lamblia, Entamoeba histolytica and Cryptosporides). Bacteria and viruses contaminate both surface and ground water, whereas parasitic protozoa appear predominantly in surface water and tap water networks respectively water reservoirs, however , especially Cryptosporides, have been found as well in ground water. Bacteria and protozoa generally induce gastrointestinal disorders with a wide range of severity. Bacteria also cause life-threatening diseases such as typhoid and cholera. Viruses cause serious diseases such as aseptic meningitis, encephalitis, poliomyelitis, hepatitis, myocarditis and diabetes (Water Quality and Health Council 2001).

According to WHO (1993), the examination for total and fecal indicator organisms is the most sensitive and specific way for assessing the hygienic quality of water, therefore this test was used in this study. Total coliform bacteria is a group of naturally occurring bacteria that are present in all surface waters. As surface water percolates through the soil, a natural filtration process takes, but soil is not removing bacteria and viruses. Due to the size of bacteria we observe a retardation process "bacteria are moving much slower than water" but they are still moving, however, due to limited survival time in this type of environment (200...400 days), it is basically a question of distance between source (cesspit) and sampling point (well). Fecal coliform bacteria are a group of bacteria which are present in sewage material. The presence of fecal coliform bacteria indicates that a fecal source such as animal feedlot run-off, septic tank or cesspool leakage, etc. is in the vicinity. Their presence also indicates that the water may be contaminated with organisms that can cause disease which represents a serious and even deathly health concern.

It is recommended by the WHO (1996) and the Palestinian (PWA 2001) standards for drinking water that the count of the total and fecal coliform bacteria must be zero in 100 ml. From the results of this study it was found that only the water of the deep wells and the network was free of coliform bacteria thus recommended for drinking. The springs and dug wells apart from housing and away from the sewage conduit showed low counts, 1-100, of both TC and FC per 100 ml. On the other hand counts between 30 and > 2000 were found in the springs between the houses such as Si'ir, Eth-Tharwa and Arroub and the dug wells along the sewage conduit, Haj Hamid, Haj Omar, Ayyad, Birkat Eid, Abed-2, indicating that the local environment of the well or the springs is the key factor in its biological contamination. From the above result it could be concluded that all the springs and dug wells are contaminated with coliform bacteria, therefore they are not suitable for drinking unless being treated. Boiling, sun disinfection, or chlorination of the water are possible treatment techniques.

8.2.1.2 Chemical and physical quality evaluation

Beside the bacterial test nitrate is a very important element to be controlled in the drinking water due to its negative effects on the human health especially infants less than 2 years old, when drinking water containing elevated amounts of nitrate is used to mix formula or juice. The life-threatening disease called "blue-baby" syndrome or methemoglobinemia occurs when the oxygen-carrying capacity of the blood is reduced (WHO 1993). Elevated nitrate concentrations in drinking water are assumed to be responsible for an increased risk to develop stomach and intestinal cancer if consumed for long periods. This is based on the reduction of NO_3^- to NO_2^- in the stomach and intestinal tract (Wilkes University 2000). Nitrate is generally an indication of contamination from major nitrogen sources such as a sewage disposal system, animal manure, or nitrogen fertilizers. Concerning the nitrate concentration, only the dug wells closed to the conduit (Haj Hamid-1, Haj Omar, Ayyad, Birkat Eid, Sowan, Abed-2, and that are located between the houses, (Si'ir, Eth-Tharwa, Qufeen and Arroub), showed concentrations between 50 and 200 mg/L, indicating nitrate values that are much more than the acceptable limits. Thus the water of these resources is not suitable for drinking unless measures are taken to prevent the leakage of the waste water from the cesspits and the conduit to these resources (i.e. establishment of a sewer system) and the tests prove that the nitrate levels are under the acceptable limits.

Because at present there are no health standards for TDS, Na, Cl, SO_4, K in drinking water, therefore they were used as indication for the effect of the immediate environment of the dug well or spring on the quality of its water. Concerning potassium, the acceptable limits were exceeded only at the same group of springs and wells that had exceeded the nitrate levels, which could be an indication of using KNO_3 as fertilizer. May be only the dug wells of Haj Hamid and Haj Omar exceeded the acceptable limits of the TDS, but the other springs and wells of this group showed the highest values of TDS, Na, Cl and SO_4, and K among all the sampled sites, indicating leakage of waste water from the sewage conduit and the cesspits. On the other hand, all the deep wells, tap water, springs and dug wells that are far from the conduit and the housing area showed good water quality and elements concentration much below the acceptable limits of the WHO and the Palestinian standards. Therefore they are suitable for drinking.

The ratios of Ca/Cl, Mg/Cl and HCO_3/Cl are another indication that proves the negative effect of the conduit and the cesspits on the water quality of the springs and dug wells in the area. All the springs and wells that are located between the houses and those close the conduit showed ratios that are relatively lower than the other springs and wells discharging the same aquifer. That indicates an additional source of chloride, which was confidently the waste water leaking to these water resources from the cesspits and the conduit.

The result for selected trace constituents (Fe, Cu, Mn, Pb, Cd, Zn) (Appendix 8.1) show that all the sampled springs, wells and tap water contain very low concentrations that are far beyond the WHO standards and in many cases even below the detection limits. This leads to the suggestion that above named trace elements in the water resources in the study area have no health hazard potential.

The results of analyses for the volatile organic chemicals (Appendix 8.5) in the water of the springs, dug wells and waste water sampled from Wadi Al Arroub drainage basin (Appendix 8.5) show that the detected concentration of the different VOC's are generally less than 2 µg/L, except for toluene (37 mg/L) and dimethyldisulfide (37.5 µg/L) in the dug well of Birkat Eid and limonene (40 µg/L) and dimethyldisulfide (10 mg/L) in the waste water. The detected VOC's concentration are far below the WHO guidelines (1995) acceptable limits for drinking water (Appendix 8.13).

Flavor and fragrance food additives and household cleaning products are responsible for the limonene in the waste water. Toluene, o-dichlorobenzene, styrene, and trichloroethylene found in the waste water and the dug well of Birkat Eid, close to the conduit, could be attributed to the industrial waste water released to the waste water conduit from the carpentries, smitheries, garages and the plastic pipes and solar heaters factories. Toluene in the other dug wells could be attributed to spill of benzene from the old motorized pumps driving the dug wells. The microbial and algal decomposition of sulfur compounds (i.e. methionen and cystine amino acids) of the waste water and animal dugs are responsible for the sulfide compounds (dimethyldisulfide, dimethylsulfide and diethyldisulfide) recorded in the waste water. Contamination of the dug wells by waste water and leaching of the animal dung explains their sulfide compound contents. Methylene chloride (dichloromethane) in the dug well of Birkat Eid and the springs of Arroub is possibly a reaction product of the sodium hypo chloride (used in the kitchen and laundry) with organic matter. Both water resources are subjected to impacts of domestic waste water rich in organics and sodium hypo chloride, from the waste water conduit and the poor cesspits.

Finally, in this study, not all of the wells along the conduit and not all the springs between the houses were sampled, but from the results of their representative sampled locations, it can be generalized that the springs and wells located between the houses and along the sewage conduit are contaminated by the water leaking from the conduit and cesspits and thus not suitable for drinking unless management measures are taken to protect these resources and recent tests proved their suitability.

8.2.2 Evaluation of water quality for irrigation uses

The suitability of water for irrigation is determined by its mineral constituents and the type of the plant and soil to be irrigated. Many water constituents are considered as macro or micro nutrients for plants, so direct single evaluation of any constituent of these will not be of great value except if complete analysis of soil and determination of plant need are done. Due to that more generalized criteria, which represent combinations of the different water parameters, were adopted worldwide (i.e. salinity (EC), SAR, SSP and RSC) for the evaluation of water quality for irrigation purposes, and will be used in this work.

8.2.2.1 Salinity

Excess salt increases the osmotic pressure of the soil water and produces conditions that keep the roots from absorbing water. This results in a physiological drought condition. Even though the soil appears to have plenty of moisture, the plants may wilt because the roots do not absorb enough water to replace water lost from transpiration. Based on the EC, irrigation water can be classified into four categories (College of Agricultural Sciences 2002) as shown in Table 8.3. Based on this classification, the rain water had C1 water type, while all the deep wells, network and the majority of the springs and dug wells are of C2 water type. Only the dug wells of Jamal Nassar, Haj Omar, Haj Hamid, Birkat Eid, Ayyad, Abed-2, Ahmed Abdel Hamid, Al Marj, Qufeen, Sowan and the springs of Si'ir and Eth-Tharwa showed C3 water type. The waste water showed C3 water type in winter and C4 in summer.

Table 8.3: Classification of irrigation water based on salinity (EC) values (College of Agricultural Sciences 2002).

Level	EC (µS/cm)	Hazard and limitations
C1	< 250	low hazard; no detrimental effects on plants, and no soil build-up expected.
C2	250 - 750	sensitive plants may show stress; moderate leaching prevents salt accumulation in soil.
C3	750 - 2250	salinity will adversely affect most plants; requires selection of salt-tolerant plants, careful irrigation, good drainage, and leaching.
C4	> 2250	generally unacceptable for irrigation, except for very salt-tolerant plants, excellent drainage, frequent leaching, and intensive management.

8.2.2.2 Sodium hazard

The main problem with high sodium concentration is its effect on soil permeability and water infiltration. Sodium also contributes directly to the total salinity of the water and may be toxic to sensitive crops. The sodium hazard of irrigation water is estimated by the sodium absorption ratio (SAR), which is calculated by the following formula:

$$SAR = Na^+ / ((Ca^{2+} + Mg^{2+}) / 2)^{0.5}$$ where the cations are expressed in meq/L.

Continued use of water having a high SAR leads to a breakdown in the physical structure of the soil. The sodium replaces calcium and magnesium sorbed on clay minerals and causes dispersion of soil particles. This dispersion results in breakdown of soil aggregates and causes a cementation of the soil under drying conditions as well as preventing infiltration of rain water. Classification of irrigation water based on SAR values is shown in Table 8.4.

Table 8.4: Classification of irrigation water based on SAR values (College of Agricultural Sciences 2002).

Level	SAR	Hazard
S1	<10	no harmful effects from sodium.
S2	10-18	an appreciable sodium hazard in fine-textured soils of high CEC, but could be used on sandy soils with good permeability.
S3	18-26	harmful effects could be anticipated in most soils and amendments such as gypsum would be necessary to exchange sodium ions.
S4	>26	generally unsatisfactory for irrigation.

All the samples collected during this study belong to S1 group with SAR values < 1, except the dug wells of C3 group mentioned above showed SAR values between 1 and 3. The waste water showed SAR vales between 3 and 4 in winter and between 12 and 15 in summer, Thus the only samples belong to the S2 group are the summer waste water samples. A graphical presentation, Wilcox diagram (Wilcox 1955) presented with the help of the GWW software (United Nations 1995), of the EC and SAR water types recorded in the study area is shown in Fig. 8.17.

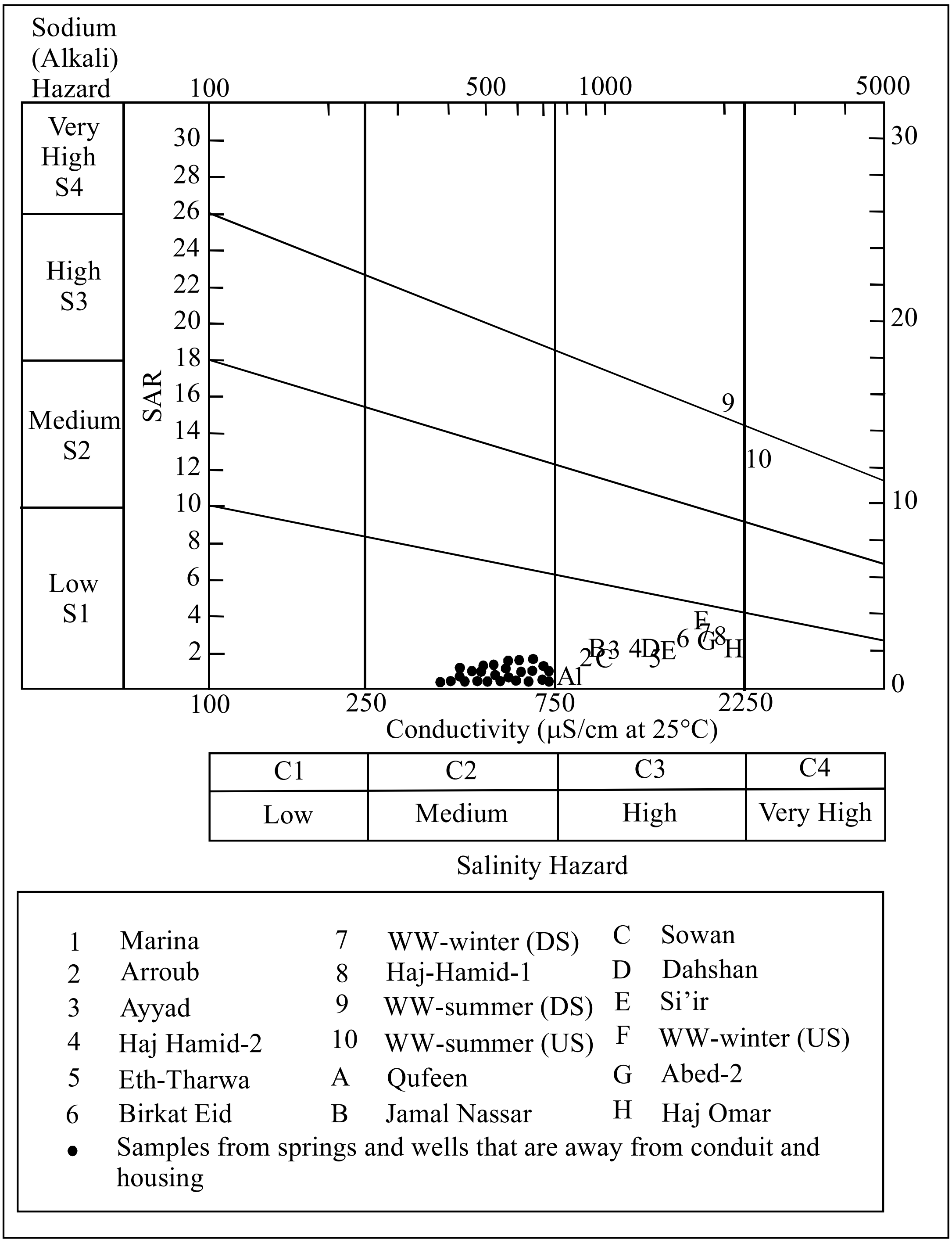


Fig. 8.17: Wilcox diagram illustrating the chemical analyses of the water samples collected from the springs, dug and deep wells, network and waste water conduit from Wadi Al Arroub drainage basin.

8.2.2.3 Soluble sodium percentage

Soluble sodium percentage (SSP) is an estimation of the sodium hazard of irrigation water like SAR, but it expresses the percentage of sodium out of the total cations and not as SAR correlating the sodium with the Ca and Mg only. SSP is calculated by the following formula

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

where the ionic concentrations are in meq/L.

Based on Todd (1980) classification of the irrigation water according to the soluble sodium percentage (Table 8.5), it was found that all the deep wells, network samples, the springs and dug wells except those of group C2 mentioned above have a SSP values less than 20 indicating excellent irrigation water type. The springs and wells of group C3 showed SSP values between 20 and 40 indicating good irrigation water type. Rain water belongs to this group with SSP values ranging between 21 and 26. In winter, the waste water showed values of SSP between 40 and 45 indicating permissible water type, while in summer they showed SSP values between 70 and 80 indicating doubtful water type.

Table 8.5: Classification of irrigation water based on SSP (Todd 1980).

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

8.2.2.4 Residual sodium carbonate

The residual sodium carbonate (RSC) equals the sum of the bicarbonate and carbonate concentrations minus the sum of the calcium and magnesium ion concentrations, where the ions are expressed in meq/L. As RSC increases, much of the calcium and some magnesium is precipitated from the solution when water is applied to soil, increasing the sodium percentages and the rate of sorption of sodium on soil particles which increases the potential for a sodium hazard. The degree of sodium hazard based on RSC is shown in Table 8.6.

Table 8.6: Classification of irrigation water based on RSC values (College of Agricultural Sciences 2002).

RSC	**Hazard**
< 0	none.
0-1.25	low, with some removal of calcium and magnesium from irrigation water.
1.25-2.50	medium, with appreciable removal of calcium and magnesium from irrigation water.
> 2.50	high, with most calcium and magnesium removed leaving sodium to accumulate.

All the samples analyzed during this study showed RSC values less than zero indicating that sodium build-up is unlikely since sufficient calcium and magnesium are in excess of what can be precipitated as carbonates when the water is applied to the soil. Based on the EC, SAR, SSP and SCR the water of the springs, dug wells, deep wells and network in the study area is of excellent to good irrigation water quality. The water of dug wells of Jamal Nassar, Haj Omar, Haj Hamid, Birkat Eid, Ayyad, Abed-2, Ahmed Abdel Hamid, Al Marj, Qufeen, Sowan and the springs of Si'ir and Eth-Tharwa is of low irrigation water quality and could result in sodium hazards when used for long time, especially as the soils are of fine textures. The waste water is of bad irrigation water quality as it has the high values of EC, SAR, RSC and SSP, so it is not recommended to be used for irrigation in fine-textured soils and with sensitive plants.

8.3 Chemical equilibrium and saturation indices

The quality of the recharge water and its interactions with soil and rocks during its percolation and its storage in the aquifers are key factors in the chemistry of ground water. These interactions involve mainly dissolution and precipitation processes, which are controlled by the solubility products of the different involved mineral phases. Generally, the saturation indices (SI) are used to express the tendency of water towards precipitation or dissolution. The saturation indices (SI) of the sampled collected in this study were calculated for the major mineral phases using the software package (PHREEQC for windows version 1.5.08) (Parkurst and Appelo 2001). The average saturation indices of the four water groups discussed above are summarized in Table 8.7.

Table 8.7 shows that all the water of the four clustering groups of springs and wells is supersaturated with respect to the main carbonate mineral (calcite, aragonite and dolomite) as well as with respect to quartz, hematite, goethite and $Fe(OH)_3$. Calcite, aragonite, and dolomite represents the major sediments that built-up the geology of the study area. Quartz is another indicator for the effect of the geology of the water type (chert bands in the limestone and dolomite of the area) as well as the aluminium silicates built-up the local soils (feldspar, kaolinite). Saturation with respect to the iron mineral phases (hematite, goethite and $Fe(OH)_3$ reflects the sensitivity of the Fe to oxidation even if its is in low concentrations. The saturation of the water of group A1 and group B with respect to hydroxyapatite suggests additional source of phosphate which could be the waste water and the fertilizers (super phosphate 20 % P_2O_5).

8.4 Corrosivity and scale forming

Corrosion is a complex series of reactions between water and metal surfaces and materials in which the water is stored or transported. The corrosion process is an oxidation/reduction reaction that returns refined or processed metals to their more stable ore state. The primary concerns of the corrosion potential of water include the potential presence of toxic metals as lead and copper; deterioration and damage to the household plumbing, and aesthetic problems such as: stained laundry, bitter taste, and greenish-blue stains around basins and drains. In soft water corrosion occurs because of the lack of dissolved cations such as calcium and magnesium while in hard water a precipitate or coating of calcium or magnesium carbonate forms inside of the piping. This coating can inhibit the corrosion of the pipe, because it acts as a barrier, but it can also clog the pipe. Water with high levels of sodium, chloride, or other ions will increase the conductivity of the water and promoting corrosion (Wilkes University 2002).

Table 8.7: Dissociation reactions, equilibrium constants, enthalpies (ΔH) (Freeze and Cherry 1979 and Parkurst and Appelo 2001) and the averages of the saturation indices (SI) for the main minerals of the four water groups (clusters).

Phase	**Master Species**	**Log K**	**ΔH Kcal**	**Saturation indices (SI)**			
				A_1	A_{2a}	A_{2b}	B
Calcite	$CaCO_3 = CO_3^{2-} + Ca^{2+}$	-8.48	-2.297	0.72	0.43	0.30	0.79
Aragonite	$CaCO_3 = CO_3^{2-} + Ca^{2+}$	-8.336	-2.589	0.57	0.29	0.15	0.64
Dolomite	$CaMg(CO_3)_2 = 2\ CO_3^{2-} + Ca^{2+} + Mg^{2+}$	-17.09	-9.436	1.07	0.64	0.26	1.17
Siderite	$FeCO_3 = Fe^{2+} + CO_3^{2-}$	-10.890	-2.480	-2.32	-1.92	-2.19	-1.82
Gypsum	$CaSO_4.2H_2O = Ca^{2+} + SO_4^{2-} + 2\ H_2O$	-4.58	-0.109	-1.99	-2.62	-2.38	-1.65
Anhydrite	$Ca\ SO_4 = Ca^{2+} + SO_4^{2-}$	-4.36	-1.710	-2.23	-2.86	-2.63	-1.90
Hydroxyapatite	$Ca_5(PO_4)_3OH + 4\ H^+ = H_2O + 3\ HPO_4^{2-} + 5\ Ca^{2+}$	-3.421	-36.155	0.93	-0.09	-0.39	1.23
Fluorite	$CaF_2 = Ca^{2+} + 2\ F^-$	-10.6	4.690	-2.64	-2.80	-2.86	-2.36
SiO_2(a)	$SiO_2 + 2\ H_2O = H_4SiO_4$	-2.71	3.340	-0.82	-0.72	-1.23	-0.92
Quartz	$SiO_2 + 2\ H_2O = H_4SiO_4$	-3.98	5.990	0.48	0.57	0.08	0.39
Chrysotile	$Mg_3Si_2O_5(OH)_4 + 6\ H^+ = 2\ H_4SiO_4 + 3\ Mg^{2+}$	32.2	-46.800	-2.70	-3.44	-4.74	-3.50
Hematite	$Fe_2O_3 + 6\ H^+ = 2\ Fe^{3+} + 3\ H_2O$	-4.008	-30.845	15.77	15.93	15.74	16.04
$Fe(OH)_3$ (a)	$Fe(OH)_3 + 3\ H^+ = Fe^{3+} + 3\ H_2O$	4.891		1.27	1.33	1.30	1.49
Vivianite	$Fe_3(PO_4)_2.8H_2O = 3\ Fe^{2+} + 2\ PO_4^{3-} + 8\ H_2O$	-36.0		-10.66	-9.17	-9.73	-9.09
Pyrochroite	$Mn(OH)_2 + 2\ H^+ = Mn^{2+} + 2\ H_2O$	15.2		-6.99	-7.38	-6.99	-7.01
Melanterite	$FeSO_4.7H_2O = 7\ H_2O + Fe^{2+} + SO_4^{2-}$	-2.209	4.910	-9.71	-9.65	-9.54	-8.93
Jarosite-K	$KFe_3(SO_4)_2(OH)_6 + 6\ H^+ = 3\ Fe^{3+} + 6\ H_2O + K^+ + 2\ SO_4^{2-}$	-9.21	-31.280	-8.25	-8.64	-8.72	-6.59
$Zn(OH)_2$ (e)	$Zn(OH)_2 + 2\ H^+ = Zn^{2+} + 2\ H_2O$	11.5		-3.37	-3.67	-3.39	-3.49
Smithsonite	$ZnCO_3 = Zn^{2+} + CO_3^{2-}$	-10.0	-4.36	-2.60	-2.72	-2.66	-2.57
Willemite	$Zn_2SiO_4 + 4\ H^+ = 2\ Zn^{2+} + H_4SiO_4$	15.33	-33.37	-3.28	-3.71	-3.84	-3.79
Cerrusite	$PbCO_3 = Pb^{2+} + CO_3^{2-}$	-13.13	4.86	-1.90	-2.16	-1.82	-1.99
$Pb(OH)_2$	$Pb(OH)_2 + 2\ H^+ = Pb^{2+} + 2\ H_2O$	8.15	-13.99	-2.89	-3.27	-2.82	-3.23

In most cases the aggressiveness of water refers to the carbonic acid, therefore the Δ pH was used as a mean of evaluating water quality data to determine if the water has a tendency to be corrosive or scale forming. The Δ pH is given by:

$$\Delta\ pH = pH - pH_c$$

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

The pH_c-values of the samples analyzed during this study was calculated with the help PHREEQC. Table 8.8 shows the classification of the water resources which were sampled during this study according to their agressivity and scale forming tendency based on the ΔpH values.

Table 8.8: The classification of the water collected from the different water resources in the study area based on its corrosivity and scale forming tendency.

Water resource		ΔpH	Average Δ pH	Agressivity
Rain water		-2.01 - -1.74	-1.85	Aggressive
Tap water		0.04 – 0.36	0.18	Balanced to scale forming
Deep wells	Albian	0.01 – 0.88	0.39	Balanced to scale forming
	Cenomanian-Turonian	0.07 – 0.77	0.40	Balanced to scale forming
Perched aquifers	Arroub upper	0.09 – 1.14	0.62	Balanced to scale forming
	Arroub lower	0.02 – 1.06	0.55	Balanced to scale forming
	Cen. upper	0.22 – 0.72	0.44	Scale forming
	Cenomanian lower	0.37 – 0.94	0.58	Scale forming
	Halhul Albian	0.23 – 1.13	0.71	Scale forming
Waste water		0.35 – 1.45	0.90	Scale forming

Table 8.8 shows that only the rain water is aggressive while the water of all the other resources is balanced to scale forming and scale forming water.

Based on the Wilkes University (2002) classification using the saturation indices as indicator of water agressivity or scale forming, the water of the different resources sampled in this study ranges between moderately corrosive, represented by the rain water and balanced to mild scaling represented by the water of all the other resources (springs, dug deep wells and even the waste water). This classification is shown in Table 8.9.

8.5 Mixing

Section (8.2.1.2) shows that the water of the springs and dug wells located between houses and those along the waste water conduit are not suitable for drinking mainly because of the bacterial contamination and the high concentrations of nitrate. The mixing models in this section mainly aims to lower the high nitrate concentration in the water of above springs and wells to levels that are below the acceptable levels of nitrates according to WHO guidelines for drinking water (50 mg/L according to the WHO 1995). The mixing could be done in the house cisterns and the roof tanks.

Table 8.9: The classification of the water sampled from the different water resources in the study area based on its tendency to be corrosive.

Water resource		**SI Calcite**	**Corrosivity**
Rain water		-3.2 - -2.1	Moderately corrosive
Tap water		0.4 - 1.7	Faint coating to mild scale forming
Deep wells	Albian	0.02 - 1.1	Balanced to mild scale forming
	Cenomanian -Turonian	0.09 - 0.9	Balanced to mild scale forming
Perched aquifers	Arroub upper aquifer	0.2 - 1.0	Faint coating to mild scale forming
	Arroub lower aquifer	0.02 - 1.4	Balanced to mild scale forming
	Cenomanian upper aquifer	0.3 - 0.85	Faint coating to mild scale forming
	Cenomanian lower aquifer	0.4 - 1.2	Faint coating to mild scale forming
	Halhul Albian aquifer	0.3 - 1.3	Faint coating to mild scale forming
Waste water		0.4 - 1.7	Faint coating to mild scale forming

In this section the spring of Si'ir represents the springs between houses and the dug well of Haj Hamid represents the dug wells along the waste water conduit. The averaged chemical composition of the water of the spring of Si'ir and the dug well of Haj Hamid was mixed with different percentages (0.9:0.1, 0.8:0.2,..., 0.1:0.9) with rain water, tap water and water of El Bas springs which represents the springs and wells a way from housing and conduit. The changes in the nitrate concentration in the water of the springs of Si'ir and the dug well of Haj Hamid-1 as a result of the mixing processes is summarized in Table 8.10, while the changes in the concentrations of the major cations and anions are shown in Appendix 8.14A and 8.14B.

Table 8.10 shows that 60 % or less mixing percentage of Si'ir spring water with 40 % or more of mixing water from El Bas spring, rain water and tap water is necessary to lower the nitrate concentration in the spring water to and even to less than the WHO acceptable level of nitrate in drinking water. On the other hand the percentages for the dug well of Haj Hamid-1 are ≤ 20 % with ≥ 80 % of tap water and water of El Bas springs and ≤ 30 % with ≥ 70 % of rain water.

Table 8.10: The concentration of nitrate of the Si'ir spring water and Haj Hamid-1 dug well after mixing with rain water, tap water and water of El Bas spring.

Spring / well		**Si'ir (75.1 mg NO_3 /L)**			**Haj Hamid (161.4 NO_3 mg/L)**		
Mixing water		**El Bas**	**Rain water**	**Tap water**	**El Bas**	**Rain water**	**Tap water**
		16.4 mg/L	2.6 mg/L	12.5 mg/L	16.4 mg/L	2.6 mg/L	12.5 mg/L
Mixing percentage	0.9 : 0.1	69.3	67.9	68.9	146.9	145.5	146.5
	0.8 : 0.2	63.4	60.6	62.6	132.4	129.6	131.6
	0.7 : 0.3	57.5	53.4	56.3	117.9	113.7	116.7
	0.6 : 0.4	51.6	46.1	50.1	103.4	97.9	101.8
	0.5 : 0.5	45.8	38.9	43.8	88.9	82.0	86.9
	0.4 : 0.6	39.9	31.6	37.6	74.4	66.1	72.0
	0.3 : 0.7	34.0	24.4	31.3	59.9	50.3	57.2
	0.2 : 0.8	28.2	17.1	25.0	45.4	34.4	42.3
	0.1 : 0.9	22.3	9.9	18.8	30.9	18.5	27.4

Nitrate content is only an example of the water characteristics that could be improved and controlled by mixing, thus mixing could be considered as an effective water "treatment" method.

9 ENVIRONMENTAL ISOTOPES ANALYSIS

9.1 Introduction

Environmental isotopes in ground water studies are not only used as tracers of the ground water provenance and age but to study ground water quality, geochemical evolution, recharge processes, rock-water interaction, the origin of salinity, and contaminant processes.

The isotopic fractioning during evaporation of water from the oceans and open water surfaces as well as the reverse process, condensation and rain formation, account for the most notable changes in the water isotopic pattern. These processes are responsible for the depletion of meteoric water and enrichment within lakes, plants and soil water of heavy isotopic species of H and O relative to the ocean (Clark and Fritz 1997).

The stable isotope composition of ground water is a telltale parameter which relates these waters to the site of precipitation, infiltration or to their origin from surface water or fossil ground water (Gat and Dansgaard 1972). On the other hand, radioisotopes decay provides us with a measure of circulation time, and thus ground water renewability (Gat 1996).

In this study the isotopic composition of the stable isotopes, deuterium (^{2}H) and oxygen-18 (^{18}O), and the radioactive isotope, tritium (^{3}H), in the precipitation, springs and shallow and deep wells were determined and evaluated.

9.2 Sampling and analysis

As part of a shared work between WSERU-Bethlehem University / Palestine and TU Bergakademie Freiberg / Germany, water samples from the springs and wells in the southern West Bank were collected between April and June 1998, and analyzed for their isotopic composition (^{18}O, ^{2}H and ^{3}H). From Wadi Al Arroub drainage basin, four springs, one dug and two deep wells at its northeastern border were sampled on April 30, 1998. The water samples for ^{18}O and ^{2}H were collected in 50 ml dark glass bottles and 500 ml polyethylene bottles for ^{3}H determination.

^{18}O and ^{2}H contents were determined in the labs of the Institut für Hydrologie / GSF-München, using gas source mass spectrometry with detection limits of 0.15 ‰ for ^{18}O and 1.5 ‰ for ^{2}H. The ^{3}H was analyzed in the labs of Weizman Institute / Israel, using the electrolytic enrichment with a detection limit of 0.2 TU. The reproducibility of the determination is ± 0.15 ‰, ± 1.5 ‰ and ± 0.2 ‰ for the ^{18}O, ^{2}H and ^{3}H, respectively.

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

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

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

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

9.3 Deuterium-oxygen-18 relationship

In spite the complexity of the hydrological cycle, the ^2H and ^{18}O in the precipitation and the fresh surface water correlate on a global scale. This correlation, as a best-fit line termed meteoric line, is expressed as follows:

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

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

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

Both the MWL and the MMWL are presented in Fig. 9.1.

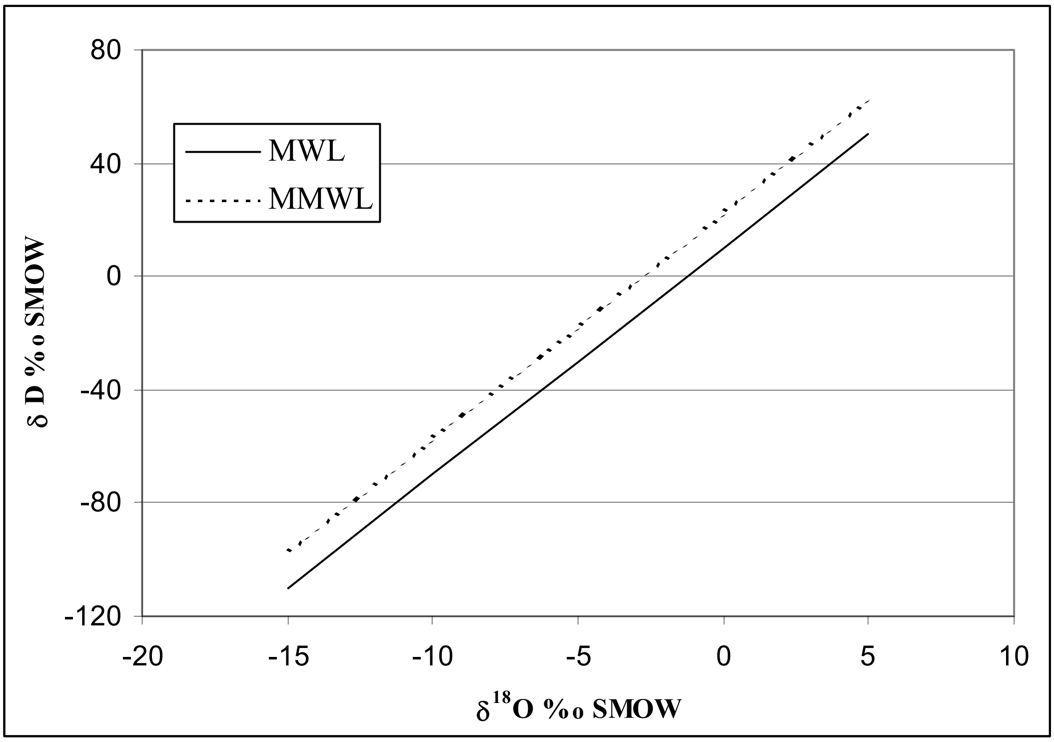


Figure 9.1: The ^2H and ^{18}O isotopic composition of precipitation and fresh surface water in the Eastern Mediterranean region compared to global meteoric line.

An important term in the $\delta\,^2H – \delta\,^{18}O$ correlation is the d-excess, which is expressed as:

$$\text{d-excess} = \delta\,^2H – 8\,\delta\,^{18}O$$

D-excess is a measure of the deuterium enrichment that exceeds the $\delta\,^{18}O$ value by more than 8 times (Clark and Fritz 1997). It is also a measure of evaporation effects both during primary evaporation, when water is evaporated to form a vapor mass, and during secondary evaporation. High d-values indicate low humidity and rapid or kinetic evaporation effects on the isotopes. Secondary evaporation of rain can only happen during rainfall in a hot, dry air column, and in this case cause a low d (usually negative) to develop (Clark and Fritz 1997 and Clark 2002).

Generally, the rain water in the Eastern Mediterranean region, part of it is the West Bank, is enriched in δ^2H relative to the meteoric water line (MWL) with a d-excess of around 22 ‰. This was attributed to the interaction of the cold and relatively dry fronts originated from the Atlantic Ocean, which is the origin of the most storm tracks reaching the Eastern Mediterranean region, with the warm and humid air above the Mediterranean Sea during winter (Gat and Dansgaard 1972; Gat and Carmi 1987 and Gat 1996).

The composition of the precipitation is reflected directly or with some modification in the composition of the ground water. These modifications are a result of secondary processes such as fractional evaporation prior to infiltration or isotope exchange with aquifer rocks at different temperatures.

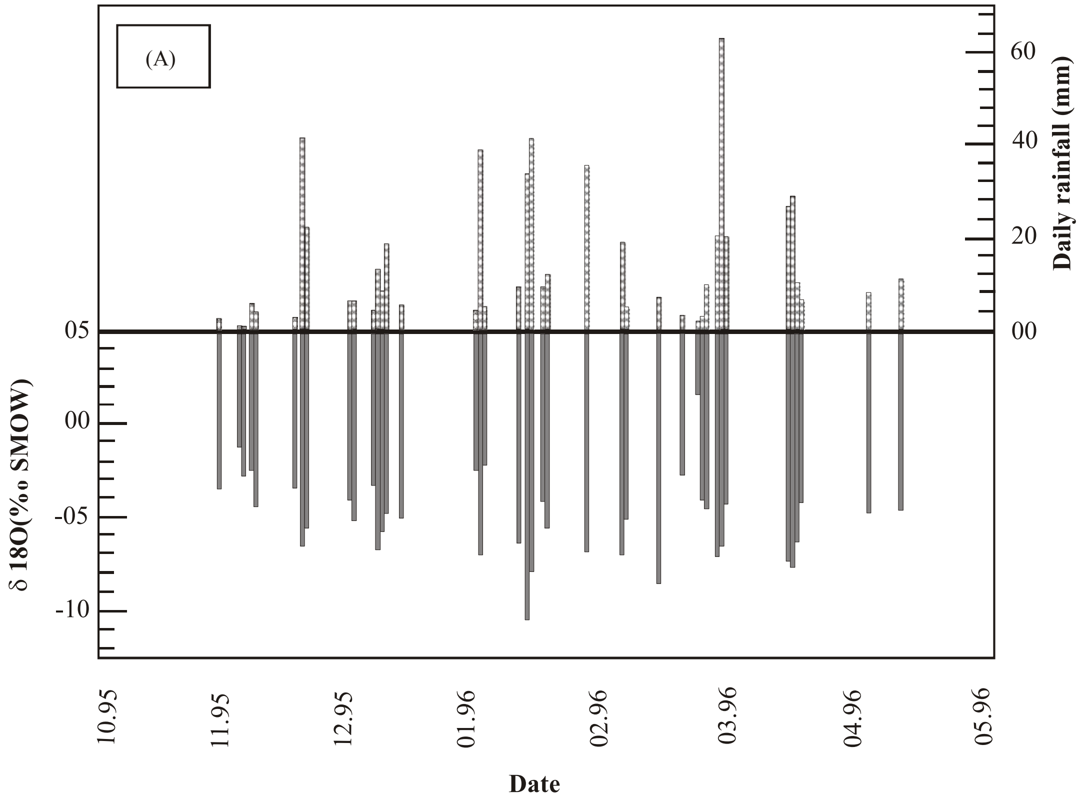
9.3.1 The ^2H and ^{18}O composition of precipitation

There are no data available about the isotopic composition of the rain water in the study area. Therefore, the results of a study that was conducted during 1995-1996 and 1996-1997 rainy seasons in an area about 10 km to the north-west of the study area will be adopted and presented here. The study was conducted on rain water of the Soreq Cave area, 152 E /129 N (Ayalon et al. (1998), for details see Fig. (9.2 and 9.3). In the above mentioned study rain water samples were collected quantitatively by allowing the water to accumulate in a large funnel to drip into a narrow-headed bottle. Generally, this type of bottles is used in order to reduce the evaporation effects on the collected rain water isotopic composition.

Fig. 9.2 shows that the most intensive rain events are correlated with the lowest isotopic composition and most depleted values are associated with the maximum rainfall amounts of the rainy season. This is attributed to the continuous depletion of the air masses by the preferential rainout of the heavy isotope species, especially when the rain originates from the same water vapor mass. It also shows that the rain water in the early and the late season is isotopically enriched, that could be attributed to the fact that the rain events at these times are of lower intensity and usually occur at higher temperatures and lower humidity compared to the rain events during the season. The range of the isotopic composition during the whole rainy season (1996-1997) varied for $\delta^{18}O$ between –12 ‰ and +4 ‰ and for δ^2H between -80 ‰ and +20 ‰.

According to Ayalon et al. (1998), the relation between $\delta^{18}O$ and δ^2H of the rain water is a function of the amount of rainfall. Fig. 9.3 shows that the intensive rainfall events, usually more than 20 mm rainfall per event, as well as the average annual isotopic values for 1996-1997, define a slope of ~8, with a d-excess of 20-30 ‰, whereas light rain showers form a trend along evaporation line with a slope of < 8 and d-excess of < 20 ‰. These deviations from the MMWL, are consequences of evaporation processes happening to rain drops during their fall from the cloud to the ground (Gat 1996; Gat and Dansgaard 1972 and Gat and Carmi 1970).

The relationship between the $\delta^{18}O$ content of the rain water and the surface temperature was also studied and plotted in Fig. 9.4 showing a positive, non-linear correlation. The intensive rain events usually occur at a temperature <15°C, while the light rain events occur at a temperature >15°C. As the rain intensity is in a negative relation with the $\delta^{18}O$, and in a negative relation with the surface temperature, consequently the $\delta^{18}O$ is positively correlated relation with surface temperature.



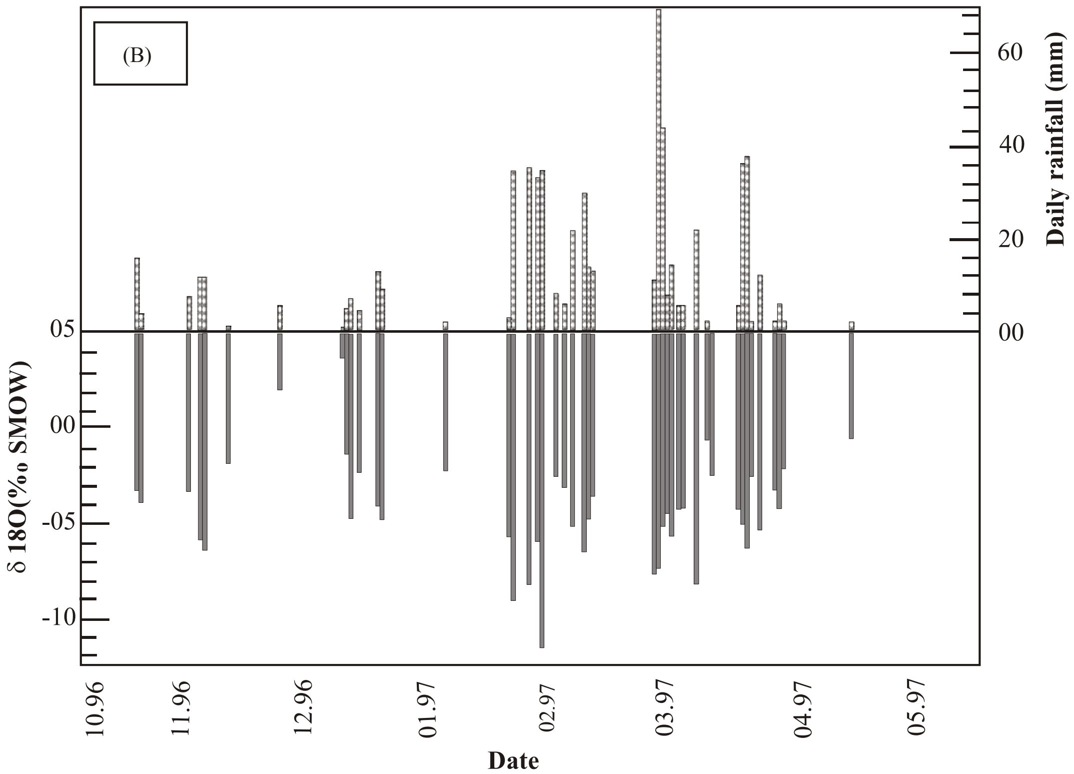


Fig. 9.2: The $\delta^{18}O$ and the daily amount of the rainfall, showing the difference in the pattern, mount and distribution of the rainfall events during the seasons (A) 1995-1996 (B) 1996-1997 (Ayalon et al. 1998).

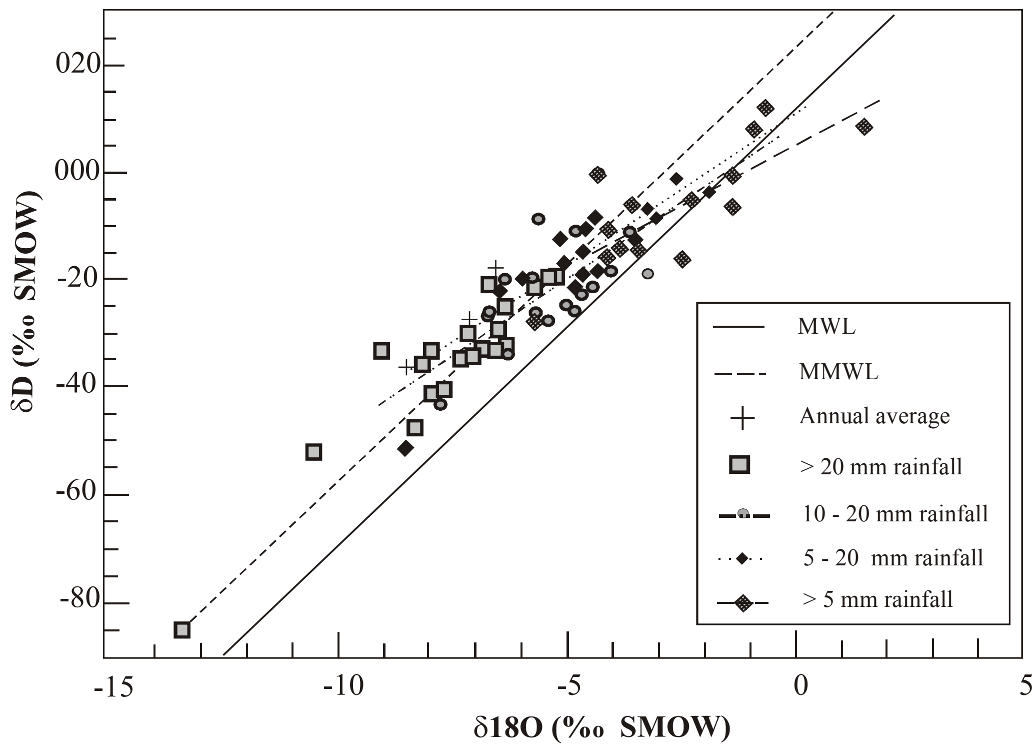


Fig. 9.3: The δ^2H versus $\delta 1^8O$ relationship of the rain water during the two rainy seasons (Ayalon et al. 1998).

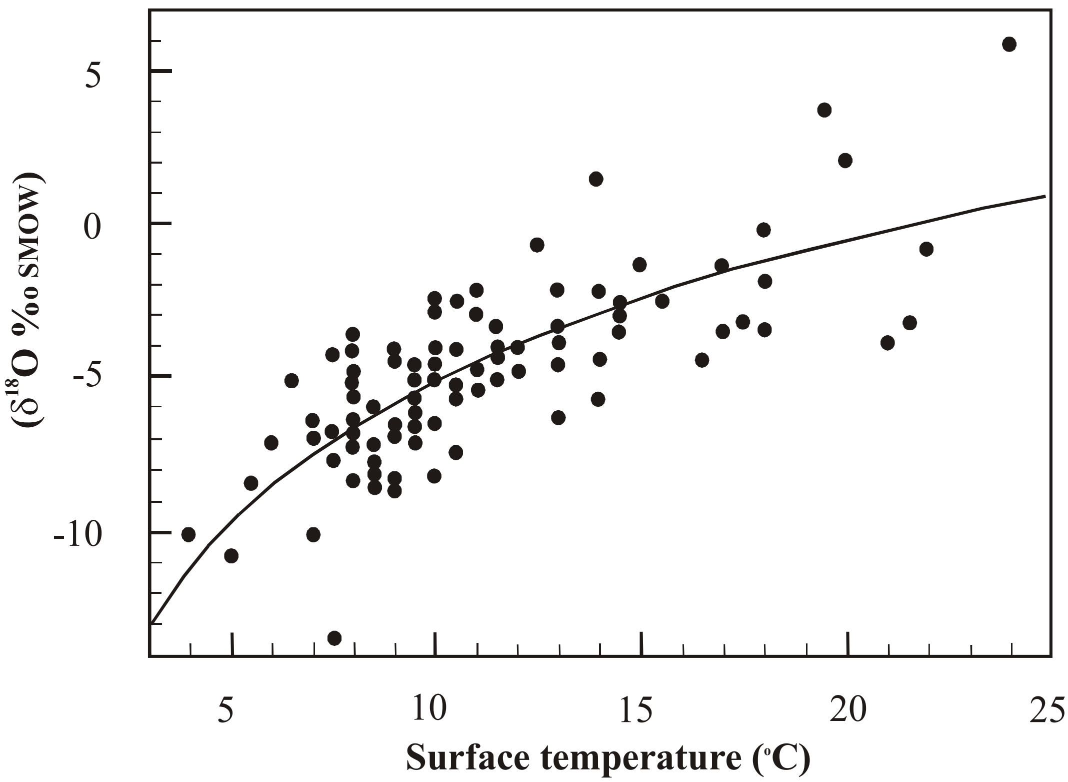


Fig. 9.4: Variation of $\delta^{18}O$ of rain water as a function of the surface temperature, showing non-linear correlation (Ayalon et al. 1998).

9.3.2 The ^2H and ^{18}O composition of the springs and wells

Table 9.1 shows results of the analyses for ^{18}O and ^2H of the samples collected on April, 30th 1998 from Wadi Al Arroub drainage basin. The relation between $\delta^{18}O$ and $\delta\,^2H$ of these samples is presented in Fig. 9.5.

Table 9.1: The ^{18}O and ^2H composition of the samples collected from Wadi Al Arroub drainage basin (April, 30th 1998).

Spring / Well		Elevation (masl)	W.L. (masl)	δ^2H	$\delta^{18}O$	d-excess
Haj Hamid	dug well	817	814	-23.8	-5.56	20.7
El Bas - West	spring	855	855	-28.0	-6.16	21.3
Dilbi	spring	819	819	-28.1	-6.22	21.7
Wadi El Dur	spring	843	843	-25.1	-5.87	21.9
Herodion 4	deep well	685	303	-26.2	-5.89	20.9
Beit Fajjar 3	deep well	728	570	-25.8	-5.78	20.5
Misleh	spring	907	907	-24.4	-5.64	20.7
Average				-25.9	-5.9	21.1

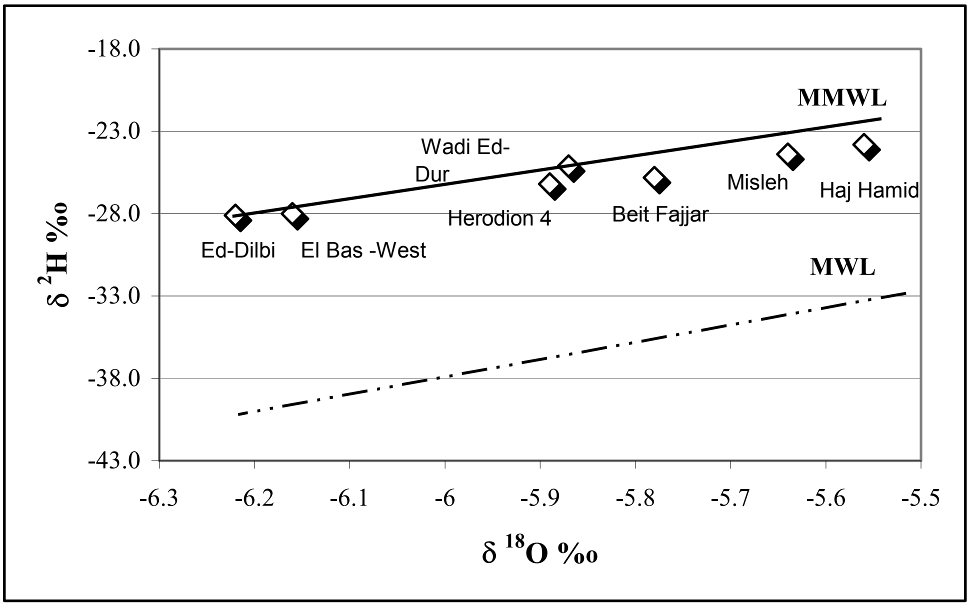


Fig. 9.5: The δ^2H versus $\delta^{18}O$ relation of the samples collected from the springs and wells of Wadi Al Arroub drainage basin compared to the MWL and the MMWL.

Table 9.1 and Fig. 9.5 show that the isotopic constituents of the water samples collected from the springs and wells distributed in the study area plot on the Mediterranean Meteoric Water Line with average values of –25.9 ‰, -5.9 ‰ and 21.1 ‰ for the δ^2H, $\delta^{18}O$ and the d-excess, respectively. This proves that the water of all these springs and wells is originating from rain water. Although the differences in isotopic compositions (δ^2H and $\delta^{18}O$) between the analyzed samples are not so large, the Haj Hamid dug-well seemed to have the most enriched isotopic composition. This could be attributed to the fact that the Haj Hamid dug-wells undergoes mixing with the waste water flowing in the wadi course of about 10 m far from the well, whereas the waste water flows in a open canal where it is subject to evaporation thus leading to the enrichment of the waste water isotopic composition. The mixing process between the well water and the waste water is also proven by the chemical constituents of the well water (see Chapter 8).

9.4 Tritium (^{3}H)

Tritium concentration in ground water provides an indication for the mean residence time of water. Accurate dating of water based on tritium is not possible, because of the spatial and temporal variation in the tritium composition of the precipitation and the complicated mixing-processes that take place in each aquifer. Generally, a piston-flow mode of recharge increases the accuracy of the water dating. In such a mode of flow a layering of recharge water exist, where the deeper layers being older than the shallower ones (Mazor 1997). But, this is not the case for unconfined and perched ground water aquifer systems in the study area.

According to Carmi and Gat (1973), the tritium concentration in the precipitation is similar for the whole West Bank and Israel. During the 1950'the tritium concentration in the precipitation of these areas was about 5 TU (Kaufman and Libby 1954). After 1953 the testing of nuclear weapons had increased the tritium level in the rainfall and consequently, ground water. This ^{3}H content of the atmosphere were peaking in 1963, after that the surface nuclear tests stopped and the tritium concentrations in precipitation decreased in general.

The variations in the tritium concentration in the precipitation in Israel, i.e. Beit Dagan 135000 E / 156000 N (IAEA 1992), are shown in Table 9.2. Under the assumption of piston flow recharge mode and no mixing and based on that the half-life of the tritium is 12.3 years, the tritium concentration which is expected to remain in the water from the initial concentration in the precipitation when it discharges in 1998 was calculated and tabulated in Table 9.2.

Table 9.2: The ^{3}H concentration in the precipitation of Israel, at Beit Dagan, and the expected remaining concentration when that water discharges at 1998.

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

* (after Kaufman and Libby 1954)

Based on Table 9.2, water that have tritium concentrations around 0.4 TU in 1998 dates back to the early 1950's. An example of this water in the study area is that of the Herodion well 4, which discharges the lower confined aquifer. Water that has 0.4 TU < ^{3}H < 3.5 TU dates back to the late 1950's to 1960. Example of this group is the Beit Fajjar well. Water of tritium values greater than 4 is expected to have contact with the atmosphere after 1963. The tritium content of the samples collected from Wadi Al Arroub drainage basin are shown in Table 9.3.

Table 9.3: The tritium concentration in the samples collected on April 30, 1998 from Wadi Al Arroub drainage basin.

Spring / Well		Elevation (masl)	W.L. (masl)	Sub-aquifer	^{3}H (TU)
Haj Hamid	dug well	817	814	Perched	3.8
El Bas - West	spring	855	855	Perched	5.7
Wadi El Dur	spring	843	843	Perched	8.7
Herodion 4	deep well	685	303	Albian	0.4
Beit Fajjar 3	deep well	728	570	Turonian-Cenomanian	1.5

Table 9.3 shows that the water of Herodion well 4 has the lowest ^{3}H content suggesting that this water is the oldest among the sampled springs and wells. Taking into consideration that all the wells and springs discharge carbonate aquifers, then the age of the water is a function of the distance traveled by the recharge water from the recharge area until being discharged by the well. As this distance to the well of Herodion 4 is the longest, then the water of this well is supposed to be of the lowest ^{3}H content. Relative to Herodion well 4, the distance to the well of Beit Fajjar is shorter then the water of this well is younger and has higher ^{3}H content (Fig. 9.6).

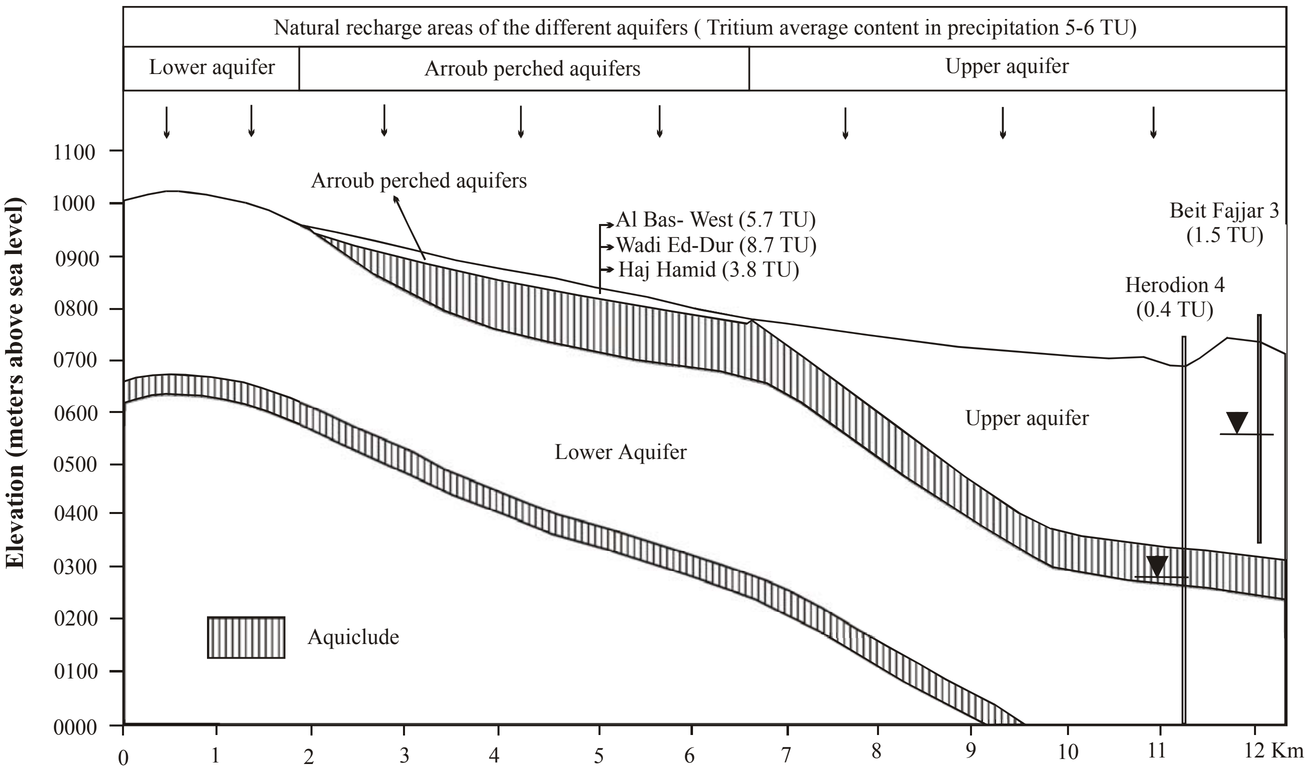


Fig. 9.6: Simplified hydrogeological section showing the recharge areas of the different aquifers discharged by the wells and springs sampled for ^{3}H during this study.

The distance traveled by the recharge water until being discharged by the springs of El Bas-West and Wadi Ed-Dur as well as the dug well of Haj Hamid is much shorter than that to the wells of Herodion and Beit Fajjar as the springs and the dug well are discharging perched aquifers, therefore their ^3H contents are higher and their water is younger.

According to a personal communications in 2002 with Israel Carmi (Weizman Institute of Science - Israel) the average tritium content in precipitation in Israel ranges between 5 and 6 TU. The spring water of El Bas-West has ^3H content of 5.7 TU suggesting recent recharge and tritium of meteoric origin. The water of this springs is possibly a mixture of the rainy events (that of high and of low tritium contents) of the last season therefore its content is close to the averaged content of precipitation.

The high tritium content of the spring water of Wadi Ed-Dur (8.7 TU) compared to the average content of precipitation (5-6 TU), could be attributed to that the water sampled from this spring represents rainy events of high tritium contents.

The water of the well of Haj Hamid, has less tritium than expected. That could be attributed to the mixing with waste water flowing in the wadi course. The waste water is mainly tap water from the deep wells of Herodion, e.g. Herodion well 4 which have low ^3H content. The mixing between waste water of low tritium content with well water of higher tritium content will produce a water with a lower content of tritium than the ground water which is directly recharged from rainfall only. In winter the waste water is being diluted with surface runoff water. So, during the winter season this well is expected to show variable ^3H levels based on the mixing between the waste water and the rainfall and between the waste water and the ground water.

According to Issar and Gat (1982), the average tritium content of the various water resources in limestone aquifers is considered to be a function of the depth of to the water table. The tritium contents of the samples were plotted against the static water levels at the sampling points (Fig. 9.7). The plot shows a positive relation between the water level and the tritium contents, proving that the different samples originated from the same recharging water (the precipitation).

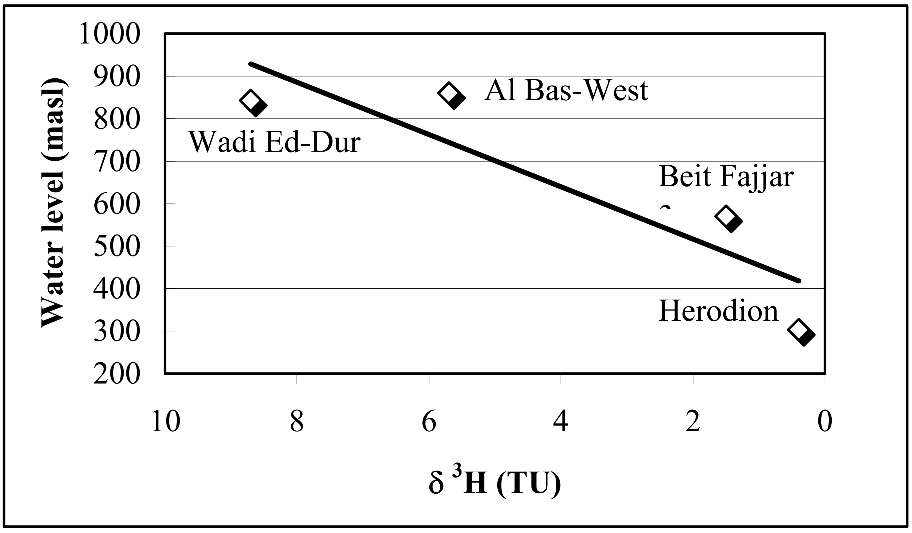


Fig. 9.7: The relationship between ^3H in TU and the static water level.

10 EXTRACTION OF SOIL WATER BY THE SUCTION-CUP METHOD

10.1 Introduction

Water in the saturated zone may be sampled by springs, wells and multi-level sampling ports, whereas it could be obtained in the unsaturated zone by suction cups, lysimeters and soil cores.

The fact that the soil in the lysimeter is isolated from the surrounding body of soil leads to the development of abnormal soil-moisture conditions. The most significant abnormality is associated with the soil-air interface, which occur at the bottom of the lysimeter. This interface prevents the development of suction of water from below, which would occur naturally if the soil column was continuous. In the absence of this suction, drainage from the bottom of the soil column is impeded until this layer of soil reaches a moisture level at or near saturation. This problem can be solved by means of suction lysimeters with suction cups or a suction plate at the bottom of the lysimeter maintaining a suction according to tensiometer readings at the bottom's depth.

The soil core sampling method is destructive and repetitive samples cannot be obtained from the same location. Whereas the suction samplers are characterized by relatively simple installation, negligible disturbance of the soil profile, the water flux and gas exchange on the soil are not hindered by the probes also continuous sampling, even at different depths within the same soil profile is possible (Grossman and Udluft 1991). According to Zabowski and Ugolini (1990), the solute concentrations in liquids obtained by centrifuging core samples are frequently higher than those from suction samplers.

The term suction cup is generally confusing, as it is being used for both the small porous body as well as for the whole sampling system, whereas the porous solid body is only part of it. Therefore in this study following what was proposed by the DVWK (1990) it will be referred to the sampling system by the term suction probe and to the soil water sampling technique by the term suction-cup method.

According to Merkel and Prömper (1984), the chemical composition of the material of the suction cups, the size and the shape of the pores and the applied vacuum are the most important factors determining the quality of the sample. The material of the suction cups should be inert in order to reduce the sorption and the ion-exchange processes between the suction cup and the surrounding. Also it should be hydrophilic so the water can infiltrate inside the suction cup under low vacuum.

Despite the worldwide usage of the suction cup method for sampling the soil water, it has never been implemented before in the West Bank. Therefore the basic science behind this method will be explained in this work.

Using the suction-cup method for sampling of the soil water in Wadi Al Arroub drainage basin – Palestine, aimed to study the changes in the inorganic and organic chemistry of the rain water as it infiltrates through the vadose zone, which will be referred to as soil water, as well as studying the effect of the waste water, flowing in the floor of the wadi, on this infiltrated rain water. To achieve these objectives, the soil water was sampled at different depths (30, 60 and 90 cm) in two locations. The first location is higher than the waste water flooding level while the second location is for sure below it.

10.2 The principles of suction samplers operation

Having a hydraulic contact between the sampler and the water films of the soil is a very important factor in the soil water sampling. Attempting to sample pore-liquid by applying suction to an open end pipe driven into the ground will fail due to the lack of hydraulic contact and only air will be drawn. But when a suction probe is installed, the pores in the wall of the suction cup will become filled with water due to capillary suction, and then the soil liquid films provide a hydraulic contact between the liquid in the pores of the cup and the soil (Fig. 10.1) (Wilson et al. 1995).

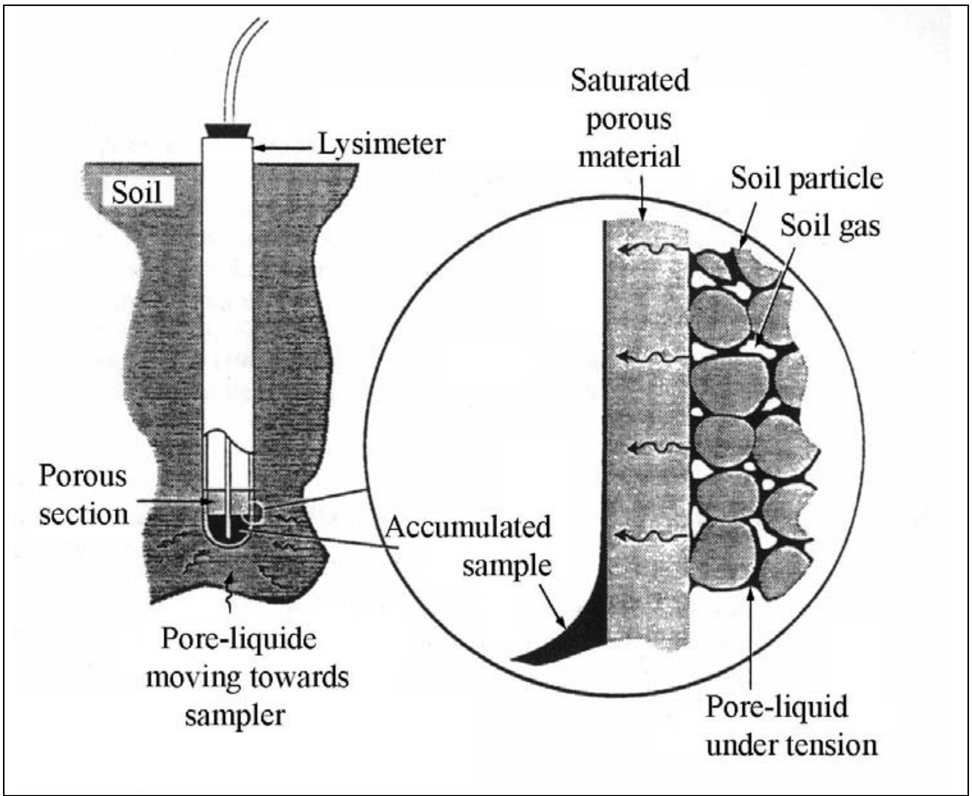


Fig. 10.1: Porous cup – soil interactions (Wilson et al. 1995).

When suction is generated within the sampling system, a pressure potential gradient towards the sampler is created. If the meniscuses of the liquid in the pores of the suction cup are able to withstand the applied suction, water flows from the soil into the suction cup until the capillary pressure in the cup and in the soil is equal. The ability of the meniscuses to withstand suction is inversely proportional to the pore size and the hydrophobicity of the suction cup. If the meniscuses cannot withstand the applied suction as a result of large pore size or great hydrophobicity they will break down and the hydraulic contact is lost and only air enters the sampler. (ASTM 1999 and Wilson, et al. 1995). Ceramic suction cups are hydrophilic and the maximum pore sizes are small enough to all the meniscuses to withstand the sampling suction up to- 800 mbar (ASTM 1999)

At low pore-liquid contents, the pore-liquid tension increases and the pressure gradient towards the sampler decreases which result in lower flow rates into the sampler. At pore-liquid tensions above 0.6 bar (for coarse grained soils) to 0.8 bar (for fine grained soils), the flow rates are effectively zero and samples cannot be collected. (ASTM 1999)

10.3 Suction and potential field

The suction in the sampling system generates a potential gradient around the suction cup, thus the seepage water flows from a specific space into the cup (Krone et al. 1952). Fig. 10.2 shows an idealized potential field for a sampler in completely homogeneous sediment with stationary flow conditions. The extent of the potential field disturbance may reach more than one meter (Germann 1972), but the actual recharge area of the suction cup, i.e. the space in which the water flows towards the cup, is always smaller. The radius of the recharge area, contained by the dividing stream line, lies between 0.1 m and 0.5 m, depending on the capillary pressure in the soil, the suction in the cup and its diameter, pore size distribution of the soil, installation depth and the depth to underlying water table. When the soil water content is low and the ground water level is sufficiently high then the flow direction may be reverse, which means the main source of seepage water is from below the suction cup (Grossmann 1988).

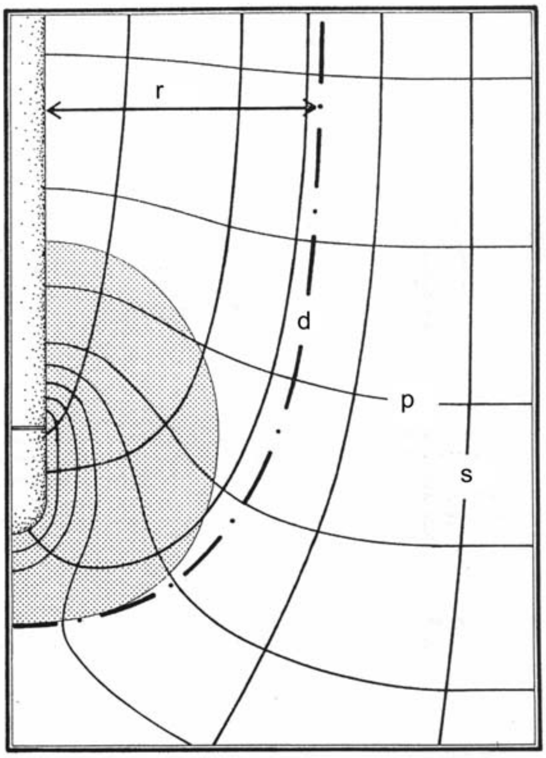


Fig. 10.2: Potential field around a suction cup in a homogeneous soil (r, radius of recharge are; d, dividing stream line; p, isopotential line; s, stream line; hatched field, space from which the sample is taken) (Grossman and Udluft 1991).

10.4 The sampling system

Generally, the sampling system consists of three functional units: the suction cup, sampling bottle and the vacuum source, out of which there are different arrangements. The most frequently used suction cups are ceramic but other cups made of aluminium oxide, glass sinter, Nylon, and Teflon are also available (Grossman et al. 1987). The suction cups used in this study are made of 99.5 % aluminium oxide sinter. The main disadvantages of this type of cups is that they are brittle and showed significant sorption of the trace elements compared to other types of cups made of Nylon or Teflon. But they were used in this study because they have no significant interactions with the organics (ASTM 1999 and Wilson et al. 1995), they are cheap in price, their hydrophilic nature allows the collection of samples from clay soil, as in the study area, at high pore liquid tensions as well as they were available at the time of the field work.

Two designs of suction probes were proposed for this study (Fig. 10.3). The main difference between both designs, is that the suction tube in design (A) teminates below the connector, whereas in design (B) it reaches the bottom of the porous cup. The suction probe (A) was the first priority, because its design allows water to accumulate in the cup which prevents air entry thereby ensuring continuous hydraulic contact between the cup and the surrounding. At the time of the fieldwork only samplers of design (B) were available for this work, therefore to save money and times these probes were used in this study.

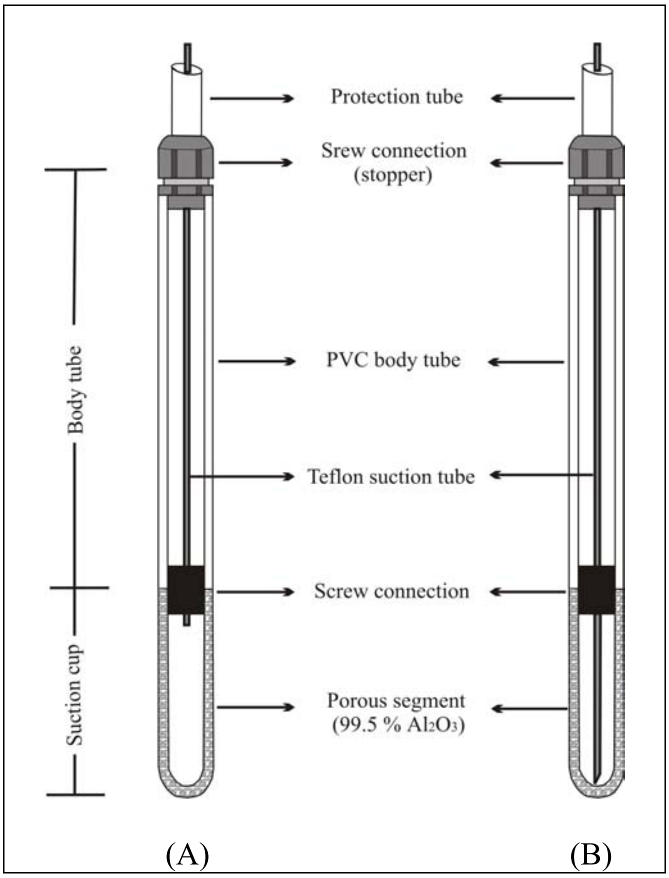


Fig. 10.3: The designs of the suction probes proposed for this study (A) after Wilson et al. (1995) and ASTM (1999) (B) after Merkel et al. (1982).

The suction probes used in this study consist of a porous cup, 24 x 19 x 60 mm, 99.5 % Al_2O_3, about 0.3 µm pore size and of 0.0-0.8 bar operational suction, mounted on the end PVC tube, which has an external diameter of 1.91 cm. The length of the tube was varied according to the desired depth of placement of the probe in the profile. The cup was attached by an epoxy adhesive with the help of a connector. A screw connection was used as stopper on the upper end of the tube. Both the connection between the cup and the tube and the stopper were tightly sealed. Soil water is sucked by means of a Teflon tube, 3.5 mm external diameter. The suction tube is connected to the sampling bottles and the vacuum pump in series. (Fig. 2.6). The different designs of the suction probes provide the possibilities of collecting the samples in both the suction cup and body tube, only in the body tube or only the suction cup as in this study.

10.5 Sampling locations and depths

During the period from January to March of the year 2000 and similarly the year 2001, two sets of sampling probes were installed in two locations in the study area, one at each side of the sewage conduit. At each location 3 sets of probes each of three were installed at 30 cm, 60 cm and 90 cm below the ground level. Both locations are in the floor of Wadi Al Arroub, 300 m southeast of Al Shat Pool and the dug well of Haj Hamid 1 (Fig. 10.4). One of the two locations was chosen to be higher than the conduit and its flooding level during the heavy rainy days, while the other is surely below. (Fig 10.5).

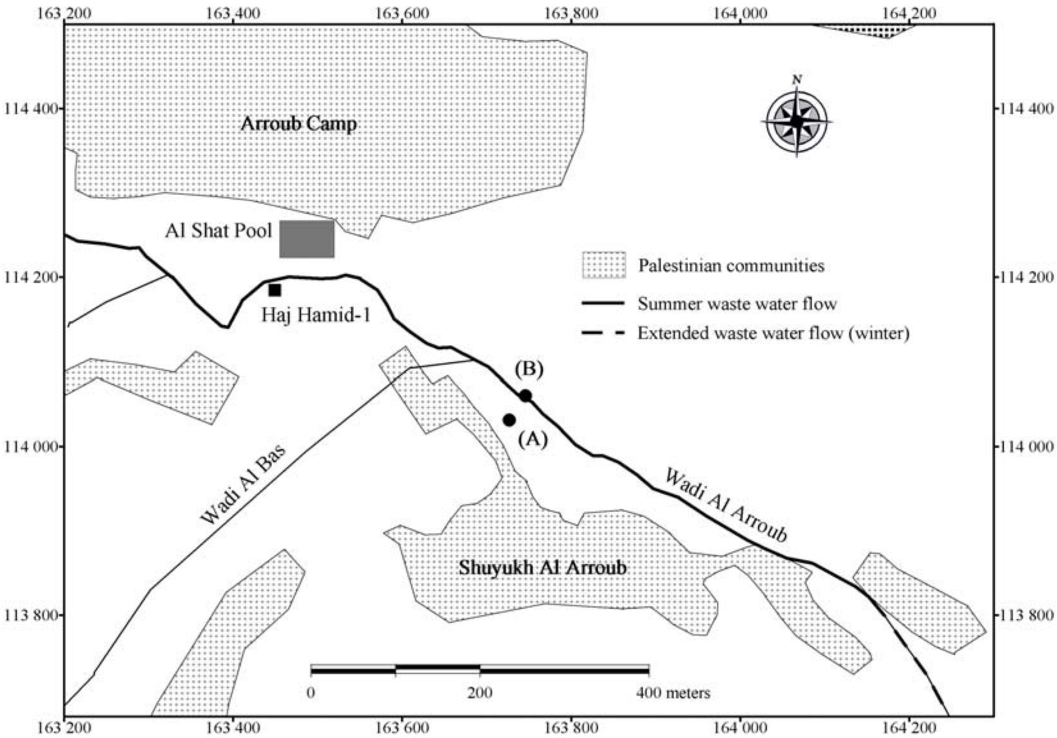


Fig. 10.4: location map of the sampling sites (A) above the conduit and (B) below it.

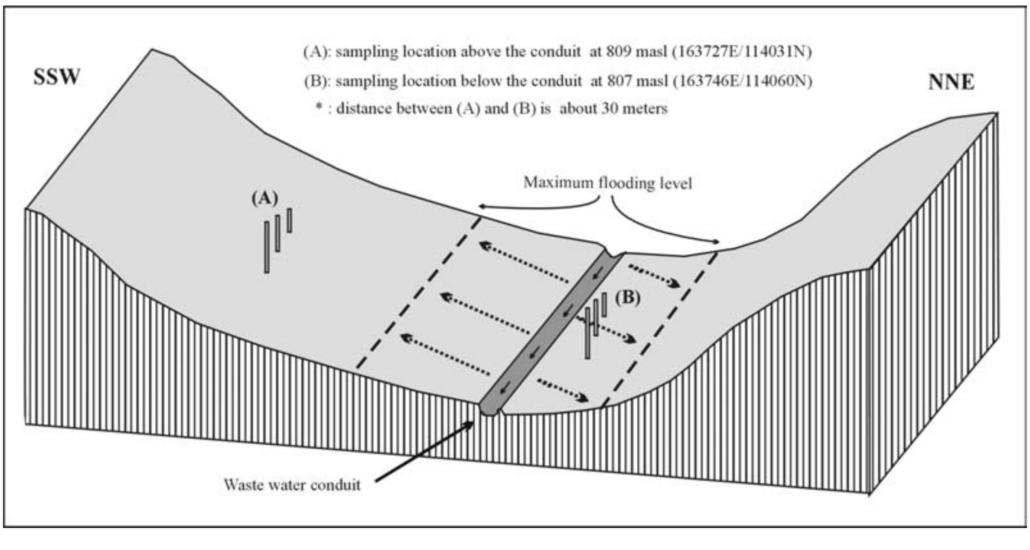


Fig. 10.5: Simplified SSE-NNW section through Wadi Al Arroub, showing the two soil water sampling locations.

10.6 Hydrochemistry of soil water

The detailed results of the field measurements and the lab analysis of the soil water samples colleted at the different depths above and below the waste water conduit are summarized in Appendix 10.1. A graphical presentation of the results is shown in Fig. 10.6 and 10.7.

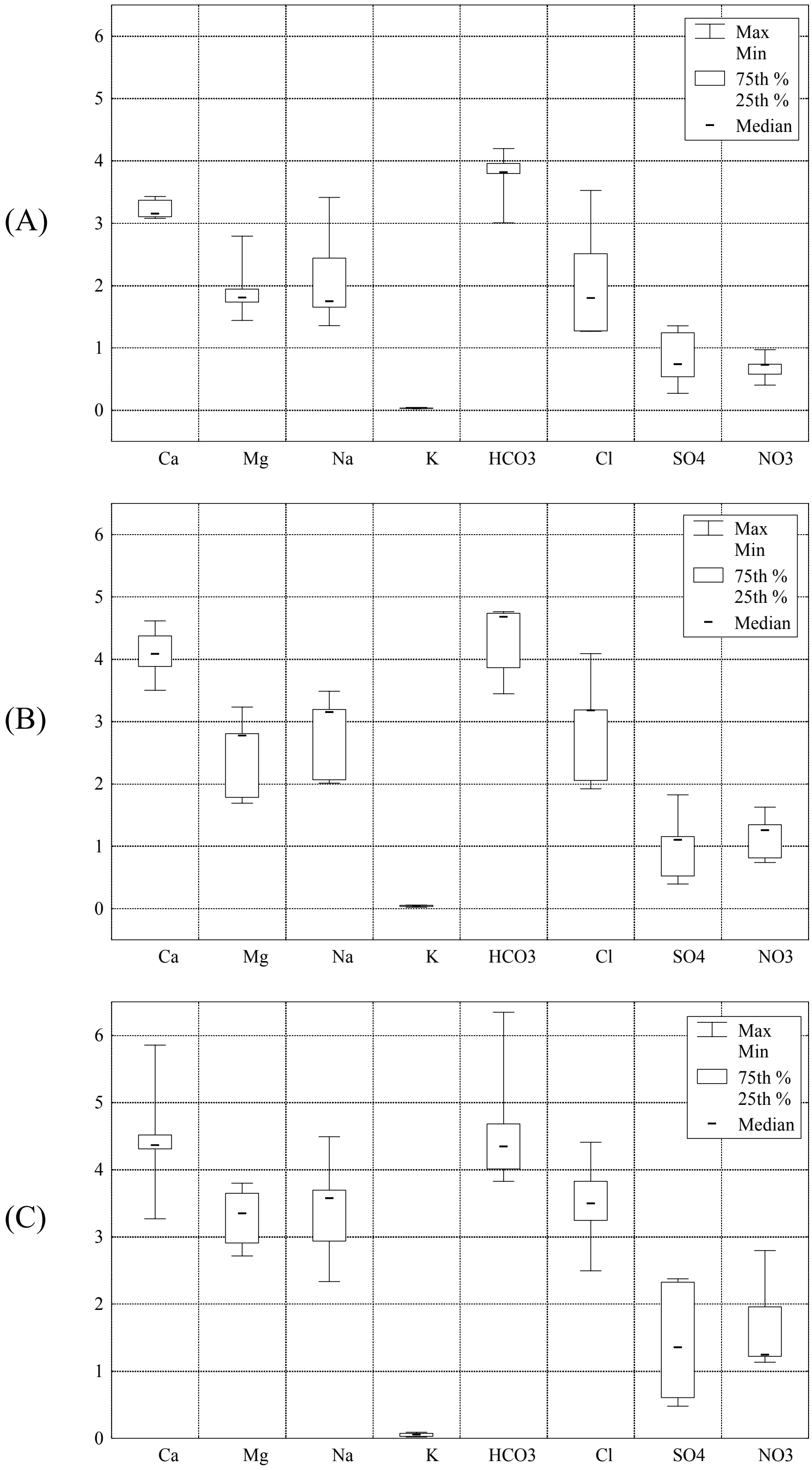


Fig. 10.6: Box plots of the main characteristics of the soil water samples collected above the waste water conduit at depths of (A) 30 cm (B) 60 cm and (C) 90 cm.

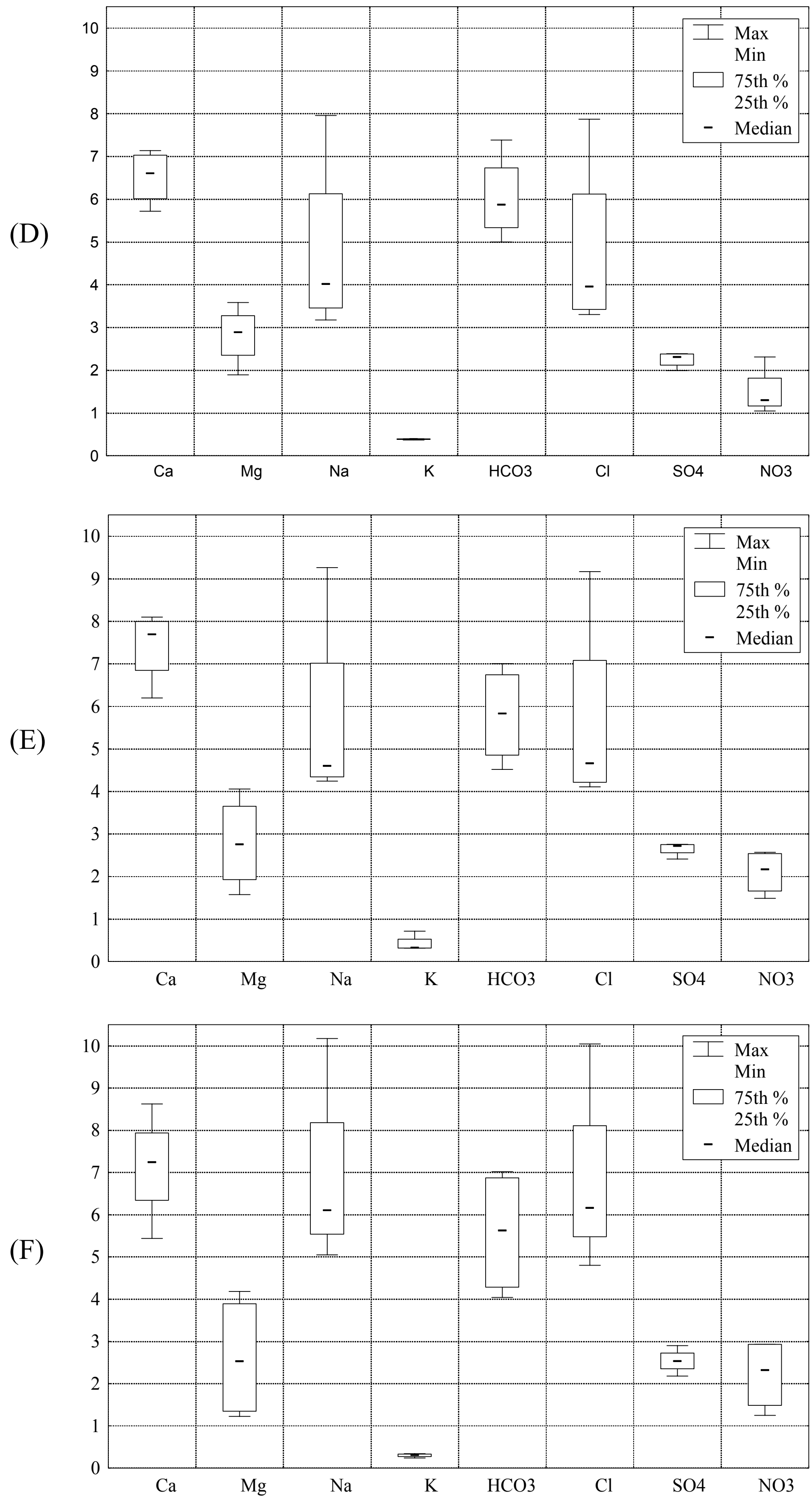


Fig. 10.7: Box plots of the main characteristics of the soil water samples collected below the waste water conduit at depths of (D) 30 cm (E) 60 cm and (F) 90 cm.

Appendix 10.1, Fig. 10.6 and Fig. 10.7 show that all the measured parameters were higher for the samples collected below the conduit. This could be attributed to differences in the mineral phases of the soil profiles of the two sampling location or to mixing with other water type below the conduit. Considering that the soil profiles at the sampling sites above and below the waste water conduit are alluvial sediments, and the distance between them is short (30 m), then low variation in the mineral composition is expected between the two location. This is supported by the results of X-ray analysis of two (0-90 cm depth) soil cores from the two sampling locations, where the mineral phases at both sites is dominated by Quartz, calcite, dolomite, kaolinite, and feldspars. The small variations in the dominancy of the mineral phases at the two location may be responsible for the variation in the Ca, Mg, HCO_3, and SiO_2 content of the soil water but not for the significant variations in the Na, K, Cl, SO_4 and NO_3 which is predominantly attributed to mixing with waste water from the conduit during flooding in the heavy rainy days. Diffusion and horizontal movement of the waste water from the conduit to the suction cups is also possible specially in the dry days during the sampling period.

Appendix 10.1 and Fig. 10.8 show that there is a significant increase in the EC, TDS as well as the concentrations of the major elements with increasing depth in both sampling sites above and below the conduit. The EC of the recharge water increase significantly in the first 30 cm of infiltration (from 64 µS/cm to 790 µS/cm above the conduit and to 1425 µS/cm below the conduit) and then increases gradually to reach 1180 µS/cm above the conduit and 1660 µS/cm below the conduit at 90 cm depth. The increase in the EC with the depth mirrors the increase in all the major parameters which showed also a significant increase in the first 30 cm of infiltration and a more gently increase through the infiltration to a depth of 90 cm. This could be attributed to the aggressiveness of the rain water which decreases with depth due to dissolution of soil minerals (Table 10.1). Table 10.1 shows that the water collected below the conduit is supersaturated with calcite, aragonite and dolomite far more compared to the water collected below the conduit, which could be a result of disposing the waste water of the stone factories to the waste water conduit.

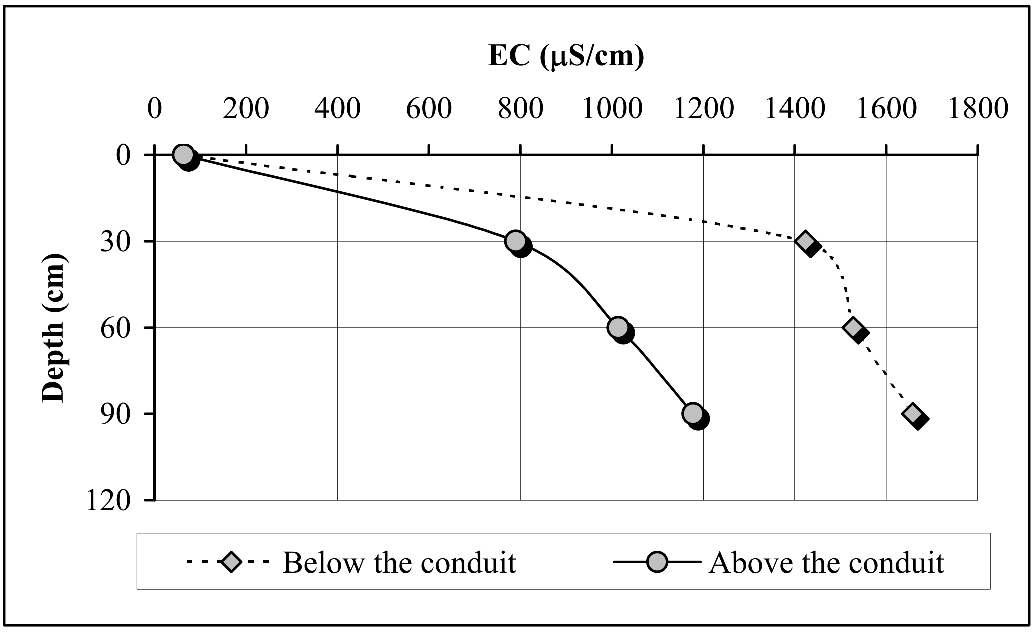


Fig. 10.8: The average EC values of the soil water at the different sampling depths below and above the sewage conduit.

Table 10.1: The saturation indices of the main mineral phases associated with the averaged soil water at the different depth above and below the conduit.

SI	Rain water	Above the conduit			Below the conduit		
		30 cm	60 cm	90 cm	30 cm	60 cm	90 cm
Calcite	-2.60375	0.4414	0.5463	0.6899	1.1878	1.1663	0.6941
Aragonite	-2.7475	0.2976	0.4025	0.5462	1.0441	1.0225	0.5503
Dolomite	-5.725125	0.7897	0.9994	1.3749	2.1098	2.2258	1.1344
Gypsum	-3.65705	-2.062	-1.9295	-1.7815	-1.4279	-1.4643	-1.3635
Anhydrite	-3.87715	-2.2819	-2.1494	-2.0013	-1.6475	-1.6839	-1.5832
SiO_2 (a)	-2.2127	-1.4108	-1.4367	-1.4539	-1.3715	-1.39	-1.2277
Quartz	-0.967975	-0.1661	-0.192	-0.2092	-0.1268	-0.1453	0.017

10.6.1 The trace elements and VOC'S

The results of the analysis for trace elements (Appendix 10.1) show that the contents of Fe, Mn and Cd are always below the detection limits, and only contents of less than 10 μg/L are recorded for Zn, Cr, Cu, Ni, Pb and AS. Therefore no significant variation between the samples from the different locations and depths could be noticed. Table 10.2 presents the results of the analysis of the soil water samples for the VOC's.

Table 10.2: The results of the analysis for the VOC's of the soil water samples collected in February 2000 from Wadi Al Arroub drainage basin compared to the waste water.

VOC's	Detection limit	Above the conduit			Below the conduit4			Birkat Eid	Waste water
		30 cm	60 cm	90 cm	30 cm	60 cm	90 cm		
Limonen	0.9	100	78	<0.85	<0.85	0.9	58	<0.85	40
Toluene	0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	1.7
Styrene	0.25	<0.25	<0.25	<0.25	<0.25	<0.25	<0.25	3.2	<0.25
Trichlorethylene	0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	3.5	<0.2
O-Dichlorobenzene	0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	14	35
Dimethyl disulfide	0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	10
Dimethylsulfide	0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.55
Diethyldisulfide	0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	1

Table 10.2 shows that limonene is the only VOC's recorded in the soil water samples, with higher contents in the samples collected above the conduit than those below it, that could be attributed to the effect of the free over ground disposal of the gray water of the washing machine from the closest house, 10-15 meters in a higher elevation, to this sampling location (house of Ismail Omar). In that house the waste water from the toilets and the kitchen is disposed to a close septic tank.

The Table shows also that the sulfide compounds were recorded only in the waste water which could be attributed to the microbial and algal decomposition of the sulfur compounds (i.e. methionen and cystine amino acids) with which the waste water is rich. Toluene, o-dichlorobenzene, styrene, and trichloroethylene recorded in the waste water and the dug well of Birkat Eid (too close to the conduit) could be attributed to the industrial waste water released to the waste water conduit from the carpentries, smitheries, garages and workshops of the plastic pipes and solar heaters.

10.6.2 Water types

Based on the ion-ordering system adopted after the HYDROWIN software (Calmbach 1995), the soil water samples collected at all the depth above the conduit are of Ca-Na-Mg-HCO_3-Cl type. Although the Na increased gradually with depth below the conduit the Ca still dominating. On the other hand the chloride percentages are lower than that of HCO_3 at the depth of 30 cm giving Ca-Na-Mg-HCO_3-Cl water type. The two anions are more or less equal at the depth of 60, but the Cl exceeds the HCO_3 at the depth of 90 cm resulting in Ca-Na-Cl-HCO_3 water type. The change in the water type of the samples collected below the conduit is a result of the increased Na and Cl with depth which is attributed to mixing of the rain water during the infiltration through the soil profile with waste water of the conduit. The suggested mixing is supported by the plot of the samples collected from below conduit in Durov diagram (Fig. 10.9) higher along the mixing line than the samples collected from above the conduit

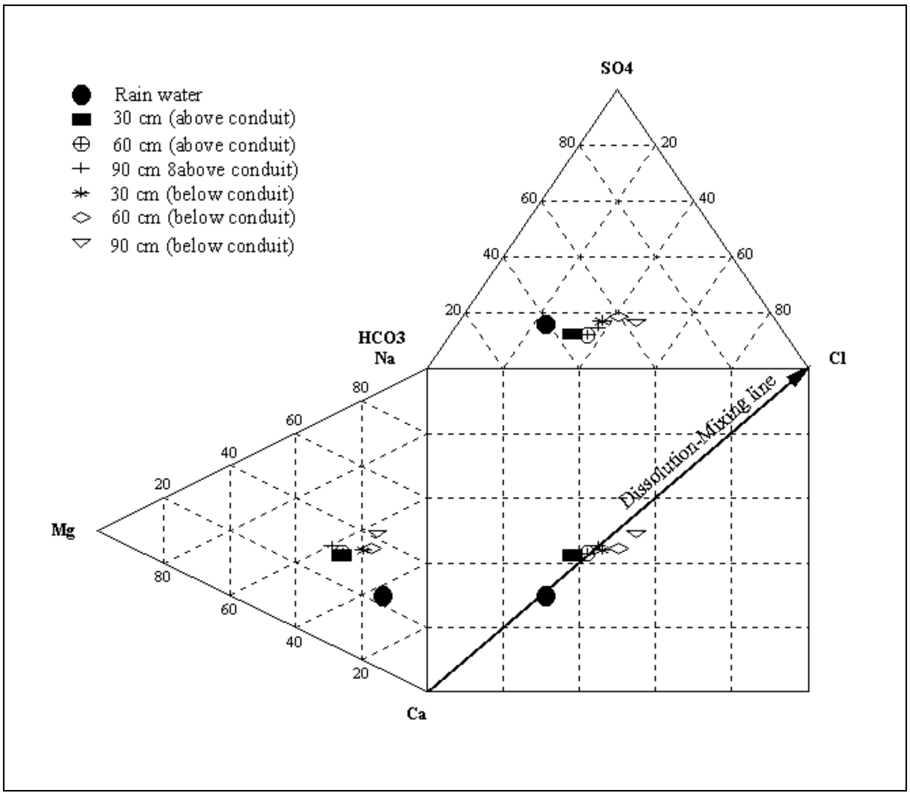


Fig. 10.9: Durov diagram illustrating the average results of the soil water samples analyzed during this study compared to rain water.

11 SUMMARY

Wadi Al Arroub drainage basin suffers water scarcity as do the whole West Bank. The people experience frequent interruptions or even absence of tap water supply for long periods forcing them to utilize the water of unprotected springs and dug wells, and/or to pay a 4-5 fold price obtaining water from trucks to meet their basic domestic needs.

Although Wadi Al Arroub drainage basin is classified to be a highly sensitive recharge area, highly valuable agricultural land with high ecological and historical significance it lives a poor environmental situation. The drinking water networks are old and poorly designed with about 30-40 % leakage; about 710 000 m^3/yr raw waste water being disposed in about 6000 open bottom and perforated cesspits and in the talweg of Wadi Al Arroub which acts as a conduit for the raw sewage from the Arroub camp. Also about 100000 m^3/yr of solid waste are being disposed in open and unmanaged dump places. The uncontrolled disposal of waste water has potential negative impacts on the human health, local socioeconomic situation, landscape as well as the perched ground water aquifers in the area.

The non-vegetated area (38%), green cover including trees, forests and crops (38%) and the built-up areas (22%) represent the main landuse activities in the study area.

The geology of Wadi Al Arroub drainage basin and its immediate surrounding is composed of sedimentary carbonate rocks (limestone, dolomite chalk) and marls of Albian to Holocene age. It is structurally dominated by the Surif anticline, Beit Fajjar-Beit Sahour syncline and the Bani Naim anticline. Most significant faults in the study area trend NNW-SSE, while N-S faults are less significant and the NE-SW faults are of much lower significance. The caves mainly in Hebron Formation and the loss of circulation during the drilling of wells are due most common karst features in the area

The topography has more effect on the drainage lineation than the structure (tectonical structure and thus direction of faults), and its main effect is in the W-E direction, while that of structure is mainly in the NNW-SSE direction and to some extent in the N-S direction.

The study area is a fourth-order catchment discharged by a fourth order stream, which have 5 tributaries of the third order, 22 tributaries of second order and 109 tributaries of first order streams. The streams has a total length of 132,9 km. The high relative relief (4.09 %) and high elongation ratio (0.78) of the area proposes that it is among the sub-basin that contributes strongly to the flooding in the Dead Sea-Jordan River Basin. The flow direction of the surface water in the main streams is at most towards the northeast and to less extent towards the east and southeast, while in the secondary creeks it is mainly eastwards. The valleys are V-shaped and the stream network is dendritic.

The exposed regional aquifers are the Albian and the Cenomanian-Turonian being seperated by the regional aquiclude (Yatta Formation). The regional water table of the Albian aquifer is a result of the two water tables of the Albian upper and lower perched aquifers, while that of the Cenomanian Turonian is a result of three water tables of the Turonian and the Cenomanian upper and lower perched aquifers. The regional aquiclude Yatta Formation supports two perched water tables referred to as Arroub upper and lower perched aquifers. The marls and clays of the following formations; Kfar Shaul; middle Aminadav; Moza; Lower Beit Meir, Soreq act as local aquicludes supporting perched aquifers in the study area. Generally the ground water flows eastward following the dip of the geological formations.

Measurements of the static water levels at the different wells in the Herodion Beit Fajjar well field show that the well field is subject to severe over-pumpage, lowering the water table e.g. at Herodion well No. 3 by 85 m between the years 1981 and 1997. Therefore sustainable management actions must be taken to protect these precious water resources.

Using the isohytal method the annual precipitation volume was calculated to be 38.14 Mill.m^3/yr. The average pan coefficient and potential evapotranspiration were calculated to be 0.72 and 1108 mm/yr respectively. Using the SCS method and Goldschmidt formula the average runoff was calculated as 17% (6.44 Mill. m^3/yr). The average recharge based on the SCS method and the chloride mass balance method is 23 % (8.87 Mill. m^3/yr). Actual evapotranspiration using the hydrometeorological method and Penman-Gridley assumption is 48.4 %. Interception, depression storage and soil moisture were assumed to account for 11%. The empirical formulas of Wundt and Turc are not suitable for implementation in the study area. The aridity indices of De Martonne, UNESCO and is Thornthwaite are 24.2, 0.75 and 83.7 classifying Al Arroub drainage basin as humid.

Mixing with the waste water leaking from the poorly designed cesspits and/or the infiltration of the leachates from washing the piles of animals dung, collected for agricultural purposes or for generation of energy, by the rainfall in winter is responsible for the increased portions of alkalis, chloride and sulfate in the springs and dug wells located between houses (i.e. Arroub, Si'ir and Eth-Tharwa). Mixing with the waste water leaking from the conduit in the floor of Wadi Al Arroub is the main factor responsible for such modifications in the water of the wells of Al Arroub upper perched aquifer that are close to the conduit (i.e. Haj Hamid-1, Ayyad, Birkat Eid, Sowan and Abed-2).

Downstream increase was found in the waste water for BOD, COD, TDS, sodium, and chloride caused by evaporation and thus decreasing the discharge of the sewage conduit gradually until it dries up completely. On the contrary a decrease of sulfate and nitrate concentrations was noticed which can be explained by gaseous loss as ammonia and hydrogen sulfide as well as absorption by plants.

Cluster analysis supported by the Kruskal-Wallis and Man-Whitney tests classified the analyzed water samples into two main groups: group A which consists of thee subgroups, group A1 includes the springs and dug wells located between the houses showing slight contamination; group A_{2a} including the deep wells and group A_{2b} including the dug wells and springs away from the conduit and housing showing a good water quality. group B including the dug wells close to the conduit shows the highest contamination. This statistical grouping is consistent with the classification of Piper and Durov.

The tap water and deep wells are free of coliform bacteria, thus recommended for drinking, while all the springs and dug wells are contaminated with coliform bacteria, therefore they are not suitable for drinking unless being treated. Boiling, sun disinfection, or chlorination of the water are possible treatments for such contamination. High nitrate levels were recorded in the springs and dug wells close to the conduit and those located between the houses thus unsuitable for drinking.

In the study area trace elements (at least those investigated) represent no health hazard potential as their concentrations in the water resources are very low and even in many cases below the detection limits.

Based on the EC, SAR, SSP and SCR the sampled water resources are generally of excellent to good irrigation water quality. The water of dug wells of Jamal Nassar, Haj Omar, Haj Hamid, Birkat Eid, Ayyad, Abed-2, Ahmed Abdel Hamid, Al Marj, Qufeen, Sowan and the springs of Si'ir and Eth-Tharwa is of less irrigation water quality and could result in sodium hazards when used for long time, especially as the soils are of fine textures. The waste water is of bad irrigation water quality as it has high EC, SAR, RSC and SSP values, so it is not recommended to be used for irrigation in fine-textured soils and with sensitive plants.

The water of all the springs and wells in the area is supersaturated with respect to carbonate minerals (calcite, aragonite and dolomite) as well as with respect to quartz, hematite, goethite and $Fe(OH)_3$. Quartz is another indicator for the effect of the geology of the water type (chert bands in the limestone and dolomite of the area) as well as the aluminium silicates built-up the local soils (feldspar, kaolinite). Saturation with respect to the iron mineral phases (hematite, goethite and $Fe(OH)_3$ reflects the sensitivity of the Fe to oxidation even if its is in low concentrations. The rain water is moderately corrosive and the water of all the water resources sampled in this study ranges between balanced to mild scaling. The water characteristics (i.e nitrate concentration) could be improved and controlled by mixing process, thus mixing could be considered as an effective water "treatment" method.

The most intensive rain events are correlated with the lowest isotopic composition and most depleted values are associated with the maximum rainfall amounts of the rainy season. The rain water in the early and the late season is isotopically enriched. The range of the isotopic composition during the whole rainy season (1996-1997) varied for $\delta^{18}O$ between -12 ‰ and +4 ‰ and for $\delta^{2}H$ between -80 ‰ and +20 ‰. The isotopic content of the water samples collected from the springs and wells distributed in the study area plot on the Mediterranean Meteoric Water Line with average values of –25.9 ‰, -5.9 ‰ and 21.1 ‰ for the $\delta^{2}H$, $\delta^{18}O$ and the d-excess, respectively. This proves that the water of all these springs and wells is of meteoric origin.

The present ^{3}H content in precipitation is 5-6 TU, thus 5.7 TU in the water of El Bas spring, suggests recent recharge and tritium of meteoric origin. The 0.4 TU in the water of Herodion well 4 tapping the Albian aquifer dates its water back to the early 1950's, while 1.5 TU in the water of Beit Fajjar well tapping the Turonian-Cenomanian aquifer dates it back to the late 1950's. The relatively enriched ^{2}H (-23.8 ‰) and ^{18}O (-5.56 ‰) and low ^{3}H (3.8 TU) in the water of the dug well of Haj Hamid-1, close to the conduit, supports the inference from the hydrochemistry, that the water of the well undergoes mixing with waste water leaking from the conduit.

Mixing with waste water leaking from the conduit is responsible for the significantly higher EC, TDS, Na, K, Cl, SO_4 and NO_3 in the soil water sampled below the conduit and consequently its plot in Durov diagram higher along the mixing line than the samples collected above the conduit. The Ca and HCO_3 dominate the cations and anion above and below the conduit at 30, 60 and 90 cm, except at 90 cm below the conduit where the anions are dominated by Cl.

The EC of the recharge water increase significantly in the first 30 cm of infiltration (from 64 µS/cm to 790 µS/cm above the conduit and to 1425 µS/cm below the conduit) and then increases gradually to reach 1180 µS/cm above the conduit and 1660 µS/cm below the conduit at 90 cm depth. The increase in the EC with the depth mirrors a similar increasing trend of all the major parameters. This could be attributed to the aggressiveness of the rain water which decreases with depth due to dissolution of soil minerals.

12 RECOMMENDATIONS

12.1 General recommendations

Following are preventive and mitigative measures recommended for the improvement of the drinking water and waste water sectors as wells as the protection of the human health and the ground water resources in the study area.

- Replacement of the present poorly designed cesspits and open waste water conduit with a proper sewerage and sanitation system and treatment plant and where that is not feasible construction of well-designed cesspits (i.e. double-walled and two chambered cesspits). This could provide treated waste water to be used for irrigation rather than putting pressure on water resources of high drinking water quality, also that alleviates health hazards to which the present population is subjected.

- Replacement or at least maintaining the drinking water networks saves 30-40 % of the water supply lost through leakage and reduces the possibility of the water contamination by the negative puncture during the failure (missing pressure) of the tap water supply.

- Prevention of uncontrolled disposal of waste water in the nearby fields and wadis.

- Prevention of uncontrolled disposal of solid wastes and creating of infrastructure for environmentally-safe solid waste disposal (i.e. of central sanitary landfills).

- Controlling urban expansion in the study area, which is a recharge area for the Albian and Turonian-Cenomanian aquifers, as it reduces the area of recharge and human activities will pollute the underlying aquifers in the long run.

- To protect the Herodion-Beit Fajjar well field against overexploitation (over-pumping) sustainable management and policy actions must be taken. Examples of these action could be: No more wells to be installed in the field and new ground water development programs should be directed to other well fields such as that of Bani Naim.

- Rain water harvesting by means of house cisterns, small scale dams and infiltration basin is recommended in order to increase ground water recharge in periods with surplus of rain water.

- Rehabilitation of springs and dug wells (i.e. construction of storage facilities). This offers protection against contaminating activities such as watering of livestock and domestic laundering. Also such storages facilitate in-situ water treatments such as disinfection.

- Legislative and executive measures are recommended to control the water quality and the hygiene of the tankers.

- It is recommend not to use the water from springs and wells especially those adjacent to the sewage conduit or in the vicinity of houses for drinking purposes unless it is treated properly.

- Long-term spatial and temporal monitoring of the water quality, especially the fecal coliform count, EC, NO_3^- and Cl^- concentrations in major springs.

- Where the contaminated springs are the major or the only water source for domestic purposes, it is recommended to supply at least the pregnant women and infants with low nitrate bottled water.

- Where disinfection of the drinking water (chlorination) is not available, boiling water and sun disinfection before use is highly recommended.

12.2 Recommended studies

- Isotopic studies (i.e. ^{15}N and ^{34}S for understanding the origin and fate of sulfate and nitrate).

- Analysis of the volatile organics in the deep wells.

- Analysis of the semi and non-volatile organic compound in the shallow and deep ground water resources.

- Analysis of the pesticide and insecticide in the ground water resources.

- Geological field surveys and mapping work is needed to produce maps of smaller scale (1:50 000 and 1:20 000) for the areas that has only 1:200 000 scale maps, especially the area between 160-180 E and 100-120 N, part of which is the study area.

- Measurements of runoff, which requests installation of runoff gauge stations.

- Measurements of the soil moisture.

- Production of vulnerability map for he study area (DRASTIC).

- Presentation of ground water potentiality maps.

- Construction of a solute-transport model.

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14. APPENDICES

Appendix 7.1: The Springs and dug wells of the Wadi Al Arroub drainage basin

Code	Dug well / Spring	Coordinates (PG)		Elevation (masl)	Aquifer	Well depth (mbgl)
		North	East			
16-11/004	Arroub Nursery	114974	162542	840	ArrLPA	50
WQ-Dw-1	Beit Ommar (Qufeen)	114446	160679	906		6.7
WM-DW-1	Marina	115804	160957	888		4.8
WD-DW-3	Naim Halayqah	112258	163072	851		3
WD-Sp-2	Wadi Ed-Dur	112370	163036	843		0
WShkh-Dw-1	Al Qet	112655	160179	972		5.2
WA-Dw-37	Abdel Fattah abed-(1A)	113473	164375	784	ArrUPA	11.8
WA-Dw-38	Abdel Fattah abed-(1B)	113469	164376	784		11.7
WA-Dw-45	Abdel Fattah abed-(2)	113310	164491	785		13.5
WA-Dw-33	Abdel Hamid Shalaldeh	113739	164241	797		8.9
WA-Dw-17	Ahmed Abdel Hamid	113939	163621	817		6.25
WA-Dw-8	Ahmed Hamid	114166	163429	818		7.9
WA-Dw-6	Ahmed Issa Mahmoud	114163	163350	819		6.8
WD-DW-1	Al Bassah	111058	161793	970		3.9
WA-Dw-31	Al Biarah	113728	164188	798		3.7
WA-Dw-13	Al Marj	114065	163584	812		7.5
WA-Dw-29	Al Thamad	113757	164181	798		9.6
WA-Dw-19	Al Zaweih	113904	163641	817		4
WA-Dw-4	Ali Taha	114206	163299	819		3.9
WA-Sp-22	Arroub	113926	163705	814		1.75
WA-Dw-46	Ayish	113245	164497	786		13.3
WA-Dw-15	Ayyad	114100	163633	809		8.5
WA-Dw-11	Baradah	114207	163511	813		0
WB-Dw-7	Bir El Bas	113789	163195	838		5.1
WA-Dw-27	Birkat Eid	113888	164024	797		9.8
WA-Dw-10	Dahshan	114210	163448	817		4.7
WD-Sp-4	Dilbi*	113088	163921	819		1.4
WA-Dw-20	Ein Ed Diwan	113941	163686	814		8.1
WB-Sp-4	El Bas – East	113575	163143	856		4.5
WB-Sp-6	El Bas-West	113664	163049	855		3.2
WB-Dw-9	Haj Hamid - 2	114013	163207	828		6.4
WA-Dw-9	Haj Hamid-1	114184	163450	817		6.6
WA-Dw-16	Haj Moustafa	113974	163620	816		7.3
WA-Dw-7	Haj Omar	114151	163425	819		3.1
WA-Dw-42	Hamad	113373	164442	785		8.5
WA-Dw-14	Harhash	114122	163638	808		10.15
WA-Dw-21	Haroon Hamid	113956	163702	812		7.15
WA-Dw-24	Hashim Ayyad	113935	163771	811		8
WA-Dw-30	Ibrahim Mana'	113751	164191	798		5.5
WA-Dw-26	Ismail Warasneh	113899	163967	797		14
WB-Dw-3	Issa Eiad -lower (1)	113599	163050	858		4.4
WB-Dw-2	Issa Eiad -upper (2)	113559	163060	860		6.2
WA-Dw-28	Issa Mahmoud	113757	164181	798		9.1
WA-Dw-25	Jamal Nassar	113891	163776	814		7.1
WA-Dw-3	Kamal Dahshan	114205	162999	830		9.2
WB-Dw-8	Mahmoud Adawi	113882	163407	828		3.8
WA-Dw-41	Mahmoud Ali Suliman	113400	164417	786		11.2

Code	Dug well / Spring	Coordinates		Elevation (masl)	Aquifer	depth (m)
WA-Dw-5	Mahmoud Dahshan	114179	163333	819	ArrUPA	5.8
WA-Dw-36	Mahmoud Zifah	113480	164375	786		10.25
WA-Dw-12	Mohamed Jaber	114203	163557	810		5.5
WA-Dw-39	Mouhamed Hussein	113452	164374	785		10.3
WA-Dw-35	Mouhamed Rasheed	113507	164338	787		11.9
WA-Dw-44	Mousa Ali	113319	164448	787		8.5
WB-Dw-5	Mousa Nassar	113624	163099	857		8
WA-Dw-34	Mousa Sarhan	113499	164314	789		10.9
WA-Dw-2	Nasser Qannam	114317	163022	828		20
WA-Dw-32	Omar Mana'	113716	164195	798		5.1
WA-Dw-43	Sameeh Mousa Hassan	113348	164468	785		12.3
WA-Dw-23	Sa'oud Ayyad	113942	163764	811		8.5
WA-Dw-40	Sowan	113439	164384	785		10.5
WB-DW-1	Wardan	113157	162210	920		3.9
WA-Dw-18	Yousef Isleem (Ghandi)	113937	163650	816		9.9
WA-Dw-1	Fredees	115070	162460	848	CenLPA	5
WShrq-Sp-1	Si'ir	110217	163847	863		4
WK-DW-2	Kuweisiba-1	112281	164437	832	CenUPA	7.2
WK-Dw-1	Kuweisiba-2	112022	164148	844		10
WSh-DW-1	Esh-Shinar	111256	161217	892	AUPA	2.3
WT-Sp-1	Eth-Tharwa	110498	159824	934		0
WT-Sp-2	Misleh	111063	160290	907		0

Appendix 8.1: The physical and chemical analysis of the sampled wells and springs in Wadi Al Arroub drainage basin (data from 1996 and 1995 are after Qannam 1997 and the data from 1995 and 1998 are after Abed Rabbo et al. 1999).

Well / Spring	Aquifer	Date	EC	TDS	pH	DO	T	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	HCO_3^-	Cl^-	SO_4^{2-}
			µS/cm	mg/L		mg/L	°C	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
Herodion 1	Albian	6.11.95	558	284	7.3	8	21.4	58.72	23.15	16.5	1.4	259	31.23	9
Herodion 1	Albian	17.6.96	568	301	7.64	6.9	15.1	74.6	14.8	19	0.9	260	36.3	9.6
Herodion 1	Albian	9.12.96	561	320	7.9	4.3	15.4	84	17.2	13.3	1	274	42.8	8.4
Herodion 1	Albian	17.3.97	537	279	7.97	7.6	17.9	55.6	23.1	17	1	240	40.2	6
Herodion 1	Albian	29.9.97	519	275	7.71	7.5	15.4	74.2	10.2	18.6	0.9	229	39.8	8.3
Herodion 1	Albian	9.6.97	532	282	7.26	7.3	17.9	71.2	12	17.5	2.5	240	35.2	6.7
Herodion 2	Albian	18.9.95	555	305	7.76	7.8	20.6	74.11	19.67	15	3	296	28.16	9.2
Herodion 2	Albian	6.11.95	613	313	7.2	7.9	19.4	64.22	29.21	15	2.2	314	27.45	9.8
Herodion 2	Albian	2.1.96	408	216	7.62	7.2	20.5	39.1	18.2	16.5	4	198	22.7	9.2
Herodion 2	Albian	17.6.96	652	332	8.15	6.5	20.5	88.5	16.2	16.5	1.5	320	29.4	12
Herodion 2	Albian	9.12.96	692	367	7.8	7.1	17.5	91.1	27.4	12.3	1.6	360	37	8.6
Herodion 2	Albian	17.3.97	516	310	8.15	7.5	15.8	57.1	31.3	17	1.8	292	40.2	8.2
Herodion 2	Albian	9.6.97	562	304	7.74	7.5	20.4	73.6	18.9	15	2.5	292	32	7.4
Herodion 2	Albian	29.9.97	548	285	7.5	6.7	18.6	75	14.1	16.3	1.8	271	33.9	9.2
Herodion 2	Albian	9.2.98	615	306	8.01	6.2	17.2	52	33.2	16.5	1.6	318	22.1	9.5
Herodion 3	Albian	18.9.95	530	323	7.39	5.9	14.8	68.94	28.47	15	3	324	30.04	9
Herodion 3	Albian	2.1.96	455	241	7.52	7.2	20.7	46.2	20.8	16.5	4	225	25.6	9.4
Herodion 3	Albian	17.6.96	643	354	7.87	8	19.7	93.1	19.4	16.5	1.5	350	31.4	10.5
Herodion 3	Albian	9.12.96	581	343	8.17	7.15	19.5	86.9	23.6	12	1.7	344	31.1	9.9
Herodion 3	Albian	17.3.97	547	312	7.44	6.2	15.6	63.7	33.6	14.5	1.7	310	30.4	8.2
Herodion 3	Albian	9.6.97	529	312	7.54	8.3	21.3	70.7	20.6	17.5	4.9	293	35.2	9.3
Herodion 3	Albian	29.9.97	585	310	7.64	6.1	17.2	81.2	14	18.6	1.6	295	31.9	11.9
Herodion 3	Albian	9.2.98	635	310	7.69	5.3	14.3	56	33.5	16.5	1.7	337	19.1	12.4
Herodion 4	Albian	17.6.96	628	358	7.83	8.9	15.8	97.7	16.6	16.5	1.7	350	29.4	14.6
Herodion 4	Albian	9.12.96	586	369	7.34	6.9	16.3	91.1	27.4	12	1.9	348	40.8	15.8
Herodion 4	Albian	17.3.97	617	327	8.14	7.2	17.8	62.4	33.6	14.5	1.8	300	45.1	13.6
Herodion 4	Albian	9.6.97	523	308	7.62	7.4	18.7	71	21.1	17.5	1.9	294	31.2	11.2
Herodion 4	Albian	29.9.97	601	312	7.72	6.6	16.5	75	21.1	16.3	1.7	301	31.9	14.6
Herodion 4	Albian	9.2.98	667	319	8.04	4.9	13.2	52.8	39.4	16.5	1.9	342	22.1	16
Herodion 4	Albian	6.11.95	626	319	6.9	7.7	17.6	66.05	26.46	17	2.9	308	32.18	13
Arroub-Nursery	ArrLPA	07.02.00	489	247	7.82	7.2	12.2	66.7	8.7	12.3	1.09	212.4	27.3	10.4
Arroub-Nursery	ArrLPA	10.05.99	554	288	7.86	6.2	17.5	77.8	10.5	15.4	1.37	247.6	29.59	13.21
Esh-shinar	ArrLPA	04.02.01	603	298	7.48	7.1	18.4	63	23	16	0.6	254.0	35	27
Qufeen	ArrLPA	07.02.00	795	455	8.11	6.9	14.1	114.2	18.3	25.3	1.21	325.3	58.4	32.5
Qufeen	ArrLPA	10.05.99	866	522	8.25	6.5	18.6	127.0	20.5	30.5	1.63	337.4	65.8	44.3
Qufeen	ArrLPA	18.3.96	1019	540	8.01	7.3	16.7	124.7	21.8	20	1.9	264	52.9	23.3
Qufeen	ArrLPA	2.12.96	896	475	8.05	1.7	19.5	101.8	34.9	25.5	2.5	374	58.4	23.4
Qufeen	ArrLPA	8.12.97	952	525	7.71	6.1	17.3	134.7	19.5	27.7	1.8	367	72.3	42.1
Qufeen	ArrLPA	26.1.98	877	465	7.82	5.6	15.6	110.2	26.4	25.9	1.6	386	45.6	30.5
Marina	ArrLPA	2.12.96	876	499	7.63	6.8	17.6	135	31.1	12.2	0.8	483	37	36.8
Marina	ArrLPA	18.3.97	856	453	7.82	7.2	18.3	109.8	19.6	15	3.1	280	37.2	49.4
Wadi Ed-Dur	ArrLPA	07.02.00	445	233	7.55	7.8	12.2	59.1	14.1	8.2	0.23	215.1	20.3	8.7
Wadi Ed-Dur	ArrLPA	10.05.99	472	267	7.81	7.7	19.2	64.3	18.4	9.9	0.61	233.6	25.64	11.01
Ahmed Abdel Hamid	ArrUPA	25.11.99	1290	684	8.16	6.6	18	115.0	25.8	95.0	4.9	305	185	56
Abdel Fattah Abed-2	ArrUPA	07.02.00	1612	800	7.61	2.8	8.2	117.3	37.2	117.5	16.30	482.1	151.6	71.2
Abdel Fattah Abed-2	ArrUPA	10.05.99	1348	684	7.64	4.9	16.8	119.0	32.8	93.7	7.17	489.3	137.8	38.93
Abdel Fattah Abed-2	ArrUPA	19.01.01	1130	635	8.06	5.2	13.5	109.7	19.4	58.5	10.6	356.7	102.5	57.7
Al Bassah	ArrUPA	06.02.01	486	278	8.04	6.9	17.8	52	16	25	6.1	197	46	14
Al Marij	ArrUPA	26.2.96	1840	1012	7.89	8.1	24.2	222.1	26	96.5	2.9	440	186.2	89.6
Al Qet	ArrUPA	05.02.01	588	305	7.83	6.7	16.6	68	10	31	2	227	35	24
Arroub	ArrUPA	07.02.00	920	476	7.12	5.3	12.3	90.3	15.8	42.5	12.50	189.5	72.8	54
Arroub	ArrUPA	10.05.99	619	386	7.97	4.3	17.6	87.9	18.2	22.4	8.19	285.0	42.41	32.7
Arroub	ArrUPA	19.01.01	825	456	8.11	5.8	17.5	91.4	16.8	22.0	10.7	217.4	48.8	42.3
Arroub	ArrUPA	26.2.96	731	431	7.73	7.5	20.5	92.2	19.9	28.2	7	271	43.1	38.9
Arroub	ArrUPA	25.6.96	809	461	7.31	7.5	16.5	117.5	10.8	23.3	7.9	275	54.5	43.8
Arroub	ArrUPA	18.3.97	773	402	7.92	8.2	16.5	79	30.3	18.7	7.8	273	52.9	39.8
Arroub	ArrUPA	28.4.97	665	379	7.93	6.5	16.5	98	10.3	23.8	4.8	277	42.2	28.5
Arroub	ArrUPA	6.10.97	1005	561	8.16	8	15.8	81.2	5.6	114.6	7.8	254	150.3	25.5
Arroub	ArrUPA	1.12.97	824	440	8.04	7.2	17.2	110.9	20	21.7	6.7	341	37.8	35.5
Arroub	ArrUPA	26.1.98	765	421	7.88	5.6	22.3	84.8	19.2	38.6	6.7	342	33.8	24
Ayyad	ArrUPA	10.05.99	1166	782	7.79	2.6	17.8	115.9	46.8	85.5	14.81	363.7	154.84	97.3
Ayyad	ArrUPA	07.02.00	1009	645	7.56	5.6	12.5	116.1	40.1	53.2	5.90	323.8	138.9	67.8
BirElBas	ArrUPA	31.08.98	970	482	7.6	6.8	17.3	92	35.1	31	0.6	280	90.9	65.3

Well / Spring	Aquifer	Date	NO_3^- mg/L	F^- mg/L	SiO_2 mg/L	PO_4^{3-} mg/L	Fe µg/L	Cu µg/L	Mn µg/L	Pb µg/L	Cd µg/L	Zn µg/L	FC #/100ml	TC #/100ml
Herodion 1	Albian	6.11.95	14.9	0.33	19.6	0.10	8.4	9.7	3.2	0.8	1.2	6.4	0	0
Herodion 1	Albian	17.6.96	15.5	0.18	20.44	0.14	23.0	26.0	1.0	15.7	< 0.1	7.0	0	0
Herodion 1	Albian	9.12.96	16.2	0.02	32.75	0.73	15.3	5.7	16.0	4.0	1.0	20.0	0	0
Herodion 1	Albian	17.3.97	16.5	0.05	22.2	0.41	57.0	4.0	9.0	< 0.7	< 0.1	< 6	0	0
Herodion 1	Albian	29.9.97	16.4	0.08	22.06	0.10	25.2	< 0.6	2.0	3.1	< 0.1	12.2	0	0
Herodion 1	Albian	9.6.97	17	0.05	12.3	0.09	9.0	14.0	1.0	< 0.7	< 0.1	< 6	0	0
Herodion 2	Albian	18.9.95	7.8	0.63	18.45	0.64	26.0	2.0	< 0.5	< 0.7	0.1	< 6	0	0
Herodion 2	Albian	6.11.95	7.8	0.29	18.8	0.09	13.0	10.8	1.0	2.0	1.3	< 6	0	0
Herodion 2	Albian	2.1.96	7.9	0.01	12.14	0.16	122.0	7.0	0.6	0.7	1.9	27.2	0	0
Herodion 2	Albian	17.6.96	8.4	0.21	9.05	0.13	6.0	3.0	11.0	1.4	5.7	6.8	0	0
Herodion 2	Albian	9.12.96	8.4	0.01	15.8	0.23	16.0	22.0	1.0	12.0	< 0.1	< 6	0	0
Herodion 2	Albian	17.3.97	7.8	0.59	42.01	0.13	15.0	0.6	0.7	< 0.7	3.1	7.2	0	0
Herodion 2	Albian	9.6.97	8.2	0.60	26.18	0.19	15.0	1.0	8.0	< 0.7	< 0.1	1.5	0	0
Herodion 2	Albian	29.9.97	8.5	0.29	21.43	0.05	56.3	20.7	20.2	2.7	0.7	17.2	0	0
Herodion 2	Albian	9.2.98	8.1	0.20	18.1	0.03	5.3	39.5	12.6	1.4	0.7	25.9	0	0
Herodion 3	Albian	18.9.95	6.6	0.00	33.19	0.30	28.0	8.0	9.0	< 0.7	1.0	6.0	0	0
Herodion 3	Albian	2.1.96	6	0.11	11.72	0.21	21.0	3.0	5.5	< 0.7	2.0	21.5	0	0
Herodion 3	Albian	17.6.96	6.7	0.02	21.83	0.13	40.4	3.8	< 0.5	< 0.7	0.1	< 6	0	0
Herodion 3	Albian	9.12.96	5.8	0.01	21.81	0.22	68.9	7.9	0.6	8.9	11.4	8.5	0	0
Herodion 3	Albian	17.3.97	4.7	0.10	18.93	0.10	24.0	2.0	4.0	< 0.7	< 0.1	6.0	0	0
Herodion 3	Albian	9.6.97	7.2	0.07	24.94	0.31	13.0	5.6	< 0.5	< 0.7	2.8	11.4	0	0
Herodion 3	Albian	29.9.97	7.3	0.29	21.52	0.02	117.8	1.7	10.3	2.3	1.6	16.7	0	0
Herodion 3	Albian	9.2.98	5.8	0.30	21.1	0.10	5.6	< 0.6	< 0.5	1.3	1.0	13.8	0	0
Herodion 4	Albian	17.6.96	6.6	0.10	11.4	0.46	9.0	3.0	2.0	0.8	0.1	13.1	0	0
Herodion 4	Albian	9.12.96	6.5	0.80	19.53	0.07	67.0	10.4	2.0	< 0.7	0.1	32.0	0	0
Herodion 4	Albian	17.3.97	6.1	0.24	16.91	0.33	0.2	3.0	< 0.5	< 0.7	< 0.1	7.9	0	0
Herodion 4	Albian	9.6.97	7.3	0.02	23.69	0.15	19.0	7.1	3.4	1.2	1.7	22.0	0	0
Herodion 4	Albian	29.9.97	7.1	0.21	21.7	0.08	17.3	0.6	10.0	3.4	0.1	16.1	0	0
Herodion 4	Albian	9.2.98	6	0.30	21	0.06	12.6	3.1	22.6	1.7	1.4	25.4	0	0
Herodion 4	Albian	6.11.95	7.8	0.41	20	0.10	24.2	4.0	0.6	0.9	< 0.1	< 6	0	0
Arroub-Nursery	ArrLPA	07.02.00	13.9	0.04	2.9	0.05	14.0	6.0	3.0	4.0	7.0	8.0	2	5
Arroub-Nursery	ArrLPA	10.05.99	16.57	0.07	3.8	0.10	12.0	2.0	1.0	6.0	5.0	7.0	5	12
Esh-shinar	ArrLPA	04.02.01	6.0	0.1	7.2	0.32	18.0	< 0.6	17.0	0.7	0.1	10.0	8	25
Qufeen	ArrLPA	07.02.00	42.1	0.02	7.9	0.11	10.0	5.0	2.0	4.0	1.0	15.0	30	85
Qufeen	ArrLPA	10.05.99	63.5	0.04	9.8	0.10	8.0	10.0	3.0	8.0	2.0	20.0	42	115
Qufeen	ArrLPA	18.3.96	169.4	0.10	21.75	0.51	13.0	2.0	0.2	3.0	1.8	< 6	32	56
Qufeen	ArrLPA	2.12.96	46.8	0.39	9.41	0.22	2.0	4.0	4.0	1.3	0.1	11.5	> 1000	> 2000
Qufeen	ArrLPA	8.12.97	36.7	0.08	36	0.06	15.2	2.8	< 0.5	1.6	0.1	31.7	> 1000	> 2000
Qufeen	ArrLPA	26.1.98	38.2	0.00	37.4	0.06	6.5	3.6	18.0	3.3	< 0.1	29.0	40	350
Marina	ArrLPA	2.12.96	5.3	0.20	22.1	0.68	12.0	2.0	11.0	3.0	0.1	10.0	> 1000	> 2000
Marina	ArrLPA	18.3.97	79.3	0.24	18.9	0.14	17.0	4.0	< 0.5	1.0	0.1	12.0	8	52
Wadi Ed-Dur	ArrLPA	07.02.00	14.4	0.12	5.5	0.15	5.0	0.8	0.8	2.0	11.0	7.0	2	10
Wadi Ed-Dur	ArrLPA	10.05.99	20.4	0.10	5.1	0.10	10.0	1.0	1.0	7.0	18.0	8.0	1	5
Ahmed Abdel Hamid	ArrUPA	25.11.99	49.6	0.30	25.5	0.74	32.0	1.9	13.0	1.3	0.1	15.0	50	120
Abdel Fattah Abed-2	ArrUPA	07.02.00	47.6	0.05	8.7	1.1	8.0	3.0	10.0	1.0	3.0	6.0	980	> 2000
Abdel Fattah Abed-2	ArrUPA	10.05.99	9.96	0.07	10.0	1.92	5.0	5.0	16.0	2.0	2.0	< 6	520	1250
Abdel Fattah Abed-2	ArrUPA	19.01.01	98.3	0.56	6.61	4.16	65.0	3.2	28.0	0.8	0.1	17.0	180	340
Al Bassah	ArrUPA	06.02.01	20	0.15	6.2	0.08	12.0	0.8	18.0	0.7	< 0.1	10.0	20	65
Al Marij	ArrUPA	26.2.96	179.1	0.10	21.06	0.23	21.0	1.0	8.0	< 0.7	< 0.1	< 6	470	770
Al Qet	ArrUPA	05.02.01	21	0.2	5.1	0.07	15.0	0.7	22.0	0.7	0.1	10.0	10	50
Arroub	ArrUPA	07.02.00	93.5	0.22	7.3	0.15	10.0	8.0	2.0	3.0	3.0	< 6	10	25
Arroub	ArrUPA	10.05.99	32.12	0.24	7.7	0.10	8.0	7.0	5.0	8.0	4.0	< 6	16	36
Arroub	ArrUPA	19.01.01	114.9	0.08	4.87	1.92	28.0	2.4	23.0	0.8	0.1	13.0	45	150
Arroub	ArrUPA	26.2.96	70.3	0.02	20.29	0.23	10.0	2.7	< 0.5	1.0	2.1	7.9	256	496
Arroub	ArrUPA	25.6.96	68.3	0.02	19.67	0.08	20.0	11.0	2.0	9.1	1.0	< 6	56	250
Arroub	ArrUPA	18.3.97	42.7	0.17	20.46	0.08	16.0	4.0	2.1	< 0.7	0.8	< 6	420	600
Arroub	ArrUPA	28.4.97	38.3	0.27	24.88	0.10	9.0	0.6	1.0	4.2	5.2	153.0	12	60
Arroub	ArrUPA	6.10.97	51.8	0.07	11.5	0.10	59.4	< 0.6	4.8	51.1	1.3	15.9	440	680
Arroub	ArrUPA	1.12.97	42	0.10	12	0.03	20.0	4.4	0.5	7.3	0.1	15.6	560	720
Arroub	ArrUPA	26.1.98	37.5	0.06	12.1	0.03	10.2	< 0.6	8.6	1.2	< 0.1	14.0	400	1000
Ayyad	ArrUPA	10.05.99	85.2	0.29	11.8	0.10	30.0	3.0	18.0	1.0	2.0	10.0	8	25
Ayyad	ArrUPA	07.02.00	61.3	0.22	10.5	0.08	15.0	5.0	10.0	3.0	7.0	11.0	20	40
BirElBas	ArrUPA	31.08.98	26.7	0.01	10.3	0.07	15.0	2.0	3.0	10.0	15.0	14.0	> 1000	> 2000

Appendix 8.1 (continue)

Well / Spring	Aquifer	Date	EC	TDS	pH	DO	T	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	HCO_3^-	Cl^-	SO_4^{2-}
			µS/cm	mg/L		mg/L	°C	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
Birkat Eid	ArrUPA	10.05.99	1375	831	7.45	4.5	10.9	140.5	25.7	107.5	20.40	451.4	152.6	29.88
Birkat Eid	ArrUPA	07.02.00	1264	772	7.96	3.8	18.1	141.3	28.6	96.3	12.81	471.8	142.91	46.86
Birkat Eid	ArrUPA	19.01.01	1589	884	7.71	4.9	18.4	128.7	22.2	92.7	15.4	395.8	162.1	89.7
Dahshan	ArrUPA	15.11.98	851	485	8.16	7	27.9	95.3	28.6	42.5	0.9	304	79.7	59.4
Ed-Dilbi	ArrUPA	07.02.00	390	168	7.68	6.8	12.1	33.5	12.1	12.5	0.50	145.9	17.7	12.42
Ed-Dilbi	ArrUPA	19.01.01	389	196	7.65	7.2	19.8	37.7	14.7	7.3	0.6	146.3	23.4	23.2
Ed-Dilbi	ArrUPA	10.05.99	387	192	7.83	6.7	19.9	37.3	13.8	14.3	0.86	162.2	18.66	16.67
El Bas - East	ArrUPA	10.05.99	630	372	7.96	5.8	21.4	79.4	22.2	27.2	2.24	315.2	27.39	37.42
El Bas - East	ArrUPA	07.02.00	585	322	7.86	6.4	13.4	65.2	21.7	23.4	1.80	281.5	23.6	30.9
El Bas-West	ArrUPA	19.01.01	651	355	7.89	6.7	16.4	78.6	24.5	12.2	0.6	289.7	22.2	50.0
El Bas-West	ArrUPA	07.02.00	655	343	8.3	4.8	20	75.4	23.8	18.3	0.63	296.3	31.53	32.6
El Bas-West	ArrUPA	10.05.99	724	368	7.23	7.0	13.2	78.2	27.2	17.5	1.40	287.5	39.4	36.6
El Bas-West	ArrUPA	15.11.97	680	360	8.13	5.69	18.5	74.4	26.8	23.5	0.4	289	42.8	35.6
El Bas-West	ArrUPA	25.11.98	694	368	7.84	6.6	18.6	78.9	25	23	0.3	299	40.8	33.3
Yousef Isleem	ArrUPA	19.01.01	1115	617	7.88	5.9	16.4	105.8	35.0	31.7	15.1	265.0	62.5	83.6
Haj Hamid-1	ArrUPA	10.05.99	1731	1172	6.88	6.5	13.1	183.5	38.5	150.0	15.60	318.9	292.3	165.1
Haj Hamid-1	ArrUPA	07.02.00	1480	841	7.93	2.5	18.5	161.2	34.1	86.3	9.15	430.1	177.52	82.1
Haj Hamid-1	ArrUPA	19.01.01	1720	954	7.41	6.9	14.8	153.4	28.3	92.3	7.1	348.7	165.0	121.6
Haj Hamid-2	ArrUPA	07.02.00	1125	640	8.1	6.5	13.4	105.1	44.5	60.2	1.93	235.0	177.3	110.8
Haj Hamid-2	ArrUPA	10.05.99	1296	754	8.15	5.1	18.8	119.0	51.3	71.6	3.92	268.6	216.97	130.19
Haj Omar	ArrUPA	07.02.00	1650	900	7.89	5.8	14.2	156.3	39.9	109.8	7.50	363.6	225.3	138.9
Haj Omar	ArrUPA	10.05.99	1910	1044	8.24	3.8	17.1	182.1	45.2	123.5	9.66	380.8	279.1	160.69
Haj Hamid-1	ArrUPA	25.6.96	2307	1199	7.93	7.4	17.8	226.5	40.2	123.8	9.3	495	213.9	103.3
Haj Hamid-1	ArrUPA	18.3.97	1949	1033	8.1	7.4	17.8	183.9	62.8	90.7	5.8	540	180.3	103
Haj Hamid-1	ArrUPA	28.4.97	1711	976	8.14	6.4	17.6	185.6	33.3	104.8	4.7	439	160.9	110.4
Haj Hamid-1	ArrUPA	6.10.97	1689	1001	7.79	5.4	16.5	139.8	30	151.2	8.3	303	173.2	100.9
Haj Hamid-1	ArrUPA	1.12.97	851	458	8.17	6.4	16.6	115.7	22.8	20.7	3.2	432	25.9	28
Haj Hamid-1	ArrUPA	26.1.98	1649	982	7.92	6.5	16.7	125.6	47.5	139.8	5.7	395	159.6	104.9
Jamal Nassar	ArrUPA	07.02.00	933	516	7.99	6.4	12.4	85.5	29.7	48.8	17.30	255.0	125.9	38.7
Jamal Nassar	ArrUPA	10.05.99	1000	590	8.32	5.6	20.1	93.6	33.4	59.3	21.46	299.0	130.2	48.2
Kamal Dahshan	ArrUPA	03.02.01	657	374	7.68	7.2	16	78	32	18.0	1.1	332.0	38.0	29.0
Mohammed Hussein	ArrUPA	07.02.00	582	308	7.69	8.1	14.3	63.4	19.5	23.9	0.98	245.9	41.3	19.9
Mohammed Hussein	ArrUPA	10.05.99	618	364	7.81	8.2	20.3	73.0	26.2	25.4	1.63	289.7	48.32	21.7
Hassan Sowan	ArrUPA	19.01.01	1310	750	7.67	6.1	12.6	103.4	32.6	78.1	10.5	442.9	113.2	46.8
Hassan Sowan	ArrUPA	25.6.96	554	316	8.01	7.2	18.7	96.5	3.3	16.7	0.6	254	33.1	16.7
Hassan Sowan	ArrUPA	18.3.97	827	438	7.65	8.6	17.9	73	41.2	28.1	2.6	259	92.1	47.7
Hassan Sowan	ArrUPA	28.4.97	664	378	7.87	6.7	27.4	87.8	20.4	28.6	2.2	327	52.9	10.1
Hassan Sowan	ArrUPA	6.10.97	589	312	8	6.2	18.2	65.6	18.8	26.8	1.3	270	36.8	16
Hassan Sowan	ArrUPA	1.12.97	714	367	7.77	6.2	17.6	100.4	21.8	9.6	0.4	340	31.9	19.4
Hassan Sowan	ArrUPA	26.1.98	984	520	7.68	4.3	16.3	75.6	41.3	59.9	3	393	74.3	36.9
Si'ir	CenLPA	18.3.96	1315	697	7.97	9.1	16.8	150.7	17.9	47.5	12	270	117.6	57.8
Si'ir	CenLPA	1.7.96	901	505	7.74	7.2	25	94.9	28.1	35	18.8	305	95.2	33.5
Si'ir	CenLPA	2.12.96	1099	626	7.99	8	20.4	140.2	29	43.5	13.9	475	77.8	36.5
Si'ir	CenLPA	18.3.97	1061	552	7.76	7.2	18	104.6	32.5	41.9	15.5	365	78.4	47.4
Si'ir	CenLPA	28.4.97	987	504	7.71	8.2	17.9	99	22.5	45.2	13	317	76.5	46
Si'ir	CenLPA	6.10.97	795	438	7.67	4.65	16.8	98.4	23.4	14.6	20	260	70.7	37.3
Si'ir	CenLPA	1.12.97	1082	659	7.67	6.3	18.3	95.6	30.9	52.3	53	298	95.6	51.8
Si'ir	CenLPA	26.1.98	1325	791	7.76	4.8	15.9	89.6	36.3	86.8	80	377	135.6	49.7
Beit Fajjar 3	Cen-Tur	18.9.95	559	302	7.4	7.1	21.4	56.87	30.55	17	2.5	290	32.86	9.2
Beit Fajjar 3	Cen-Tur	2.1.96	455	241	8.04	6.5	15.8	53.3	15	19	3.5	208	30.3	10
Beit Fajjar 3	Cen-Tur	17.6.96	630	334	7.52	6.4	20.5	81.5	20.3	19	1.1	310	35.3	10.1
Beit Fajjar 3	Cen-Tur	9.12.96	645	342	7.61	6.8	22.5	86.9	23.6	13.9	1.3	318	44.7	6.6
Beit Fajjar 3	Cen-Tur	17.3.97	604	314	7.9	7.9	22.5	61.1	28.5	17	1.4	273	48	7.6
Beit Fajjar 3	Cen-Tur	9.6.97	586	323	7.57	8.1	25	68.7	22.1	22.5	1.4	306	31.2	8.1
Beit Fajjar 3	Cen-Tur	29.9.97	542	287	7.75	7.9	18.2	60.2	20.7	20.9	1.3	259	35.8	8.3
Beit Fajjar 3	Cen-Tur	9.2.98	624	320	7.87	6.8	15	52.8	31.7	21.5	1.4	318	26.5	7.5
Herodion 5	Cen-Tur	17.6.96	675	358	8.02	7.69	17.6	90.8	16.2	24	1.3	322	39.4	11.1
Herodion 5	Cen-Tur	9.12.96	618	389	7.24	7.3	15.5	91.1	31.1	14.5	1.4	358	48.6	9.4
Herodion 5	Cen-Tur	17.3.97	643	341	8.19	8.5	21.8	62.6	28.5	26.5	1.3	304	45	9.5
Herodion 5	Cen-Tur	9.6.97	595	327	7.83	7.5	23.2	73.2	20.2	20	1.8	301	36.1	10.3
Herodion 5	Cen-Tur	29.9.97	568	301	7.96	8.3	18.2	59.4	21.1	25.6	1.3	254	42.8	10.4
Herbron 1	Cen-Tur	17.6.96	1005	573	8	7.4	22.8	19.23	2.3	195.2	3.6	170	196	52.4

Well / Spring	Aquifer	Date	NO_3^-	F^-	SiO_2	PO_4^{3-}	Fe	Cu	Mn	Pb	Cd	Zn	FC	TC
			mg/L	mg/L	mg/L	mg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	#/100ml	#/100ml
Birkat Eid	ArrUPA	10.05.99	129	0.23	11.8	0.06	31.0	8.0	15.0	3.0	5.0	16.0	650	780
Birkat Eid	ArrUPA	07.02.00	67.2	0.22	12.1	0.12	54.0	2.0	30.0	1.0	1.0	22.0	640	980
Birkat Eid	ArrUPA	19.01.01	175.2	0.2	5.74	3.04	44.0	2.4	25.0	0.7	0.1	8.0	350	1200
Dahshan	ArrUPA	15.11.98	26.8	0.50	25.8	0.69	14.9	3.0	2.0	28.0	6.0	76.9	> 1000	> 2000
Ed-Dilbi	ArrUPA	07.02.00	6.4	0.1	8.8	0.02	7.0	9.0	12.0	25.0	10.0	8.0	5	12
Ed-Dilbi	ArrUPA	19.01.01	16.3	0.21	1.39	0.56	10.0	0.7	7.0	0.7	< 0.1	< 6	8	19
Ed-Dilbi	ArrUPA	10.05.99	8.94	0.13	9.1	0.09	9.0	15.0	8.0	6.0	11.0	15.0	13	27
El Bas - East	ArrUPA	10.05.99	18.44	0.18	13.4	0.10	8.0	10.0	7.0	11.0	10.0	8.0	10	56
El Bas - East	ArrUPA	07.02.00	14.3	0.10	10.8	0.05	15.0	7.0	10.0	18.0	15.0	14.0	2	5
El Bas-West	ArrUPA	19.01.01	22.4	0.1	3.13	0.32	15.0	2.1	8.0	0.7	0.1	< 6	8	24
El Bas-West	ArrUPA	07.02.00	12.34	0.12	13.4	0.09	14.0	6.0	5.0	18.0	13.0	18.0	8	21
El Bas-West	ArrUPA	10.05.99	24.2	0.09	11.5	0.1	12.0	8.0	3.0	8.0	15.0	11.0	5	15
El Bas-West	ArrUPA	15.11.97	12.3	0.67	27.53	0.05	11.9	3.9	6.6	13.2	28.0	21.7	> 1000	> 2000
El Bas-West	ArrUPA	25.11.98	16.9	0.62	24.28	0.09	27.1	< 0.6	< 0.5	5.8	38.0	16.3	> 1000	> 2000
Yousef Isleem	ArrUPA	19.01.01	150.4	0.09	4	0.8	14.0	6.0	15.0	0.7	0.1	< 6	15	34
Haj Hamid-1	ArrUPA	10.05.99	168	0.018	12.8	0.11	50.0	1.0	1.0	8.0	2.0	30.0	120	350
Haj Hamid-1	ArrUPA	07.02.00	75.5	0.26	14.2	0.09	32.0	3.0	6.0	10.0	1.0	45.0	200	570
Haj Hamid-1	ArrUPA	19.01.01	211.6	0.12	2.26	0.44	35.0	2.7	3.0	1.0	< 0.1	< 6	430	920
Haj Hamid-2	ArrUPA	07.02.00	23.1	0.25	18.5	0.05	10.0	5.0	6.0	3.0	4.0	10.0	20	80
Haj Hamid-2	ArrUPA	10.05.99	27.01	0.30	20.3	0.09	15.0	3.0	10.0	5.0	2.0	7.0	35	65
Haj Omar	ArrUPA	07.02.00	40.2	0.40	9.5	0.06	25.0	2.0	1.0	5.0	3.0	10.0	5	15
Haj Omar	ArrUPA	10.05.99	53.1	0.51	10.9	0.11	15.0	2.0	3.0	8.0	5.0	8.0	30	90
Haj Hamid-1	ArrUPA	25.6.96	235	0.06	25.42	0.40	123.0	5.0	0.6	0.0	< 0.1	< 6	> 1000	> 2000
Haj Hamid-2	ArrUPA	18.3.97	136.8	0.29	18.17	0.10	9.0	1.0	< 0.5	1.0	0.1	8.0	240	508
Haj Hamid-3	ArrUPA	28.4.97	156.3	0.61	24.74	0.07	3.7	3.3	< 0.5	< 0.7	0.8	10.0	> 1000	> 2000
Haj Hamid-4	ArrUPA	6.10.97	255	0.09	23.6	0.04	71.0	1.0	< 0.5	7.8	1.4	20.3	> 1000	> 2000
Haj Hamid-5	ArrUPA	1.12.97	17.5	0.16	12	0.03	14.2	4.4	< 0.5	5.7	1.3	29.5	370	550
Haj Hamid-6	ArrUPA	26.1.98	196.3	0.04	19.7	0.04	21.7	0.6	28.9	1.9	0.1	34.4	250	> 2000
Jamal Nassar	ArrUPA	07.02.00	42.3	0.15	8.9	0.17	15.0	2.0	10.0	9.0	5.0	25.0	100	250
Jamal Nassar	ArrUPA	10.05.99	54.5	0.16	9.3	0.15	5.0	7.0	6.0	5.0	8.0	12.0	140	370
Kamal Dahshan	ArrUPA	03.02.01	12.0	0.1	8.5	0.25	30.0	1.3	15.0	0.8	< 0.1	20.0	15	40
Mohammed Hussein	ArrUPA	07.02.00	15.8	0.00	7.3	0.15	15.0	3.0	2.0	8.0	8.0	10.0	12	20
Mohammed Hussein	ArrUPA	10.05.99	22.81	0.02	7.1	0.11	7.0	5.0	5.0	10.0	5.0	13.0	14	34
Hassan Sowan	ArrUPA	19.01.01	144.0	0.23	7.48	5.28	70.0	2.3	150.0	1.8	0.1	20.0	50	250
Hassan Sowan	ArrUPA	25.6.96	21.7	0.08	24.78	0.36	17.0	4.0	16.0	3.0	6.4	8.5	> 1000	> 2000
Hassan Sowan	ArrUPA	18.3.97	24.2	0.26	7.87	0.21	0.0	7.0	< 0.5	< 0.7	0.1	11.0	26	100
Hassan Sowan	ArrUPA	28.4.97	12.5	0.30	26.7	0.64	29.7	2.0	1.0	1.0	3.0	20.0	0	0
Hassan Sowan	ArrUPA	6.10.97	17.2	0.03	14	0.09	111.7	< 0.6	22.4	2.1	0.1	10.8	180	230
Hassan Sowan	ArrUPA	1.12.97	18.1	0.06	12.5	0.04	1.2	3.2	1.8	4.3	0.7	21.4	> 1000	> 2000
Hassan Sowan	ArrUPA	26.1.98	29.8	0.16	16	0.37	30.5	1.4	22.5	1.7	< 0.1	23.1	400	> 2000
Si'ir	Cen-LPA	18.3.96	158.4	0.33	16.23	0.25	9.0	3.0	< 0.5	1.7	< 0.1	9.9	16	80
Si'ir	Cen-LPA	1.7.96	46.9	0.35	21.3	0.22	10.0	12.0	1.0	< 0.7	1.0	< 6	25	60
Si'ir	Cen-LPA	2.12.96	48	0.02	19.43	0.12	31.1	4.6	39.9	1.0	1.9	8.6	462	> 2000
Si'ir	Cen-LPA	18.3.97	48.8	0.10	14.9	0.45	17.3	3.0	1.0	1.0	2.0	< 6	> 1000	> 2000
Si'ir	Cen-LPA	28.4.97	42.7	0.91	11.4	0.13	5.0	5.0	13.0	1.3	1.7	6.4	0	0
Si'ir	Cen-LPA	6.10.97	53.4	0.08	20.92	0.60	71.5	< 0.6	10.7	4.5	< 0.1	17.6	450	620
Si'ir	Cen-LPA	1.12.97	134	0.01	22.3	0.07	8.7	2.6	90.5	1.3	< 0.1	32.3	280	620
Si'ir	Cen-LPA	26.1.98	127.8	0.02	29.9	0.77	3.7	1.3	35.4	1.9	0.1	25.6	400	800
Beit Fajjar 3	Cen-Tur	18.9.95	13.3	0.03	28.6	0.32	23.0	5.0	1.0	0.7	0.1	< 6	0	0
Beit Fajjar 3	Cen-Tur	2.1.96	12.9	0.17	11.49	0.26	77.0	3.0	6.0	< 0.7	1.8	6.4	0	0
Beit Fajjar 3	Cen-Tur	17.6.96	13.4	0.06	18.61	0.57	24.0	17.0	7.0	< 0.7	0.5	6.4	0	0
Beit Fajjar 3	Cen-Tur	9.12.96	14.2	0.12	11.35	0.16	25.0	5.0	3.0	1.1	2.3	6.0	0	0
Beit Fajjar 3	Cen-Tur	17.3.97	14	0.21	23.09	0.10	4.0	1.0	< 0.5	1.9	0.1	< 6	0	0
Beit Fajjar 3	Cen-Tur	9.6.97	15.6	0.28	30.05	0.10	7.0	1.0	< 0.5	< 0.7	0.1	< 6	0	0
Beit Fajjar 3	Cen-Tur	29.9.97	15.4	0.09	20.81	0.01	25.6	< 0.6	12.7	7.2	1.6	15.6	0	0
Beit Fajjar 3	Cen-Tur	9.2.98	13.5	0.07	19.3	0.10	2.9	0.6	26.9	1.7	0.1	18.8	0	0
Herodion 5	Cen-Tur	17.6.96	13.7	0.03	21.45	0.06	11.0	6.5	< 0.5	0.7	1.7	7.2	0	0
Herodion 5	Cen-Tur	9.12.96	14.1	0.80	19.12	0.09	36.0	6.0	5.0	1.0	< 0.1	14.0	0	0
Herodion 5	Cen-Tur	17.3.97	15.4	0.28	8.72	0.24	47.0	4.0	< 0.5	< 0.7	< 0.1	15.6	0	0
Herodion 5	Cen-Tur	9.6.97	15.5	0.05	28.51	0.18	26.0	2.0	10.0	< 0.7	< 0.1	3.1	0	0
Herodion 5	Cen-Tur	29.9.97	17.9	0.11	19.55	0.07	15.6	9.4	8.6	1.9	< 0.1	18.0	0	0
Herbron 1	Cen-Tur	17.6.96	19.1	0.49	19.7	0.12	10.0	22.0	5.0	12.0	1.0	< 6	0	0

Appendix 8.1 (continue)

Well / Spring	Aquifer	Date	EC	TDS	PH	DO	T	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	HCO_3^-	Cl^-	SO_4^{2-}
			µS/cm	mg/L		mg/L	°C	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
Kuweisiba-1	Cen-UPA	18.3.96	541	276	8.1	7.2	22	67	15.6	10	0.8	231	17.6	15.3
Kuweisiba-1	Cen-UPA	1.7.96	492	281	7.89	6.7	19.7	67.5	18.3	11.5	2	227	40.8	14.6
Kuweisiba-1	Cen-UPA	2.12.96	714	385	7.96	6.6	14.6	95.6	25.2	14	2.5	360	31.1	24
Kuweisiba-1	Cen-UPA	18.3.97	664	339	7.63	6.8	17.8	79.3	24.9	11.6	1.6	271	56.8	15.5
Kuweisiba-1	Cen-UPA	28.4.97	471	269	8.08	7.2	25	70.3	13	14.3	0.4	244	29.4	7.82
Kuweisiba-1	Cen-UPA	6.10.97	521	276	8	7.8	16.7	58.6	20.7	17.1	0.5	240	30.9	15
Kuweisiba-1	Cen-UPA	1.12.97	546	294	7.66	6.4	17.6	65.7	19.5	14.5	0.9	237	29.9	21.5
Kuweisiba-1	Cen-UPA	26.1.98	568	291	7.81	6.5	14.9	49.6	28.4	19.3	0.9	271	20.6	19.9
Kuweisiba-1	Cen-UPA	07.02.00	525	292	7.29	6.4	10.1	65.3	15.5	22.5	0.40	237.7	37.4	13.7
Kuweisiba-1	Cen-UPA	10.05.99	472	281	7.7	5.9	18.5	57.1	13.8	30.2	0.41	250.3	25.64	16.04
Misleh	AUPA	07.02.00	725	387	7.57	7.9	10.3	88.5	31.4	11.1	0.30	322.5	32.2	38.9
Misleh	AUPA	19.11.98	689	393	7.96	7.2	25	112.3	17.9	12.5	0.15	363	31.1	25.9
Misleh	AUPA	18.3.97	689	379	7.72	7.6	21.7	90	26.5	14	0.7	310	45.1	35.1
Misleh	AUPA	28.4.97	621	329	8.09	7.6	15.9	74.3	26.5	14.3	0.24	310	34.3	11.5
Misleh	AUPA	6.10.97	643	341	8.1	8	15.9	78.1	22.5	16.6	5.6	301	33.8	27.8
Misleh	AUPA	26.1.98	701	355	7.83	6.6	16.5	67.2	31.7	26.5	0.2	341	22.8	30.1
Misleh	AUPA	10.05.99	655	356	8.55	6.4	19.2	78.4	26.2	14.8	0.51	295.3	30.1	33.96
Eth Tharwa	AUPA	10.05.99	1075	617	8.22	6.4	19.5	131.7	31.5	49.4	1.02	365.1	108.35	65.09
Eth Tharwa	AUPA	07.02.00	1235	652	7.47	7.0	11.2	137.7	27.7	50.0	2.00	320.1	98.4	82.4
Eth Tharwa	AUPA	28.4.97	1009	535	8.15	8.5	17.4	100	35	50	1.6	365	100	23.9
Eth Tharwa	AUPA	4.3.96	1227	699	7.54	7.2	15.2	163.7	21.2	53	2	451	101.9	17.8
Eth Tharwa	AUPA	1.7.96	1121	639	7.92	6.8	24.6	155.6	27.1	39.5	0.9	400	103.1	65.8
Eth Tharwa	AUPA	19.11.96	1228	700	8.03	6.5	23.9	163.5	30.8	46	2.8	445	112.8	69.2
Eth Tharwa	AUPA	18.3.97	1221	623	7.8	8.2	20.4	100	32.5	81.4	2.8	366	98	75.9
Eth Tharwa	AUPA	6.10.97	1195	658	8.09	7.9	18.7	132.8	27.2	61	1.1	355	89.6	66.1
Eth Tharwa	AUPA	26.1.98	1210	670	7.8	6.9	16.8	104	37.2	84.3	1.6	373	98.6	71.6

Well / Spring	Aquifer	Date	NO3-	F-	SiO2	PO4	Fe	Cu	Mn	Pb	Cd	Zn	FC	TC
			mg/L	mg/L	mg/L	mg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	#/100ml	#/100ml
Kuweisiba-1	Cen-UPA	18.3.96	34.4	0.06	15.66	0.20	46.8	13.1	< 0.5	4.9	8.8	10.0	> 1000	> 2000
Kuweisiba-1	Cen-UPA	1.7.96	12.5	0.10	20.2	0.84	17.8	1.0	1.0	4.0	1.0	< 6	0	0
Kuweisiba-1	Cen-UPA	2.12.96	12.9	0.13	22.37	0.28	17.0	1.0	< 0.5	0.7	< 0.1	15.2	0	8
Kuweisiba-1	Cen-UPA	18.3.97	13.7	0.08	16.4	0.15	57.0	8.0	0.7	1.7	< 0.1	15.2	52	124
Kuweisiba-1	Cen-UPA	28.4.97	11.7	0.56	18.5	0.15	12.0	6.0	4.0	15.0	1.0	< 6	46	70
Kuweisiba-1	Cen-UPA	6.10.97	17.3	0.05	16.1	0.07	33.5	< 0.6	3.5	3.2	0.7	12.5	570	840
Kuweisiba-1	Cen-UPA	1.12.97	17.5	0.22	15.1	0.06	22.9	3.3	< 0.5	3.7	0.6	27.1	> 1000	> 2000
Kuweisiba-1	Cen-UPA	26.1.98	13.3	0.08	15.8	0.05	28.1	0.6	10.5	1.3	< 0.1	18.0	> 1000	> 2000
Kuweisiba-1	Cen-UPA	07.02.00	17.9	0.013	9.4	0.06	12.0	2.0	4.0	5.0	1.0	15.0	5	25
Kuweisiba-1	Cen-UPA	10.05.99	12.66	0.15	10.3	0.09	18.0	5.0	8.0	7.0	3.0	8.0	2	12
Misleh	AUPA	07.02.00	23.6	0.029	11.3	0.9	6.0	10.0	5.0	3.0	4.0	12.0	0	0
Misleh	AUPA	19.11.98	11.7	0.58	22.4	0.17	6.0	10.0	2.0	1.0	< 0.1	< 6	22	45
Misleh	AUPA	18.3.97	12.3	0.04	26.86	0.27	25.0	1.0	0.5	< 0.7	0.1	< 6	> 1000	> 2000
Misleh	AUPA	28.4.97	13.1	0.04	34.82	0.57	64.0	1.0	3.0	< 0.7	0.1	6.0	> 1000	> 2000
Misleh	AUPA	6.10.97	12.7	0.09	18.16	0.09	16.1	< 0.6	8.3	10.3	0.7	14.3	140	220
Misleh	AUPA	26.1.98	12.2	0.09	17.4	0.01	10.2	1.3	13.7	2.3	< 0.1	30.0	0	30
Misleh	AUPA	10.05.99	23.97	0.36	11.6	0.08	8.0	15.0	4.0	5.0	7.0	10.0	0	5
Eth Tharwa	AUPA	10.05.99	47.5	0.73	10.6	0.08	2.0	15.0	4.0	3.0	3.0	10.0	30	98
Eth Tharwa	AUPA	07.02.00	93.9	0.55	9.8	0.01	3.0	10.0	6.0	1.0	1.0	7.0	12	40
Eth Tharwa	AUPA	28.4.97	41.8	0.27	26.7	0.10	13.0	< 0.6	< 0.5	1.3	< 0.1	7.6	152	224
Eth Tharwa	AUPA	4.3.96	114	0.20	10.99	0.02	11.0	30.0	3.0	9.6	0.1	< 6	> 1000	> 2000
Eth Tharwa	AUPA	1.7.96	46.9	0.56	19.8	0.23	8.0	12.0	3.0	< 0.7	0.1	< 6	30	90
Eth Tharwa	AUPA	19.11.96	52.3	0.66	20.3	0.19	3.0	15.0	4.0	< 0.7	< 0.1	< 6	45	120
Eth Tharwa	AUPA	18.3.97	48.8	0.39	19.9	0.16	7.8	5.5	1.3	1.5	1.6	19.3	0	0
Eth Tharwa	AUPA	6.10.97	122.9	0.09	16.58	0.05	86.2	< 0.6	4.0	2.3	4.1	24.1	10	20
Eth Tharwa	AUPA	26.1.98	94	0.03	16.3	0.01	19.0	1.3	4.3	2.3	0.1	28.8	70	250

Appendix 8.2: The physical and chemical analysis of the rain water in Wadi Al Arroub drainage basin (1999-2001).

Parameter	Unit	Sample 1	Sample 2	Sample 3	Sample 4
Date		1.3.2000	26.12.01	27.01.01	22.02.01
pH		6.27	5.89	6.58	6.84
EC	µS/cm	66	64	49	75
TDS	mg/L	33	36	28	39
DO	mg/L	6.5	7.1	7.3	6.8
Ca^{2+}	mg/L	7.3	7.8	6.7	8.3
Mg^{2+}	mg/L	1.2	0.9	0.8	1.1
Na^{+}	mg/L	3.1	3.4	2.2	3.5
K^{+}	mg/L	0.30	0.65	0.2	0.5
HCO_3^-	mg/L	21.2	21.8	18.0	23.1
Cl^-	mg/L	5.2	4.8	3.9	4.1
SO_4^{2-}	mg/L	4.1	5.1	3.2	4.9
NO_3^-	mg/L	1.5	2.2	1.7	5.2
SiO_2	mg/L	0.21	0.5	1.86	0.72
PO_4^{3-}	mg/L	0.09	0.05	0.13	0.1
Fe	µg/L	19	25	20	15
Cu	µg/L	6	2.9	4.1	2.6
Mn	µg/L	6	23	19	21
Pb	µg/L	7	2.1	0.8	3
Cd	µg/L	1	0.13	0.11	1
Zn	µg/L	2	7	8	22
Cr	µg/L	0.46	1.2	1.2	1.8
Ni	µg/L	0.2	2.4	2.1	2
As	µg/L	1.1	1.0	1.9	0.2

Appendix 8.3: The physical and chemical analysis of the drinking water network (tap water) in Arroub Camp (1996-2000).

Sample	Unit	Sample 1	Sample 2	Sample 3	Sample 4
Date		15. 8.96	10.3.97	10.05.99	07.02.00
pH		7.53	7.46	7.45	7.8
EC	µS/cm	563	558	580	597
TDS	mg/L	298.05	286.05	310	321
DO	mg/L	7.63	7.92	7.55	7.42
Temp	°C	20.30	14.90	16.7	13.8
Ca^{2+}	mg/L	72.5	67.6	68.9	66.2
Mg^{2+}	mg/L	12.1	10.7	22.3	26.8
Na^{+}	mg/L	21.8	23.8	13.5	16.5
K^{+}	mg/L	1.9	2.1	1.2	2.0
HCO_3^-	mg/L	245.5	229.3	295.3	302.5
Cl^-	mg/L	39.3	42.3	32.0	35.6
SO_4^{2-}	mg/L	13.2	12.1	14.5	10.2
NO_3^-	mg/L	14.5	12.8	10.3	12.5

Appendix 8.4: The physical and chemical analysis of the waste water collected of the sewage conduit in Wadi Al Arroub (1999-2000).

Sample	Unit	Sample 1 upstream	Sample 2 downstream	Sample 3 upstream	Sample 4 downstream
Date		10.05.99	10.05.99	07.02.00	07.02.00
pH		8.78	8.75	7.54	7.55
EC	µS/cm	2850	3250	1675	1540
TDS	mg/L	1851	2042	1088	956
DO	mg/L	0.25	0.11	3.15	5.75
T	°C	24.6	23.4	9.2	8.7
Ca^{2+}	mg/L	135.0	123.0	141.2	134.4
Mg^{2+}	mg/L	34.8	36.7	42.7	33.5
Na^{+}	mg/L	618.0	720.0	195.0	165.0
K^{+}	mg/L	57.0	85.0	25.0	18.0
HCO_3^-	mg/L	487.0	550.0	463.0	420.0
Cl^-	mg/L	452.0	525.0	191.0	205.0
SO_4^{2-}	mg/L	59.0	43.0	67.0	45.0
NO_3^-	mg/L	65.0	59.0	95.0	45.0
F^-	mg/L	0.89	0.67	0.54	0.42
SiO_2	mg/L	1.5	1.3	8.8	6.9
PO_4^{3-}	mg/L	60.2	47.3	1.78	1.1
FC	Colony/100ml	$8*10^6$	$15*10^7$	$5*10^4$	$2*10^4$
TC	Colony/100ml	$16*10^7$	$25*10^8$	$10*10^4$	$14*10^4$
BOD_5	mg O_2/L	890	1432	145	87
COD	mg O_2/L	2746	3571	275	124
TSS	mg/L	2115	1980	950	430
Fe	µg/L	0.62	0.43	0.2	0.5
Mn	µg/L	0.13	0.055	0.05	0.11
Zn	µg/L	0.21	0.18	0.045	0.074
Cd	µg/L	0.09	0.1	0.08	0.05
Cr	µg/L	6	13	4	9
Cu	µg/L	13	18	3	7
Ni	µg/L	12	15	2	6
Pb	µg/L	1.1	1.5	0.8	1.1
As	µg/L	1	5	1	1.5

Appendix 8.5: The volatile organic chemicals content of the springs and dug wells sampled from Wadi Al Arroub drainage basin.

VOC's	Detection limit	Eth-Tharwa	Haj Hamid-1	Ed-Dilbi	Kuweisiba	Birkat Eid	Arroub	Birkat Eid	Waste water
Date		12.07.1999	12.07.1999	12.07.1999	12.07.1999	12.07.1999	12.07.1999	15.03.2000	15.03.2000
Limonen	0.9	< 0.85	< 0.85	< 0.85	< 0.85	< 0.85	< 0.85	< 0.85	40
Toluene	0.1	< 0.1	< 0.1	1.51	0.19	37.54	0.31	< 0.1	1.7
Styrene	0.25	< 0.25	< 0.25	< 0.25	< 0.25	< 0.25	< 0.25	3.2	< 0.25
Trichlorethylene	0.2	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2	3.5	< 0.2
O-dichlorobenzene	0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	14	35
Dimethyl disulfide	0.1	< 0.1	< 0.1	1.50	0.19	37.5	0.31	< 0.1	10
Dimethylsulfide	0.1	< 0.1	<0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	0.55
Diethyldisulfide	0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	1
Methylene chloride	0.04	< 0.04	< 0.04	< 0.04	< 0.04	0.89	1.24	< 0.04	< 0.04

Appendix 8.6: Descriptive statistics of the samples collected from the local and perched aquifers exposed in Wadi Al Arroub drainage basin.

A: Descriptive statistics of Albian aquifer

	N	Min.	Max.	Mean	Std. dev.
EC	30	408.00	692.00	572.9667	61.3056
TDS	30	216.00	369.00	309.8667	32.8599
DO	30	6.90	8.17	7.6853	0.3137
PH	30	4.30	8.90	6.9917	1.0028
T	30	13.20	21.40	17.7533	2.2903
Ca	30	39.10	97.70	70.5280	14.6682
Mg	30	10.20	39.40	22.9420	7.4537
Na	30	12.00	19.00	15.9800	1.8210
K	30	0.90	4.90	2.0533	0.9475
HCO_3	30	198.00	360.00	296.1333	41.7329
Cl	30	19.10	45.10	32.1953	6.3657
SO_4	30	6.00	16.00	10.3500	2.6135
NO_3	30	4.70	17.00	8.8967	3.7786
F	30	0.00	0.80	0.2173	0.2122
SIO_2	30	9.05	42.01	20.6860	6.7673
PO_4	30	0.02	0.73	0.1953	0.1719
Fe	30	0.20	122.00	29.3513	30.4355
Cu	30	0.11	104.00	10.7740	19.7241
Mn	30	0.06	22.59	5.2753	6.2661
Pb	30	0.00	15.65	2.3067	3.6064
Cd	30	0.00	11.40	1.3003	2.2830
Zn	30	0.96	32.00	11.9543	8.5578
FC	30	0.00	0.00	0.0000	0.0000
TC	30	0.00	0.00	0.0000	0.0000

B: Descriptive statistics of Arroub lower perched aquifer

	N	Min.	Max.	Mean	Std. dev.
EC	13	445.00	1019.00	746.1538	202.3746
TDS	13	233.00	540.00	405.1538	118.0338
DO	13	7.48	8.25	7.8400	0.2220
PH	13	1.70	7.80	6.4692	1.5665
T	13	12.20	19.50	16.7077	2.4737
Ca	13	59.10	135.00	99.1000	28.9837
Mg	13	8.70	34.90	20.5231	7.3808
Na	13	8.20	30.50	18.7615	7.4515
K	13	0.23	3.10	1.4185	0.8023
HCO_3	13	212.40	483.00	306.1077	80.7529
Cl	13	20.30	72.30	43.4946	16.6605
SO_4	13	8.70	49.40	27.1246	13.6941
NO_3	13	5.30	169.40	42.5054	44.2098
F	13	0.00	0.39	0.1154	0.1064
SIO_2	13	2.90	37.40	14.4431	11.8306
PO_4	13	0.02	0.68	0.1977	0.1952
Fe	13	2.00	18.00	10.9769	4.7056
Cu	13	0.10	10.00	3.3315	2.6329
Mn	13	0.24	18.00	4.7485	6.3365
Pb	13	0.70	8.00	3.4500	2.3197
Cd	13	0.00	18.00	3.5538	5.5006
Zn	13	5.15	31.74	13.4115	8.4751
FC	13	1.00	1500.00	359.2308	650.5025
TC	13	5.00	2500.00	631.9231	1068.8179

C: Descriptive statistics of Arroub upper perched aquifer

	N	Min.	Max.	Mean	Std. dev.
EC	60	387.00	2307.00	1030.9000	461.8599
TDS	60	168.00	1199.00	575.6667	266.1540
DO	60	6.88	8.32	7.8445	0.2821
PH	60	2.50	8.60	6.1548	1.3650
T	60	8.20	27.90	17.0850	3.4979
Ca	60	33.50	226.50	105.7333	41.6989
Mg	60	3.30	62.80	27.4433	11.7921
Na	60	7.30	151.20	55.6750	40.9043
K	60	0.30	21.46	6.3373	5.5052
HCO_3	60	145.90	540.00	320.7883	88.6451
Cl	60	17.70	292.30	99.3325	71.3765
SO_4	60	10.10	165.10	56.2660	38.5112
NO_3	60	6.40	255.00	65.0270	63.8742
F	60	0.00	0.67	0.1903	0.1600
SIO_2	60	1.39	27.53	13.3638	7.0670
PO_4	60	0.01	5.28	0.4488	0.9617
Fe	60	0.03	123.00	24.2013	24.0472
Cu	60	0.11	15.00	3.7042	3.0082
Mn	60	0.04	150.00	11.0147	20.0468
Pb	60	0.00	51.11	5.8473	8.3384
Cd	60	0.00	38.00	4.2667	6.8644
Zn	60	0.84	153.01	16.6767	21.3479
FC	60	0.00	1500.00	372.0667	521.1831
TC	60	0.00	2500.00	734.0333	935.8469

D: Descriptive statistics of the Cenomanian lower perched aquifer

	N	Min.	Max.	Mean	Std. dev.
EC	8	795.00	1325.00	1070.6250	184.0760
TDS	8	438.00	791.00	596.5000	117.5573
DO	8	7.67	7.99	7.7838	0.1263
PH	8	4.65	9.10	6.9313	1.5922
T	8	15.90	25.00	18.6375	2.9007
Ca	8	89.60	150.70	109.1250	22.9865
Mg	8	17.90	36.30	27.5750	5.9825
Na	8	14.60	86.80	45.8500	20.1319
K	8	12.00	80.00	28.2750	24.8225
HCO_3	8	260.00	475.00	333.3750	70.3926
Cl	8	70.70	135.60	93.4250	22.8155
SO_4	8	33.50	57.80	45.0000	8.4745
NO_3	8	42.70	158.40	82.5000	48.5347
F	8	0.01	0.91	0.2275	0.3077
SIO_2	8	11.40	29.90	19.5475	5.5896
PO_4	8	0.07	0.77	0.3263	0.2538
Fe	8	3.68	71.52	19.5387	22.7499
Cu	8	0.42	12.00	3.9975	3.5715
Mn	8	0.02	90.47	23.9363	31.0118
Pb	8	0.12	4.54	1.6063	1.2990
Cd	8	0.01	2.00	0.8350	0.9171
Zn	8	1.20	32.26	12.9338	11.2291
FC	8	0.00	1500.00	391.6250	489.6448
TC	8	0.00	2500.00	897.5000	1033.3545

E: Descriptive statistics of the Cenomanian upper perched aquifer

	N	Min.	Max.	Mean	Std. dev.
EC	10	471.00	714.00	551.4000	79.8947
TDS	10	269.00	385.00	298.4000	36.1116
DO	10	7.29	8.10	7.8120	0.2493
PH	10	5.90	7.80	6.7500	0.5339
T	10	10.10	25.00	17.6900	4.1184
Ca	10	49.60	95.60	67.6000	12.7048
Mg	10	13.00	28.40	19.4900	5.2672
Na	10	10.00	30.20	16.5000	6.1304
K	10	0.40	2.50	1.0410	0.7432
HCO_3	10	227.00	360.00	256.9000	39.2319
Cl	10	17.60	56.80	32.0140	11.1185
SO_4	10	7.82	24.00	16.3360	4.5244
NO_3	10	11.70	34.40	16.3860	6.7388
F	10	0.01	0.56	0.1443	0.1571
SIO_2	10	9.40	22.37	15.9830	3.9672
PO_4	10	0.05	0.84	0.1950	0.2384
Fe	10	12.00	57.00	26.5060	15.1485
Cu	10	0.09	13.11	4.0050	4.1322
Mn	10	0.06	10.53	3.2480	3.5835
Pb	10	0.67	15.00	4.6440	4.1079
Cd	10	0.02	8.79	1.6280	2.6609
Zn	10	2.00	27.13	12.7470	7.1891
FC	10	0.00	1500.00	517.5000	699.3399
TC	10	0.00	2500.00	857.9000	1160.3057

F: Descriptive statistics of the Cenomanian Turonian aquifer

	N	Min.	Max.	Mean	Std. dev.
EC	14	455.00	1005.00	624.9286	122.1459
TDS	14	241.00	573.00	339.4286	75.5286
DO	14	7.24	8.19	7.7786	0.2741
PH	14	6.40	8.50	7.4421	0.6627
T	14	15.00	25.00	20.0000	3.2363
Ca	14	19.23	91.10	65.5500	19.0091
Mg	14	2.30	31.70	22.2750	7.9197
Na	14	13.90	195.20	32.6143	46.9482
K	14	1.10	3.60	1.7571	.8309
HCO_3	14	170.00	358.00	285.0714	49.2395
Cl	14	26.50	196.00	49.4686	42.7279
SO_4	14	6.60	52.40	12.1786	11.6490
NO_3	14	12.90	19.10	14.8571	1.7999
F	14	0.03	0.80	0.1993	0.2151
SIO_2	14	8.72	30.05	20.0250	6.4310
PO_4	14	0.01	0.57	0.1700	0.1433
Fe	14	2.87	77.00	23.8664	19.7312
Cu	14	0.38	22.00	5.9164	6.3886
Mn	14	0.07	26.85	6.1429	7.1919
Pb	14	0.14	12.00	2.1593	3.3369
Cd	14	0.02	2.28	.6700	0.8305
Zn	14	1.21	18.75	8.9143	6.0801
FC	14	0.00	0.00	0.0000	0.0000
TC	14	0.00	0.00	0.0000	0.0000

G: Descriptive statistics of Albian upper perched aquifer

	N	Min.	Max.	Mean	Std. dev.
EC	16	621.00	1235.00	952.7500	261.1402
TDS	16	329.00	700.00	520.8125	149.2525
DO	16	7.47	8.55	7.9275	0.2816
PH	16	6.40	8.50	7.2938	0.6787
T	16	10.30	25.00	18.2625	4.2906
Ca	16	67.20	163.70	111.1125	32.4444
Mg	16	17.90	37.20	28.3063	5.0696
Na	16	11.10	84.30	39.0250	24.3429
K	16	0.15	5.60	1.4700	1.4049
HCO_3	16	295.30	451.00	355.1875	46.9410
Cl	16	22.80	112.80	71.2594	35.6370
SO_4	16	11.50	82.40	46.3156	23.5904
NO_3	16	11.70	122.90	48.2294	38.0856
F	16	0.03	0.73	.2943	0.2528
SIO_2	16	9.80	34.82	18.3444	6.9713
PO_4	16	0.01	0.90	0.1850	0.2364
Fe	16	2.00	86.22	18.0194	23.4611
Cu	16	0.05	30.00	8.0006	8.2886
Mn	16	0.00	13.68	4.1306	3.2640
Pb	16	0.14	10.33	2.7513	3.0813
Cd	16	0.00	7.00	1.3669	2.0805
Zn	16	2.28	29.99	11.7850	9.0653
FC	16	0.00	1500.00	313.1875	590.6366
TC	16	0.00	2500.00	540.1250	975.7175

Appendix 8.7: The results of the Kolmogorov-Smirnov test for normality.

Variable	**Sig.**	**Nor. / asym.**		**Variable**	**Sig.**	**Nor. / asym.**
EC	0.000	asymmetric		NO_3	0.000	asymmetric
TDS	0.000	asymmetric		F	0.000	asymmetric
DO	0.004	asymmetric		SiO_2	0.012	asymeteric
pH	0.004	asymmetric		PO_4	0.000	asymeteric
T	0.156	normal		Fe	0.000	asymmetric
Ca	0.051	normal		Cu	0.000	asymmetric
Mg	0.708	normal		Mn	0.000	asymmetric
Na	0.000	asymmetric		Pb	0.000	asymmetric
K	0.000	asymmetric		Cd	0.000	asymmetric
HCO_3	0.206	normal		Zn	0.000	asymmetric
Cl	0.000	asymmetric		FC	0.000	asymmetric
SO_4	0.000	asymmetric		TC	0.000	asymmetric

Appendix 8.8: The strength of the relation between the different studied variables based on Spearman correlation coefficients.

		EC	TDS	pH	DO	T	Ca	Mg	Na	K	HCO_3	Cl	SO_4	NO_3	F	SiO_2	PO_4	Fe	Cu	Mn	Pb	CD	Zn	FC	TC
EC	Pearson Correlation	1,000																							
	Sig. (2-tailed)	,																							
	N	151																							
TDS	Pearson Correlation	0,987**	1,000																						
	Sig. (2-tailed)	0,000	,																						
	N	151	151																						
PH	Pearson Correlation	0,097	0,078	1,000																					
	Sig. (2-tailed)	0,235	0,338	,																					
	N	151	151	151																					
DO	Pearson Correlation	-0,290**	-0,311**	-0,077	1,000																				
	Sig. (2-tailed)	0,000	0,000	0,346	,																				
	N	151	151	151	151																				
T	Pearson Correlation	-0,131	-0,121	0,249**	0,228**	1,000																			
	Sig. (2-tailed)	0,108	0,137	0,002	0,005	,																			
	N	151	151	151	151	151																			
Ca	Pearson Correlation	0,868**	0,871**	0,103	-0,199*	-0,036	1,000																		
	Sig. (2-tailed)	0,000	0,000	0,210	0,014	0,664	,																		
	N	151	151	151	151	151	151																		
Mg	Pearson Correlation	0,579**	0,577**	0,057	-0,284**	-0,125	0,419**	1,000																	
	Sig. (2-tailed)	0,000	0,000	0,485	0,000	0,125	0,000	,																	
	N	151	151	151	151	151	151	151																	
Na	Pearson Correlation	0,852**	0,867**	0,069	-0,296**	-0,113	0,581**	0,386**	1,000																
	Sig. (2-tailed)	0,000	0,000	0,398	0,000	0,167	0,000	0,000	,																
	N	151	151	151	151	151	151	151	151																
K	Pearson Correlation	0,382**	0,416**	-0,053	-0,288**	-0,115	0,214**	0,219**	0,366**	1,000															
	Sig. (2-tailed)	0,000	0,000	0,521	0,000	0,159	0,008	0,007	0,000	,															
	N	151	151	151	151	151	151	151	151	151															
HCO_3	Pearson Correlation	0,657**	0,645**	0,085	-0,273**	-0,017	0,718**	0,564**	0,422**	0,183*	1,000														
	Sig. (2-tailed)	0,000	0,000	0,297	0,001	0,835	0,000	0,000	0,000	0,024	,														
	N	151	151	151	151	151	151	151	151	151	151														
Cl	Pearson Correlation	0,901**	0,920**	0,083	-0,304**	-0,113	0,721**	0,524**	0,907**	0,379**	0,432**	1,000													
	Sig. (2-tailed)	0,000	0,000	0,312	0,000	0,168	0,000	0,000	0,000	0,000	0,000	,													
	N	151	151	151	151	151	151	151	151	151	151	151													
SO_4	Pearson Correlation	0,868**	0,882**	0,091	-0,301**	-0,136	0,739**	0,584**	0,758**	0,282**	0,384**	0,871**	1,000												
	Sig. (2-tailed)	0,000	0,000	0,267	0,000	0,095	0,000	0,000	0,000	0,000	0,000	0,000	,												
	N	151	151	151	151	151	151	151	151	151	151	151	151												
NO_3	Pearson Correlation	0,806**	0,820**	0,002	-0,151	-0,144	0,705**	0,308**	0,664**	0,428**	0,370**	0,644**	0,669**	1,000											
	Sig. (2-tailed)	0,000	0,000	0,978	0,064	0,077	0,000	0,000	0,000	0,000	0,000	0,000	0,000	,											
	N	151	151	151	151	151	151	151	151	151	151	151	151	151											
F	Pearson Correlation	0,121	0,123	0,105	-0,036	0,212**	0,143	0,130	0,100	-0,082	0,142	0,157	0,160*	-0,043	1,000										
	Sig. (2-tailed)	0,137	0,134	0,201	0,660	0,009	0,080	0,111	0,223	0,315	0,082	0,054	0,050	0,603	,										
	N	151	151	151	151	151	151	151	151	151	151	151	151	151	151										
SiO_2	Pearson Correlation	-0,044	-0,035	0,052	0,140	0,275**	0,028	0,090	-0,062	0,009	0,156	-0,061	-0,147	-0,085	0,100	1,000									
	Sig. (2-tailed)	0,595	0,670	0,524	0,087	0,001	0,737	0,271	0,451	0,916	0,055	0,461	0,071	0,302	0,223	,									
	N	151	151	151	151	151	151	151	151	151	151	151	151	151	151	151									

		EC	TDS	pH	DO	T	Ca	Mg	Na	K	HCO_3	Cl	SO_4	NO_3	F	SiO_2	PO_4	Fe	Cu	Mn	Pb	CD	Zn	FC	TC
PO_4	Pearson Correlation	0,204*	0,195*	0,006	-0,177*	-0,122	0,090	0,027	0,153	0,179*	0,200*	0,140	0,100	0,256**	0,027	-0,163*	1,000								
	Sig. (2-tailed)	0,012	0,017	0,944	0,030	0,137	0,270	0,747	0,060	0,028	0,014	0,088	0,221	0,002	0,739	0,045	,								
	N	151	151	151	151	151	151	151	151	151	151	151	151	151	151	151	151								
Fe	Pearson Correlation	0,106	0,115	-0,034	-0,026	-0,025	0,082	-0,060	0,145	0,002	0,034	0,110	0,025	0,198*	-0,120	0,066	0,201*	1,000							
	Sig. (2-tailed)	0,195	0,160	0,680	0,752	0,761	0,317	0,467	0,076	0,976	0,682	0,180	0,756	0,015	0,141	0,420	0,013	,							
	N	151	151	151	151	151	151	151	151	151	151	151	151	151	151	151	151	151							
Cu	Pearson Correlation	-0,099	-0,084	-0,151	0,036	0,024	-0,031	-0,063	-0,082	-0,085	0,022	-0,079	-0,120	-0,109	0,266**	-0,004	-0,081	0,040	1,000						
	Sig. (2-tailed)	0,228	0,307	0,064	0,659	0,769	0,707	0,443	0,315	0,300	0,791	0,334	0,144	0,184	0,001	0,964	0,320	0,625	,						
	N	151	151	151	151	151	151	151	151	151	151	151	151	151	151	151	151	151	151						
Mn	Pearson Correlation	0,158	0,179*	-0,008	-0,222**	-0,169*	0,014	0,121	0,175*	0,407**	0,186*	0,113	0,065	0,240**	-0,079	-0,089	0,599**	0,144	-0,082	1,000					
	Sig. (2-tailed)	0,052	0,027	0,927	0,006	0,038	0,865	0,140	0,032	0,000	0,022	0,167	0,427	0,003	0,337	0,279	0,000	0,077	0,317	,					
	N	151	151	151	151	151	151	151	151	151	151	151	151	151	151	151	151	151	151	151					
Pb	Pearson Correlation	-0,040	-0,030	0,179*	-0,019	-0,033	-0,082	-0,228**	0,134	-0,055	-0,193*	0,078	0,015	-0,067	-0,045	-0,114	-0,114	-0,016	0,026	-0,088	1,000				
	Sig. (2-tailed)	0,622	0,717	0,028	0,815	0,690	0,318	0,005	0,100	0,506	0,017	0,341	0,855	0,413	0,585	0,163	0,165	0,848	0,749	0,284	,				
	N	151	151	151	151	151	151	151	151	151	151	151	151	151	151	151	151	151	151	151	151				
Cd	Pearson Correlation	-0,141	-0,143	0,105	-0,059	-0,042	-0,142	-0,069	-0,105	-0,109	-0,184*	-0,100	-0,017	-0,154	0,098	-0,096	-0,122	-0,093	-0,035	-0,111	0,331**	1,000			
	Sig. (2-tailed)	0,083	0,081	0,198	0,474	0,605	0,082	0,398	0,199	0,182	0,024	0,220	0,839	0,059	0,229	0,243	0,136	0,255	0,665	0,175	0,000	,			
	N	151	151	151	151	151	151	151	151	151	151	151	151	151	151	151	151	151	151	151	151	151			
Zn	Pearson Correlation	0,028	0,053	0,090	-0,155	-0,044	0,034	0,014	0,061	0,088	0,047	0,025	0,063	0,047	0,002	0,137	-0,017	0,047	-0,001	0,103	0,155	0,063	1,000		
	Sig. (2-tailed)	0,733	0,516	0,271	0,058	0,592	0,677	0,866	0,459	0,282	0,564	0,761	0,440	0,563	0,979	0,092	0,832	0,563	0,987	0,207	0,058	0,441	,		
	N	151	151	151	151	151	151	151	151	151	151	151	151	151	151	151	151	151	151	151	151	151	151		
FC	Pearson Correlation	0,253**	0,232**	0,087	-0,155	0,028	0,276**	0,103	0,161*	0,044	0,272**	0,132	0,151	0,213**	-0,026	0,180*	0,010	0,099	-0,092	-0,054	0,095	0,192*	0,080	1,000	
	Sig. (2-tailed)	0,002	0,004	0,286	0,058	0,733	0,001	0,209	0,048	0,596	0,001	0,106	0,064	0,009	0,750	0,027	0,904	0,225	0,261	0,510	0,247	0,018	0,327	,	
	N	151	151	151	151	151	151	151	151	151	151	151	151	151	151	151	151	151	151	151	151	151	151	151	
TC	Pearson Correlation	0,325**	0,305**	0,081	-0,193*	0,016	0,307**	0,181*	0,242**	0,080	0,348**	0,185*	0,208*	0,272**	-0,062	0,165*	0,045	0,090	-0,109	0,033	0,062	0,157	0,104	0,948**	1,000
	Sig. (2-tailed)	0,000	0,000	0,322	0,017	0,847	0,000	0,026	0,003	0,331	0,000	0,023	0,010	0,001	0,449	0,043	0,586	0,271	0,184	0,688	0,448	0,054	0,202	0,000	,
	N	151	151	151	151	151	151	151	151	151	151	151	151	151	151	151	151	151	151	151	151	151	151	151	151

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

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

Appendix 8.9: Results of the Mann-Whitney test result, comparisons between the means of summer and winter (significant level of 0.05).

Variable	Sig.	Significant difference		Variable	Sig.	Significant difference
EC	0.959	No		NO_3	0.710	No
TDS	0.710	No		F	0.568	No
DO	0.703	No		SiO_2	0.250	No
PH	0.616	No		PO_4	0.622	No
T	0.000	Yes		Fe	0.489	No
Ca	0.320	No		Cu	0.295	No
Mg	0.556	No		Mn	0.876	No
Na	0.467	No		Pb	0.183	No
K	0.736	No		Cd	0.597	No
HCO_3^-	0.665	No		Zn	0.004	Yes
Cl^-	0.815	No		FC	0.509	No
SO_4^{2-}	0.883	No		TC	0.537	No

Appendix 8.10: Descriptive statistics of the samples collected from the local and perched aquifers exposed in Wadi Al Arroub drainage basin

A: Descriptive statistics of cluster 1 (Group A_1).

	N	Min.	Max.	Mean	Std. dev.
EC	61	471.00	1325.00	854.9836	238.3715
TDS	61	269.00	791.00	470.9836	137.8465
DO	61	7.12	8.55	7.8811	0.2719
PH	61	1.70	9.10	6.6892	1.1864
T	61	10.10	25.00	17.7049	3.3450
Ca	61	49.60	163.70	98.4607	26.8378
Mg	61	5.60	51.30	24.8131	8.1306
Na	61	10.00	114.60	33.2541	22.2141
K	61	0.15	80.00	6.6016	12.6663
HCO_3	61	189.50	483.00	311.1426	63.2452
Cl	61	17.60	216.97	66.2459	41.5000
SO_4	61	7.82	130.19	39.7984	22.5935
NO_3	61	5.30	169.40	47.5951	38.7438
F	61	.00	0.91	0.2090	0.2143
SIO_2	61	3.13	37.40	17.2228	7.3435
PO_4	61	0.01	1.92	0.2184	0.3025
Fe	61	2.00	86.22	18.1789	17.2876
Cu	61	0.05	30.00	5.1062	5.2777
Mn	61	0.00	90.47	7.0998	13.1961
Pb	61	0.12	51.11	4.6280	7.1285
Cd	61	0.00	38.00	2.9615	6.4040
Zn	61	0.84	153.01	14.9795	19.7816
FC	61	0.00	1500.00	385.2787	576.3945
TC	61	0.00	2500.00	695.0984	976.0308

B: Descriptive statistics of cluster 2 (GroupA_{2a}).

	N	Min.	Max.	Mean	Std. dev.
EC	43	408.00	692.00	579.8372	60.1716
TDS	43	216.00	389.00	313.3721	33.7851
DO	43	6.90	8.19	7.7084	0.3020
PH	43	4.30	8.90	7.1288	0.9352
T	43	13.20	25.00	18.3674	2.7484
Ca	43	39.10	97.70	70.1002	14.3466
Mg	43	10.20	39.40	23.2049	6.9071
Na	43	12.00	26.50	17.2279	3.2254
K	43	0.90	4.90	1.9209	0.8876
HCO_3	43	198.00	360.00	295.4651	40.1813
Cl	43	19.10	48.60	34.0098	7.0921
SO_4	43	6.00	16.00	9.9674	2.3629
NO_3	43	4.70	17.90	10.6000	4.1538
F	43	.00	0.80	0.2051	0.2088
SIO_2	43	8.72	42.01	20.4937	6.6714
PO_4	43	0.01	0.73	0.1888	0.1637
Fe	43	0.20	122.00	28.0156	27.5570
Cu	43	0.11	104.00	8.9314	16.8120
Mn	43	0.06	26.85	5.5642	6.5790
Pb	43	0.00	15.65	2.0333	3.1813
Cd	43	0.00	11.40	1.1021	1.9754
Zn	43	0.96	32.00	11.1788	7.9027
FC	43	0.00	0.00	0.0000	0.0000
TC	43	0.00	0.00	0.0000	0.0000

C: Descriptive statistics of cluster 3 (Group A_{2b}).

	N	Min.	Max.	Mean	Std. dev.
EC	13	387.00	657.00	513.4615	95.3079
TDS	13	168.00	374.00	272.3077	64.6289
DO	13	7.48	8.04	7.7731	0.1580
PH	13	5.80	7.80	6.9000	0.5627
T	13	12.10	21.40	16.6538	3.2398
Ca	13	33.50	79.40	60.1538	15.7055
Mg	13	8.70	32.00	16.7077	6.5832
Na	13	7.30	31.00	16.9615	7.5339
K	13	0.23	6.10	1.4692	1.5225
HCO_3	13	145.90	332.00	228.4462	58.7989
Cl	13	17.70	46.00	28.2754	8.2821
SO_4	13	8.70	37.42	19.8408	9.2624
NO_3	13	6.00	21.00	14.5115	5.0480
F	13	0.04	0.21	0.1231	4.990E-02
SIO_2	13	1.39	13.40	6.7531	3.3314
PO_4	13	0.01	0.56	0.1462	0.1516
Fe	13	5.00	30.00	12.6923	6.3428
Cu	13	0.10	15.00	4.1846	4.7637
Mn	13	0.80	22.00	9.3692	7.0620
Pb	13	0.70	25.00	6.3538	7.5761
Cd	13	0.02	18.00	6.7169	6.3147
Zn	13	5.00	20.00	10.0000	4.0825
FC	13	1.00	20.00	7.7692	5.7757
TC	13	5.00	65.00	25.4615	20.8391

D: Descriptive statistics of cluster 3 (Group B).

	N	Min.	Max.	Mean	Std. dev.
EC	26	554.00	2307.00	1337.7692	464.1640
TDS	26	312.00	1199.00	756.6923	264.0648
DO	26	6.88	8.24	7.8012	0.2883
PH	26	2.50	8.60	5.5615	1.5725
T	26	8.20	27.40	16.3692	3.5012
Ca	26	65.60	226.50	130.9385	39.7813
Mg	26	3.30	62.80	32.8769	12.0828
Na	26	9.60	151.20	82.5231	41.9715
K	26	0.40	20.40	8.0769	5.3622
HCO_3	26	254.00	540.00	387.1769	77.0925
Cl	26	25.90	292.30	139.6373	70.7046
SO_4	26	10.10	165.10	73.5331	45.0355
NO_3	26	9.96	255.00	95.6369	76.3985
F	26	0.02	0.61	0.2122	0.1635
SIO_2	26	2.26	26.70	13.8412	6.6832
PO_4	26	0.03	5.28	0.7327	1.3643
Fe	26	00.03	123.00	35.0635	31.8099
Cu	26	0.34	8.00	2.9931	1.8790
Mn	26	0.04	150.00	15.7608	29.3347
Pb	26	0.00	10.00	2.9158	2.8007
Cd	26	0.01	7.00	1.7369	2.0691
Zn	26	3.00	45.00	15.8231	10.4064
FC	26	0.00	1500.00	505.7308	548.1318
TC	26	0.00	2500.00	1074.9231	1008.9155

Appendix 8.11: Results of the Kruskal – Wallis test applied on the four groups resulted from cluster analysis.

Variable	**Sig.**	**Groups similarity**		**Variable**	**Sig.**	**Groups similarity**
EC	0.000	D		NO_3	0.000	D
TDS	0.000	D		F	0.766	S
DO	0.023	D		SiO_2	0.000	D
pH	0.000	D		PO_4	0.513	S
T	0.104	S		Fe	0.007	D
Ca	0.000	D		Cu	0.220	S
Mg	0.000	D		Mn	0.134	S
Na	0.000	D		Pb	0.000	D
K	0.000	D		Cd	0.027	D
HCO_3	0.000	D		Zn	0.175	S
Cl	0.000	D		FC	0.000	D
SO_4	0.000	D		TC	0.000	D

D: at least the mean of one group differs from the means of the other groups for the considered parameter.
S: all the group are of similar means for the considered parameter

Appendix 8.12: Comparison between the means of the four clusters (group A_1, A_{2a}, A_{2b}, and B) based on the nonparametric Mann-Whitney test ($\alpha = 0.05$).

EC	A_1	A_{2a}	A_{2b}	B
A_1	---------	0.000	0.000	0.000
A_{2a}		---------	0.094*	0.000
A_{2b}			---------	0.000
B				---------

TDS	A_1	A_{2a}	A_{2b}	B
A_1	---------	0.000	0.000	0.000
A_{2a}		---------	0.038	0.000
A_{2b}			---------	0.000
B				---------

pH	A_1	A_{2a}	A_{2b}	B
A_1	---------	0.091*	0.436*	0.661*
A_{2a}		---------	0.528*	0.041
A_{2b}			---------	0.185*
B				---------

DO	A_1	A_{2a}	A_{2b}	B
A_1	---------	0.205*	0.791*	0.000
A_{2a}		---------	0.347*	0.000
A_{2b}			---------	0.000
B				---------

T	A_1	A_{2a}	A_{2b}	B
A_1	---------	0.371*	0.270*	0.051*
A_{2a}		---------	0.092*	0.014
A_{2b}			---------	0.749*
B				---------

Ca	A_1	A_{2a}	A_{2b}	B
A_1	---------	0.001	0.004	0.000
A_{2a}		---------	0.575*	0.000
A_{2b}			---------	0.000
B				---------

Mg	A_1	A_{2a}	A_{2b}	B
A_1	---------	0.676*	0.000	0.000
A_{2a}		---------	0.010	0.000
A_{2b}			---------	0.000
B				---------

Na	A_1	A_{2a}	A_{2b}	B
A_1	---------	0.057*	0.003	0.000
A_{2a}		---------	0.056*	0.000
A_{2b}			---------	0.000
B				---------

K	A_1	A_{2a}	A_{2b}	B
A_1	---------	0.364*	0.002	0.000
A_{2a}		---------	0.001	0.000
A_{2b}			---------	0.000
B				---------

HCO_3	A_1	A_{2a}	A_{2b}	B
A_1	---------	0.882*	0.000	0.000
A_{2a}		---------	0.001	0.000
A_{2b}			---------	0.000
B				---------

Cl	A_1	A_{2a}	A_{2b}	B
A_1	---------	0.013	0.001	0.000
A_{2a}		---------	0.038	0.000
A_{2b}			---------	0.000
B				---------

SO_4	A_1	A_{2a}	A_{2b}	B
A_1	---------	0.000	0.310*	0.000
A_{2a}		---------	0.000	0.000
A_{2b}			---------	0.000
B				---------

NO3	A_1	A_{2a}	A_{2b}	B
A_1	---------	0.000	0.267*	0.000
A_{2a}		---------	0.026	0.000
A_{2b}			---------	0.000
B				---------

F	A_1	A_{2a}	A_{2b}	B
A_1	---------	0.793*	0.314*	0.500*
A_{2a}		---------	0.398*	0.407*
A_{2b}			---------	0.030
B				---------

SiO_2	A_1	A_{2a}	A_{2b}	B
A_1	---------	0.047	0.000	0.001
A_{2a}		---------	0.000	0.000
A_{2b}			---------	0.000
B				---------

PO_4	A_1	A_{2a}	A_{2b}	B
A_1	---------	0.651*	0.549*	0.576*
A_{2a}		---------	0.404*	0.889*
A_{2b}			---------	0.376*
B				---------

Fe	A_1	A_{2a}	A_{2b}	B
A_1	---------	0.221*	0.093*	0.026
A_{2a}		---------	0.013	0.385*
A_{2b}			---------	0.002
B				---------

Cu	A_1	A_{2a}	A_{2b}	B
A_1	---------	0.738*	0.134*	0.033
A_{2a}		---------	0.116*	0.029
A_{2b}			---------	0.579*
B				---------

Mn	A_1	A_{2a}	A_{2b}	B
A_1	---------	0.691*	0.225*	0.080*
A_{2a}		---------	0.154*	0.068*
A_{2b}			---------	0.771*
B				---------

Pb	A_1	A_{2a}	A_{2b}	B
A_1	---------	0.08*	0.123*	0.605*
A_{2a}		---------	0.001	0.002
A_{2b}			---------	0.351*
B				---------

Cd	A_1	A_{2a}	A_{2b}	B
A_1	---------	0.137*	0.010	0.184*
A_{2a}		---------	0.002	0.007
A_{2b}			---------	0.023
B				---------

Zn	A_1	A_{2a}	A_{2b}	B
A_1	---------	0.574*	0.661*	0.132*
A_{2a}		---------	0.611*	0.062*
A_{2b}			---------	0.062*
B				---------

FC	A_1	A_{2a}	A_{2b}	B
A_1	---------	0.000	0.836*	0.000
A_{2a}		---------	0.000	0.000
A_{2b}			---------	0.000
B				---------

TC	A_1	A_{2a}	A_{2b}	B
A_1	---------	0.000	0.749*	0.000
A_{2a}		---------	0.000	0.000
A_{2b}			---------	0.000
B				---------

- *: There is no significant difference between the means of the corresponding groups for the considered parameter.
- All other values indicate that there is significant difference between the means of the corresponding groups for the considered parameter.

Appendix 8.13: Palestinian standards and World Health Organization (WHO) guidelines for drinking water (After PWA, 2002 and WHO, 1995).

Parameters	**Palestinian standards (2001)**		**WHO guidelines 1996**	**Type of effect leads to consumer complains**
	Basic	**Conditional**		
Temp. ^{o}C	8-25			Aesthetic: should be acceptable
pH-value	6.5-8.5	9.5		Aesthetic: low pH: corrosion, high pH: taste and soapy feeling if > 12.
Na (mg/L)	200	400	200	Aesthetic: taste
Mg (mg/L)	50	120		Aesthetic
K (mg/L)	10	12	12	Aesthetic
Cl (mg/L)	250	600	250	Aesthetic: taste, corrosion
SO_4 (mg/L)	200	400	250	Aesthetic: taste, corrosion
NO_3 (mg/L)	50	70	50	Health significance
TDS (mg/L)	1000	1500	1000	Aesthetic: taste
Hardness (mg/L)	500	500	500	Aesthetic: high hardness: scale deposition, scum formation. Low hardness: possible corrosion
Fe (mg/L)	0.3	1.0	0.3	Aesthetic: Staining of laundry and sanitary ware
Mn (mg/L)	0.5	0.5	0.1	Aesthetic: staining of laundry and sanitary ware. Health significance: health based provisional guidelines value 0.5 mg/L.
Cu (mg/L)	1.0	1.5	1	Aesthetic: Staining of laundry and sanitary ware. Health significance: health based provisional guidelines value 2 mg/L.
Zn (mg/L)	5	10	3	Aesthetic: appearance and taste
Pb (mg/L)	0.1		0.01	Health significance
As (mg/L)	0.05		0.01	Health significance
Cr (mg/L)	0.05		0.05	Health significance
Cd (mg/L)	0.05		0.003	Health significance
Ni (mg/L)	0.05		0.02	Health significance
F (mg/L)	0.61	1.5	1.5	Health significance
Toluene	700			Nervous system, kidney, or liver problems *
Styrene	20			Liver, kidney or circulatory system problems*
o-dichlorobenzene	1000			Liver, kidney or circulatory system problems
Trichloroethylene	70			Liver problems, increased risk of cancer*
Methylene chloride	20			Cancer**

Parameters	Palestinian standards (2001)		WHO guidelines 1996	Type of effect leads to consumer complains
	Basic	Conditional		
Fecal coliform (colony/100 ml)	0	0	0	Health significance
Total coliform (colony/100 ml)	0	0	0	Health significance

Note: -Conditional Palestinian standards: are the maximum allowable limits, in the absence of other resources of better water quality.
*: U.S. Environmental Protection Agency (1995).
**: Minnesota Department of Health (2002).

Appendix 8.14A: Changes in the chemistry of the dug well water of Haj Hamid-1 as a result of mixing with rain water, tap water and water of El Bas springs.

Parameter	Mixing water		Haj Hamid	Mixing percentages (Haj Hamid : mixing water)								
				0.9 : 0.1	**0.8 : 0.2**	**0.7 : 0.3**	**0.6 : 0.4**	**0.5 : 0.5**	**0.4 : 0.6**	**0.3 : 0.7**	**0.2:0.8**	**0.1 : 0.9**
pH	El Bas	7.89	7.81	7.81	7.82	7.83	7.83	7.84	7.85	7.86	7.87	7.88
	Rain water	6.40		7.76	7.71	7.65	7.58	7.49	7.39	7.26	7.10	6.86
	Tap water	7.56		7.79	7.77	7.75	7.72	7.70	7.68	7.65	7.62	7.59
Ca	El Bas	75.2	164.0	155.1	146.2	137.4	128.5	119.6	110.7	101.8	93.0	84.1
	Rain water	7.5		148.3	132.7	117.0	101.4	85.7	70.1	54.5	38.8	23.2
	Tap water	68.8		154.5	144.9	135.4	125.9	116.4	106.9	97.3	87.8	78.3
Mg	El Bas	24.4	37.5	36.2	34.9	33.6	32.3	31.0	29.6	28.4	27.0	25.7
	Rain water	1.0		33.8	30.2	26.5	22.9	19.2	15.6	11.9	8.3	4.6
	Tap water	18.0		35.5	33.6	31.6	29.7	27.7	25.8	23.8	21.9	19.9
Na	El Bas	22.1	106.6	98.2	89.7	81.3	72.8	64.4	55.9	47.5	39.0	30.6
	Rain water	3.0		96.3	85.9	75.6	65.2	54.9	44.5	34.1	23.8	13.4
	Tap water	18.9		97.9	89.1	80.3	71.6	62.8	54.0	45.2	36.5	27.7
K	El Bas	1.1	7.6	7.0	6.3	5.7	5.0	4.4	3.7	3.1	2.4	1.8
	Rain water	0.4		6.9	6.2	5.5	4.8	4.0	3.3	2.6	1.9	1.1
	Tap water	1.8		7.1	6.5	5.9	5.3	4.7	4.1	3.6	3.0	2.4
HCO_3	El Bas	294.9	411.6	400.0	388.3	376.6	365.0	353.3	347.9	329.9	318.2	306.6
	Rain water	21.0		372.6	333.5	294.4	255.4	216.3	177.3	138.2	99.1	60.1
	Tap water	268.2		397.3	383.0	368.6	354.3	339.9	325.6	311.2	296.9	282.6
Cl	El Bas	34.2	172.2	158.4	144.6	130.8	117.0	103.2	89.4	75.6	61.8	48.0
	Rain water	4.5		155.4	138.6	121.9	105.1	88.3	71.6	54.8	38.0	21.3
	Tap water	37.3		158.7	145.2	131.7	118.2	104.7	91.2	77.8	64.3	50.8
SO_4	El Bas	34.4	102.2	95.4	88.6	81.9	75.1	68.3	61.5	54.7	47.9	41.2
	Rain water	4.3		92.4	82.6	72.8	63.0	53.3	43.5	33.7	23.9	14.1
	Tap water	12.5		93.2	84.3	75.3	66.3	57.3	48.4	39.4	30.4	21.5
NO_3	El Bas	16.4	161.4	146.9	132.4	117.9	103.4	88.9	74.4	59.9	45.4	30.9
	Rain water	2.6		145.5	129.6	113.7	97.9	82.0	66.1	50.3	34.4	18.5
	Tap water	12.5		146.5	131.6	116.7	101.8	86.9	72.0	57.2	42.3	27.4

Appendix 8.14B: Changes in the chemistry of the spring water of Si'ir as a result of mixing with rain water, tap water and water of El Bas springs.

Parameter	Mixing water		S'ir	Mixing percentages (Si'ir : mixing water)								
				0.9 : 0.1	0.8 : 0.2	0.7 : 0.3	0.6 : 0.4	0.5 : 0.5	0.4 : 0.6	0.3 : 0.7	0.2:0.8	0.1 : 0.9
pH	El Bas	7.89	7.8	7.808	7.816	7.824	7.832	7.841	7.85	7.86	7.869	7.879
	Rain water	6.395		7.745	7.683	7.612	7.531	7.438	7.33	7.201	7.039	6.812
	Tap water	7.56		7.777	7.754	7.73	7.707	7.682	7.658	7.634	7.609	7.585
Ca	El Bas	75.2	111.1	107.5	103.9	100.3	96.7	93.2	89.6	86.0	82.4	78.8
	Rain water	7.5		100.7	90.4	80.0	69.6	59.3	48.9	38.6	28.2	17.9
	Tap water	68.8		106.8	102.6	98.4	94.2	89.9	85.7	81.5	77.2	73.0
Mg	El Bas	24.4	27.1	26.8	26.6	26.3	26.0	25.8	25.5	25.2	25.0	24.7
	Rain water	1.0		24.5	21.9	19.3	16.7	14.0	11.4	8.8	6.2	3.6
	Tap water	18.0		26.2	25.3	24.4	23.4	22.5	21.6	20.7	19.8	18.9
K	El Bas	1.1	24.7	22.4	20.0	17.7	15.3	12.9	10.6	8.2	5.9	3.5
	Rain water	0.4		22.3	19.9	17.4	15.0	12.6	10.1	7.7	5.3	2.8
	Tap water	1.8		22.4	20.2	17.9	15.6	13.3	11.0	8.7	6.4	4.1
Na	El Bas	22.1	44.9	42.7	40.4	38.1	35.8	33.5	31.2	29.0	26.7	24.4
	Rain water	3.0		40.7	36.5	32.4	28.2	24.0	19.8	15.6	11.4	7.2
	Tap water	18.9		42.3	39.7	37.1	34.5	31.9	29.3	26.7	24.1	21.5
HCO_3	El Bas	294.9	338.5	334.1	329.8	325.4	321.0	316.7	312.3	308.0	303.6	299.3
	Rain water	21.0		306.7	275.0	243.2	211.5	179.7	148.0	116.3	84.5	52.7
	Tap water	268.2		331.4	324.4	317.4	310.4	303.4	296.3	289.3	282.2	275.2
Cl	El Bas	34.2	93.1	87.2	81.3	75.5	69.6	63.7	57.8	51.9	46.0	40.1
	Rain water	4.5		84.3	75.4	66.5	57.7	48.8	40.0	31.1	22.2	13.4
	Tap water	37.3		87.5	81.9	76.4	70.8	65.2	59.6	54.0	48.5	42.9
NO_3	El Bas	16.4	75.1	69.3	63.4	57.5	51.6	45.8	39.9	34.0	28.2	22.3
	Rain water	2.6		67.9	60.6	53.4	46.1	38.9	31.6	24.4	17.1	9.9
	Tap water	12.5		68.9	62.6	56.3	50.1	43.8	37.6	31.3	25.0	18.8
SO_4	El Bas	34.4	44.0	43.1	42.1	41.1	40.2	39.2	38.2	37.3	36.3	35.4
	Rain water	4.3		40.1	36.1	32.1	28.1	24.2	20.2	16.2	12.3	8.3
	Tap water	12.5		40.9	37.7	34.6	31.4	28.3	25.1	22.0	18.8	15.6

Appendix 10.1: Characteristics of the soil water at the different depths, above and below the conduit.

Code	Location	Depth	Date	pH	DO	EC	TDS	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	HCO_3^{-}	Cl^{-}	SO_4^{2-}	NO_3^{-}
					mg/L	µS/cm		mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
A30-1		30 cm	07.02.00	7.96	6.81	623	329	61.7	17.3	38.0	1.40	256.0	45.0	13.0	25.0
A30-2		30 cm	29.02.00	7.89	6.34	753	383	67.5	21.7	40.2	1.80	232.8	63.8	25.8	45.8
A30-3		30 cm	27.01.01	7.87		749	378	68.7	20.8	31.2	1.20	183.4	44.9	59.7	60.2
A30-4		30 cm	03.02.01	7.52	7.83	795	419	62.2	23.3	56.1	1.10	231.5	89.0	35.5	35.8
A30-5		30 cm	08.02.01	7.63		1030	532	63.2	33.5	78.5	1.10	241.5	125.0	65.0	45.2
A60-1	above the conduit	60 cm	07.02.00	8.01	6.81	729	437	81.9	21.4	47.5	2.10	289.0	68.2	25.0	45.9
A60-2		60 cm	29.02.00	7.94	6.19	1086	543	92.5	20.3	72.5	2.30	290.5	112.7	19.0	78.0
A60-3		60 cm	27.01.01	7.60		995	508	77.8	33.7	46.3	1.30	210.3	72.8	87.7	83.5
A60-4		60 cm	03.02.01	7.45	7.88	1129	614	87.7	38.8	73.5	1.80	285.5	113.0	55.5	101.0
A60-5		60 cm	08.02.01	7.72		1131	551	70.2	33.3	80.2	0.90	235.5	145.0	53.0	50.3
A90-1		90 cm	07.02.00	8.00	6.53	1253	629	117.3	32.6	67.5	3.50	387.0	115.0	23.0	77.0
A90-2		90 cm	29.02.00	7.86	6.12	1128	671	87.5	34.9	85.0	2.90	244.5	135.7	29.0	173.4
A90-3		90 cm	27.01.01	7.80		1128	607	90.5	43.8	53.7	1.00	285.6	88.4	111.6	75.5
A90-4		90 cm	03.02.01	7.72	8.04	1130	654	86.3	40.2	82.2	2.10	265.0	124.0	65.0	121.3
A90-5		90 cm	08.02.01	7.81		1250	672	65.5	45.6	103.3	0.80	233.5	156.3	114.0	70.2
B30-1		30 cm	07.02.00	8.00	0.05	1567	1068	143.0	43.0	183.0	15.00	450.3	279.0	114.6	65.0
B30-2		30 cm	29.02.00	8.09	1.05	1492	879	138.7	35.6	98.9	14.40	370.6	155.0	107.4	143.3
B30-3		30 cm	27.01.01	7.71		1312	700	126.0	22.7	73.0	15.40	305.0	117.0	114.0	79.0
B30-4		30 cm	08.02.01	8.12		1324	726	114.6	33.7	85.9	15.60	345.6	125.6	95.6	82.0
B60-1	below the conduit	60 cm	07.02.00	7.99	1.08	1711	1256	162.3	38.9	213.0	28.00	427.2	325.0	115.7	159.3
B60-2		60 cm	29.02.00	8.07	2.17	1614	991	158.2	48.7	109.6	12.30	395.3	177.0	131.6	155.6
B60-3		60 cm	27.01.01	8.10		1432	841	150.1	18.9	102.0	13.10	316.0	153.2	132.3	113.2
B60-4		60 cm	08.02.01	8.15		1354	767	124.2	27.3	97.6	12.40	275.6	145.6	129.5	92.3
B90-1		90 cm	07.02.00	8.04	5.83	2010	1302	145.3	50.2	234.0	9.40	410.4	356.0	120.9	181.4
B90-2		90 cm	29.02.00	8.13	5.99	1755	1123	172.8	43.2	142.3	11.60	428.0	218.0	139.2	181.6
B90-3		90 cm	27.01.01	7.54		1465	825	145.0	14.7	116.1	12.60	275.8	170.2	122.2	106.3
B90-4		90 cm	08.02.01	7.62		1403	802	109.0	17.5	138.5	13.30	246.5	218.9	104.5	77.4

Code	Location	Depth	Date	F^-	NH_3	SiO_2	PO_4^{3-}	Fe	Mn	Zn	Cd	Cr	Cu	Ni	Pb	As
				mg/L	mg/L	mg/L	mg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L
A30-1	above the conduit	30 cm	07.02.00	0.12	0.70	3.60	0.02									
A30-2		30 cm	29.02.00	0.14	0.00	4.45	0.05									
A30-3		30 cm	27.01.01			4.75	0.49	< 0.5	< 0.5	14	< 0.1	2.4	3.8	2.6	0.7	4.5
A30-4		30 cm	03.02.01			4.87	0.31	< 0.5	< 0.5	8	< 0.1	2.7	6.1	2. 0	2.3	6.0
A30-5		30 cm	08.02.01			5.11	0.42	< 0.5	< 0.5	< 6	< 0.1	3.3	3.8	2.8	1.0	2.3
A60-1		60 cm	07.02.00	0.35	0.06	4.40	0.06									
A60-2		60 cm	29.02.00	0.18	0.00	4.42	0.04									
A60-3		60 cm	27.01.01			4.00	0.71	< 0.5	< 0.5	33	< 0.1	2.8	4.5	2.8	0.8	3.0
A60-4		60 cm	03.02.01			4.23	0.42	< 0.5	< 0.5	6	< 0.1	3.7	3.9	1.9	1.5	< 1.5
A60-5		60 cm	08.02.01			4.39	0.47	< 0.5	< 0.5	34	< 0.1	2.4	3.0	1.5	0.8	2.3
A90-1		90 cm	07.02.00	0.31	0.05	3.90	0.02									
A90-2		90 cm	29.02.00	1.19	0.00	4.15	0.04									
A90-3		90 cm	27.01.01			4.03	0.07	< 0.5	< 0.5	15	< 0.1	6.0	7.3	2.5	1.0	< 1.5
A90-4		90 cm	03.02.01			4.24	0.05	< 0.5	< 0.5	<6	< 0.1	2.2	2.9	1.5	1.4	8.0
A90-5		90 cm	08.02.01			4.33	0.11	< 0.5	< 0.5	6	< 0.1	3.2	4.4	2.4	1.2	4.0
B30-1	below the conduit	30 cm	07.02.00	0.31	0.03	6.90	0.23									
B30-2		30 cm	29.02.00	0.58	0.05	6.80	0.03									
B30-3		30 cm	27.01.01			6.61	0.40	< 0.5	< 0.5	13	< 0.1	1.2	8.0	5.6	0.7	6.5
B30-4		30 cm	08.02.01			6.76	1.29	< 0.5	< 0.5	10	< 0.1	3.2	7.2	5.3	1.2	7.0
B60-1		60 cm	07.02.00	0.21	0.04	5.00	0.03									
B60-2		60 cm	29.02.00	0.38	0.06	5.20	0.05									
B60-3		60 cm	27.01.01			6.28	0.52	< 0.5	30	13	< 0.1	2.9	10.0	6.4	1.5	6.3
B60-4		60 cm	08.02.01			6.28	1.76	< 0.5	< 0.5	10	< 0.1	2.8	7.9	5.6	0.8	6.5
B90-1		90 cm	07.02.00	0.18	1.60	4.80	0.00									
B90-2		90 cm	29.02.00	0.32	0.80	4.97	0.37									
B90-3		90 cm	27.01.01			6.22	0.49	< 0.5	30	9	< 0.1	2.2	6.0	4.8	1.2	5.5
B90-4		90 cm	08.02.01			6.25	2.46	< 0.5	< 0.5	<6	< 0.1	1.5	5.0	5.0	0.8	6.5

Curriculum Vitae of the author

Ziad Qannam was born on July, 18, 1968 in Arroub Camp, Hebron in Palestine. Between 1974 and 1983 he attended the Arroub Camp Boys Preparatory School and from 1983 to 1986 the Beit Ummar Secondary School, where he obtained his General Secondary Certificate- Scientific Stream (Tawjihi) in 1986. In the same year he joined the Chemistry Department –Bethlehem University, Palestine and was awarded a combined B.Sc. degree in Chemistry and Biology in 1993. Between 1987 and 1990 the Palestinian universities were closed because of the Intifada .

Between 1989 and 1995 he worked as undergraduate researcher, research assistant and as a researcher at the Water and Soil Environmental Research Unit - Chemistry Department, Bethlehem University, Palestine (WSERU).

He joined the Faculty of Graduate Studies, University of Jordan - Amman, Jordan in 1995 and was awarded M.Sc. in the Environmental Sciences and Management in 1997(First Honor Degree 3.96/4.0). Between 1997 and 1998 he worked as researcher at WSERU.

From 1998 to 2002 he was a Ph.D. student at the TU Bergakademie Freiberg, Germany, Institute of Geology, Department of Hydrogeology. During this time he attended the following courses: GIS using TNT-mips; hydrogeochemical modelling with PhreeqC; groundwater modeling using Modflow, transport in porous media - modeling of flow contaminants in the subsurface; and a two weeks SOCRATES-ERAASMUS intensive course on environmental geology at the Masaryk University, Berno, Czech Republic. He is a member of the International Association of Hydrogeologist since January 2000. He is a member of the committee that established the voluntary environmental society “Wadi Al Arroub Society for the Protection of Environment and Green Land” and since then he has been the head of society which was officially registered in May 2001. Mr. Qannam’s mother tongue is Arabic. In addition, he is effluent in speaking, reading and writing English and German.

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