"GROUNDWATER VULNERABILITY ASSESSMENT FOR THE WESTERN AQUIFER BASIN LOCATED IN THE WEST BANK"

By

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This Thesis was prepared under the supervision of Dr. Amjad Aliewi, Dr. Ziad Mimi, and has been approved by all members of the examination committee.

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EXECUTIVE SUMMARY

The majority of groundwater quality deterioration caused by human beings. Among the reasons that cause such phenomenons are: increased urbanization, shortage of wastewater systems, lack of solid waste facilities, industry, and agriculture. The in- hand study will identify the most vulnerable resources of water, in western aquifer basin portion of the West Bank, to pollution caused by human beings activities. The study is based on Geographic Information System (GIS) technique and displaying groundwater vulnerability as a map. Vulnerability map is useful for groundwater protection as well as for decision making regarding future investment related to aquifer protection measurements. Two methods are applied: the DRASTIC method and PI method. The "DRASTIC" methodology principle depends on seven hydrogeologic factors: Depth to water, net recharge, aquifer media, soil media, topography, impact of the vadose zone media, and hydraulic conductive. "Extreme" vulnerability is assigned in Ramallah and Jerusalem since there are many springs located near the surface in those two areas. "High" vulnerability is assigned to rocks, which make up the regionally Turonian/ upper cretaceous, and upper cretaceous like in some parts of Jenin, west side of Tulkarem, Qalqilia, Salfit, Bethlehem and Hebron. "Moderate" vulnerability is assigned to upper cretaceous like in east side of Tulkarem and parts of Bethlehem. These deposits are not typically used for drinking water purposes but are important sources of water for agriculture. However, "low" vulnerability is assigned in parts of Hebron district.

The PI method (alongside with DRASTIC method) is applied only in Qalqilia governorate. The PI-method takes into account two main factors: the Protective Cover (P-factor) and the Infiltration conditions (I-factor). The P-factor considers: soil field capacity, subsoil type, lithology type and fracturing, aquifer type and recharge condition. On the other hand, the I-factor considers the infiltration conditions and accordingly the flow concentration of the surface water. In this approach the protective effectiveness of the rock cover above the aquifer is determined by the point-counting system. Depending on the findings of applying PI method in Qalqilia Governorate, "extreme" vulnerability assess around sinking streams, "high" vulnerability is located in the middle and in the majority of eastern part of the governorate, "moderate" vulnerability is assigned

in the areas of brown rendzians and pale renzians top soil, and the low vulnerability is assigned in the western part.

Comparing the findings of the two applied methods in Qalqilia, reported that PI method is more accurate as it takes into account the land use while the DRASTIC method does not. In addition to that, the PI method is more suitable for karst features than DRASTIC method taking into consideration that most of the West Bank is karst.

Concerning the potential groundwater pollution sources in the West Bank, they are numerous that are divided into four categories: wastewater, solid waste, industrial and hazardous waste, and agriculture.

Following identifying the vulnerability map for the western basin portion of the West Bank, water resources (wells and springs) and water pollution sources (sewage wadis, olivemills, dumping sites, quarries, gas stations, and cesspits) were endorsed in the same map.

In a region (such as the study area) with limited available water resources, logistical obstacles, weak economy, political uncertainty, water protection will be placed as a top priority and therefore, pollution prevention measurements should be considered part of good aquifer management policy.

الملخص

إن تدهور جودة المياه الجوفية يرجع إلى النشاطات البشرية. والمسببات لهذه الظاهرة هي: زيادة عدد السكان، نقص أنظمة المياه العادمة، قلة نظم تجميع النفايات الصلبة، الصناعة، والزراعة. الدراسة التي بين أيدينا ستعرِّف حساسية مصادر المياه من منطقة الحوض الغربي الواقعة في الضفة الغربية للتلوث الناتج عن النشاطات البشرية. الدراسة تعتمد على نظام المعلومات الجغرافية، وتعرض حساسية المياه الجوفية للتلوث على شكل خارطة. خارطة حساسية المياه الجوفية للتلوث مهمة لحمايتها، كما أنها مهمة لأخذ القرارات الهامة والمتعلقة بالاستثمارات المستقبلية لحماية الحوض المائي.

تم تطبيق أسلوبين في هذا البحث: أسلوب DRASTIC، وأسلوب PI، مبدأ DRASTIC يعتمد على سبعة عوامل هيدروجيولوجية: العمق لسطح المياه الجوفي، تغذية الحوض المائي، طبيعة وسط الحوض المائي، طبيعة وسط التربة، الطوبوغرافيا، تأثير طبيعة وسط vadose zone. الحساسية العالية جداً للتلوث شوهدت في رام الله والقدس بسبب وجود الينابيع القريبة من سطح الأرض. الحساسية العالية شوهدت في المناطق الصخرية، والتي هي من نوع Turonian/ Upper Cretaceous, and Upper Cretaceous، كما هو الحال في بعض مناطق جنين، الجزء الغربي من طولكرم، قلقيلية، سلفيت، بيت لحم، والخليل. الحساسية المتوسطة للتلوث شوهدت في المناطق الصخرية، والتي هي من نوع Upper Cretaceous، كما هو الحال في الجزء الشرقي من طولكرم، ومناطق من بيت لحم. هذه المياه لا تستخدم لغرض الشرب وإنما للزراعة. الحساسية المنخفضة للتلوث شوهدت في بعض مناطق محافظة الخليل.

تم تطبيق أسلوب PI في محافظة قلقيلية. أسلوب PI يأخذ بعين الاعتبار عاملين رئيسيين وهما: عامل P– طبقة الحماية، والذي يعتمد على: سعة التربة، نوع طبقة Subsoil، طبيعة تكون الصخر، طبيعة تشقق الطبقات الصخرية، نوع الحوض المائي وظروف التدفق المائي. العامل الآخر هو: عامل I، ويعتمد على ظروف التغذية للمياه الجوفية، وبالتالي تركيز التدفق للمياه السطحية. في هذا الأسلوب، فعالية حماية الصخور التي تغطي الحوض المائي تحسب بواسطة نظام الحساب النقطي.

بالاعتماد على النتائج من تطبيق أسلوب PI في محافظة قلقيلية، الحساسية العالية جداً شوهدت حول أودية المجاري، الحساسية العالية شوهدت في وسط ومعظم الجزء الشرقي من المحافظة، الحساسية المتوسطة شوهدت في المناطق التي تحتوي على تربة من نوع Brown Randzians and Pale Renzians . والحساسية المنخفضة شوهدت في الجزء الغربي من المحافظة.

من مقارنة نتائج تطبيق الأسلوبين على محافظة قلقيلية، تبين أن أسلوب PI أكثر دقة من أسلوب DRASTIC وذلك لأن الأول يأخذ بعين الاعتبار عوامل استخدام سطح الأرض، كما أنه ملائم أكثر للمناطق التي تحتوي على Karst Features كما هو الحال في الضفة الغربية.

بالنسبة لمصادر التلوث في الضفة الغربية، فهي متعددة ويمكن تقسيمها إلى أربع مجموعات: المياه العادمة، النفايات الصلبة، نفايات الصناعة الخطرة، والزراعة.

أنتجت هذه الدراسة خارطة توضح حساسية المياه الجوفية من منطقة الحوض الغربي، والواقعة في الضفة الغربية للتلوث، وكذلك مصادر المياه: آبار، وينابيع، ومصادر التلوث: أودية المجاري، معاصر الزيتون، مواقع تجميع النفايات، مناطق استخراج الحجارة، محطات الوقود، وبالوعات المجاري الواقعة في منطقة البحث.

في منطقة البحث، والتي تحتوي على: مصادر مياه محددة، اقتصاد ضعيف، تذبذب سياسي، يجب أن يأخذ موضوع حماية المياه الأولوية. وكذلك فإن منع مصادر المياه من التلوث يجب أن يؤخذ بعين الاعتبار في سياسة إدارة الأحواض المائية.

CHAPTER ONE

INTRODUCTION

1.1 Problem

The deterioration in the quality of water leads to a decrease in the utilizable water resources. The problem will be severe in Palestine. Lack of adequate sewage systems and widespread use of cesspits are considered main causes of water quality deterioration. Wastewater collection and treatment facilities are restricted to few localities and it is estimated that only about 25-30% of the Palestinian population benefits from sewer collection systems. Existing sewer systems are generally in poor physical status and leakage rates, from sewage networks, may be as high as 50% (CH2MHill 2003). Estimates developed by Palestinian Water Authority, Applied Research Institute Jerusalem (ARIJ) and others suggest that total wastewater quantity generated from Palestinian communities in the West Bank is about 25-30 million cubic meters per year (Mcm/yr). The BOD level of raw sewage in the West Bank averages about 600-700 mg/ L, while salinity (represented by chloride) averages about 1,000 mg/ L. Existing collection systems and treatment plants in Hebron, Tulkarm, and Jenin, for example, are overloaded or not properly functioning. The total annual solid waste generated from Palestinian localities in the West Bank has been estimated to exceed 500,000 tons (Al-Hmaidi, M., 2002).

At present, there is no functioning wastewater system that targets industrial effluents in particular. Quarrying and stone-cutting are the largest industries in the West Bank and an estimated 100,000 tons/ year of slurry is disposed of in wadis and dumping sites (CDM, 2004).

Commercial activities contribute to water quality pollution like car service areas, gas stations, and other mechanical facilities. These facilities dispose waste products (e. g. motor oils) to sewers, cesspits and so it pours in the ground surface. At the same time, underground storage oil tanks, without proper lining, represent a critical problem. On the other hand, pesticide use in the West Bank was highlighted in some reports as a potential environmental problem. Applied Research

Institute Jerusalem (ARIJ) estimated that the total quantity of pesticides used in the West Bank may exceed 700 tons/ year (CDM, 2004).

From the sources of groundwater pollution, it is important to conduct a study about the assessment of groundwater vulnerability to contamination resulting from human activities in the West Bank.

1.2 Objective

The objective of this study is to develop a vulnerability map for the study area (Western Aquifer Basin portion of the West Bank). The map connects the groundwater vulnerability with the human activities (industrial, agriculture, petrol stations, landfills, sewage system …etc.) which cause pollution for groundwater. The vulnerability map assessment has examined which sources of groundwater are most vulnerable to pollution and where future aquifer protection measures should be targeted. This map will be used as a tool for groundwater protection from pollution. The research area is the Western Aquifer Basin portion of the West Bank; this area was chosen to be a research area due to the main two reasons:

1. The large annual natural recharge for the West Aquifer Basin which is around 400-440 Mcm/yr (Palestine Water Authority, 2007).
2. Available data for the West Aquifer Basin which are needed for applying DRASTIC methodology.

Qalqilia area is taken for further analysis.

1.3 Motivation

The main contributor of data and information for this research is the House of Water and Environment. Other contributors of data and information, whether through meetings or literature, are:

- Palestinian Water Authority (PWA);
- Palestinian Central Bureau Statistics (PCBS);
- Municipalities;

- Bir Zeit University (BZU);
- Applied Research Institute Jerusalem (ARIJ);
- Palestinian Hydrology Group (PHG);
- Environmental Quality Authority (EQA).

1.4 Beneficians of the work

The groundwater vulnerability assessment map is useful for:

- Decision makers of future investment related to aquifer protection measurements.
- Researchers in the field of groundwater protection from pollution caused by human beings activities.

1.5 Thesis Outline

As mentioned above, this research aims to develop a map for the groundwater vulnerability to pollution caused by human beings activities for the Western Aquifer Basin located in the West Bank. To do that, research was divided into several chapters.

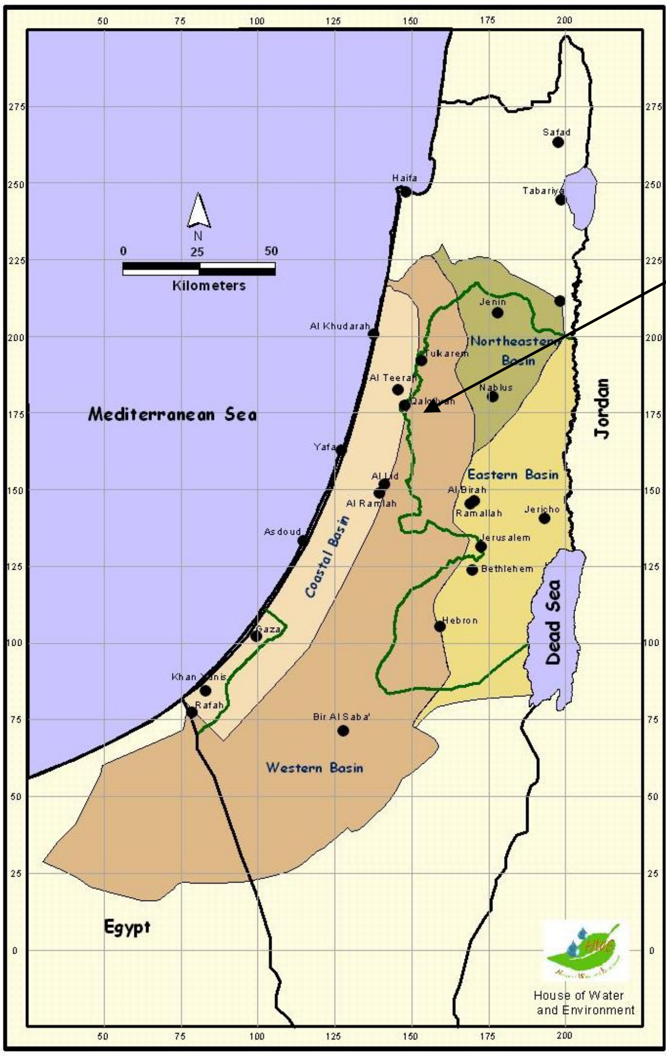
In chapter two, attention is paid to the background of the research area. The Methodologies of the research are described in chapter three. While chapter four concentrates on vulnerability assessment to pollution caused by human beings activities in the research area using the DRASTIC method. Chapter five discusses the aquifer vulnerability assessment to pollution caused by human beings activities in Qalqilia governorate using the PI method. The pollution sources are described in chapter six. Finally, chapter seven tries to conclude the vulnerability assessment to pollution caused by human beings activities in the research area. It also display recommendations which are useful for groundwater protection as well as for decision making future investment related to aquifer protection measurements.

CHAPTER TWO

BACKGROUND OF THE STUDY AREA

2.1 Location

The Western Aquifer Basin portion located in the West Bank (Figure 2.1) is the study area. Palestine is located to the east of the Mediterranean Sea between 29 and 33 North latitude 35 and 39 longitude. The borders of Palestine are: Jordan on the east, the Mediterranean Sea on the west, Lebanon on the North, and Egypt on the south (Wildlife-Palestine, 2006).



Location of the Western Basin portion of the West Bank

Figure 2.1 Location Map of the Western Basin portion of the West Bank

2.2 Area

The Western Aquifer Basin is the largest of all groundwater basins in historical Palestine and a shared basin between Palestinians, Israelis, and Egyptians (Table 2.1). The study area (Western Aquifer Basin portion located in the West Bank) is around 1720 km^2 large (Wildlife-Palestine, 2006).

Table 2.1 Spatial Extent of the Western Aquifer Basin (Wildlife- Palestine, 2006).

	Total Area (km^2)
West Bank	1720
Israel	7438
Sinai	4990
Sum	14148

2.3 Climate

The geographical location of the West Bank makes the area highly influenced by the Mediterranean climate. The Mediterranean climate is characterized by a hot, dry summer and cool, rainy winter. Rainfall is limited to the winter and spring months. It usually starts in the middle of October and continues up to the end of April. Snow and hail, although uncommon, may occur anywhere in the area especially to the west of and over the highlands.

The mountainous areas in the West Bank that stretch from north to south, serve as a barrier to the passage of moist air coming from the western direction. The western air is always wet as it is coming from the Mediterranean Sea. The marine influence passes deep into Tulkarm and Jenin districts. It also reaches the western edges of Nablus, Ramallah Jerusalem, Bethlehem, and Hebron districts. It does not pass deep into these districts due to the presence of high lands that counter the wind. In the southern area of the West Bank, the marine influence decreases as the Mediterranean shore bends to the southwest, thus increasing the distance between the sea and the West Bank.

In the north, there are no hills to block the sea winds, the marine influence passes easily across the open lands of Marj Ben Amer Plain and reaches to the Jordan Valley. This explains the increased quantity of rain in the northern Jordan Valley despite the fact that most of it is below sea level.

The climate of the West Bank, especially in the south, is influenced by the vast nearby deserts, Negev and Arabian deserts. Especially during the spring and early summer, desert storms move through with hot winds full of sand and dust *(khamaseen)*. These storms increase the temperature and decrease the humidity.

The climate of the West Bank as a whole and the Western Basin portion located in the West Bank in particular, is of the Mediterranean type, marked by a mild, rain winter and a prolonged dry and hot summer. The annual amount of rainfall decreases from north to south. Temperatures, on the other hand, increase from north to south. In a west to east direction, annual rainfall and mean temperatures undergo similar but less regular changes. Also, there is a gradual decrease in the annual, monthly, and diurnal averages of relative humidity from north to south and from west to east throughout the whole area (Wildlife-Palestine, 2006).

2.4 Geological and Hydrogeologic Properties

This section gives a brief description of the stratigraphy, lithology and the geological structure of the West Bank as it is highly related to the geological setting and aquifer systems of the study area. A detailed description of the study area's stratigraphy and aquifer systems is stated.

2.4.1 Stratigraphy and Lithology of the West Bank

Within the West Bank, the outcrops are predominantly carbonate sediments and rocks of Tertiary and Cretaceous ages. 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.

The exposed rocks of the West Bank are:

1. Albian - Lower Cretaceous formations comprising the regional West Bank groundwater system (Beit Kahil, Yatta formations). The thickness of the groundwater system in this area ranges from 500-970 meters.

2. Upper Cretaceous formations comprising the regional West Bank groundwater system (Hebron, Bethlehem and Jerusalem formations). The thickness of the groundwater system in this area ranges from 190-490 meters

3. Senonian age rocks (Abu Dis formation) are composed mainly of chalks and marls. The thickness ranges between 0-450m

4. Pleistocene to Eocene age rocks overlay the Senonian age rocks in the Northern and Northeastern area of the West Bank, the rocks are composed mainly of limestone, chalky limestone, chalks, marls, and siltstone, which are of limited extent and thickness

5. Unconsolidated, Quaternary alluvial sediments overlie the major rock formations (Rofe and Rafty, 1965).

2.4.2 Tectonics and Structure of the West Bank

The structural geology of the West Bank is dominated by a series of regional, parallel, Southwest-northeast trending folds dissected by faults associated with the Jordan Rift Valley. The main structural elements are Hebron, Ramallah, 'Anabta, Fari'a, Al-‘Auja, Mar Saba and Um-Daraj anticlines. The largest fractured and faulted structure in the West Bank is the Dead Sea Graben. The fault turns towards the northwest near Jericho. The folds in the West Bank represent a period of uplifting and compression of the earth crust during the late Turonian-Early Eocene times. Some faults in West Bank act as conduits and some others represent barriers to groundwater flows (Rofe and Rafty, 1965).

- **Cretaceous Rocks**

The following paragraphs give an introduction to the general lithostratigraphy of the West Bank formations that build up the aquifers in. The lithology, thickness and other features relevant to the aquifer characteristics are presented in briefly.

- **Kobar Formation (Aptian to Albian)**

Kobar formation consists mainly of marl, marly limestone, and limestone. In some location it is comprised of limestone and intercalation of marl.

- **Albian Rocks**

This includes the rocks of Lower Beit Kahil Formation, Upper Beit Kahil Formation, and Yatta Formation. The Lithology of these formations is:

- **Lower Beit Kahil Formation**

The Lower Beit Kahil Formation consists mainly of limestone, which is well bedded, fine crystalline and highly karstic, and sometimes dolomitic in the upper part. This formation has sometimes-intermediate marl layers, and marl. Its thickness ranges from 120–280 m. In some places the Lower Beit Kahil formation has dark grey dolomite, massively bedded, fine crystalline and hard.

- **Upper Beit Kahil Formation**

The Upper Beit Kahil contains light and yellowish limy to marly dolomite, fine crystalline and sometimes soft, which is interbedded with thin marly layers. Its thickness ranges between 40-220 m. In some places it is built up of dolomite and reef limestone, massively bedded to cliff forming, usually coarse crystalline (Rofe and Rafty, 1965).

- **Lower Cenomanian Rocks**

Yatta Formation

The Yatta Formation consists of yellowish and brown and contains fine to medium crystalline dolomite and limestone, with marly intercalation, marly at bottom. In some places it consists of marly limestone, usually highly enriched with fossilized fauna. Its thickness lies between 50 m to 130 m (Rofe and Rafty, 1965).

- **Upper Cenomanian**

Hebron Formation

Hebron formation consists of hard and massive dolomite or limestone. It is highly karstic. Its thickness ranges from 20-120 m (Rofe and Rafty, 1965).

Bethlehem Formation

The Bethlehem Formation consists of limestone and dolomite, chalky limestone, with marl and rich in faunal remains. In some places it is built up of dolomite, massive and coarse crystalline Limestone lenses, well bedded. The thickness is 80-270 m (Rofe and Rafty, 1965).

Jerusalem Formation (Turonian)

The Jerusalem Formation consists mainly of limestone, soft, thin-bedded, dolomitic, chalky and marly limestone. In some place it consists of limestone, hard and massive. In other places it consists of hard limestone, dolomitic limestone and marl. Its thickness ranges 90-130 m (Rofe and Rafty, 1965).

Abu Dis Formation (Senonian)

This formation is part of Senonian age. It consists of chalk and chert, the chalk is usually white but in some areas it is 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. The thickness of this formation ranges between 0-450 m (Rofe and Rafty, 1965).

Tertiary (Eocene)

The Eocene age rocks are composed mainly of limestone, chalky limestone, chalks, marls, and siltstone, which are of limited extent and thickness. The thickness of this formation ranges between 0-630 m (Rofe and Rafty, 1965).

- **Quaternary**

Alluvial formations are of Pleistocene to Recent Aage, consisting of unconsolidated, laminated marls, clay, silt, gravel and conglomerate (Rofe and Rafty, 1965).

- **The Albian Aquifer**

The Albian aquifer consists 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 (up to 500 m).

- **The Regional Water of the Albian Aquifer**

Two regional aquifers are distinguished in the Albian Formation. These are:

1. The Albian upper regional aquifer, which is found in lower part of the Upper Beit Kahil Formation

2. Another regional aquifer supported by the underlying aquiclude of upper Kobar Formation is expected in the Lower Beit Kahil Formation. This aquifer will be referred to as the Albian lower perched aquifer. Thus the Albian regional water table is a result of two regional water tables. Wells discharging from these regional water tables are illustrated in Table 2.2.

Table 2.2 Wells (in the Research Area) Discharging from Regional Water of the Albian Aquifer

Well Name	Locality	Governorate	Formation	Aquifer
DAIR SHARAF NO. 2A	Dair Sharaf	Nablus	Upper Beit Kahil/ Lower Beit Kahil	Lower Cenomanian
'AZZUN VILLAGE COUNCIL	Azzun	Qalqilia	Upper Beit Kahil/ Lower Beit Kahil	Lower Cenomanian
SUDQI SHBAITAH	Azzun	Qalqilia	Upper Beit Kahil/ Lower Beit Kahil	Lower Cenomanian
KARNI SHAMRUN	Jinsaut	Qalqilia	Upper Beit Kahil/ Lower Beit Kahil	Lower Cenomanian
SHEBTEEN NO. 1	Shabtin	Ramallah	Upper Beit Kahil/ Lower Beit Kahil	Lower Cenomanian
SHEBTEEN NO. 2	Shabtin	Ramallah	Upper Beit Kahil/ Lower Beit Kahil	Lower Cenomanian
SHEBTEEN NO. 4	Shabtin	Ramallah	Upper Beit Kahil/ Lower Beit Kahil	Lower Cenomanian
SHEBTEEN No.5	Shabtin	Ramallah	Upper Beit Kahil/ Lower Beit Kahil	Lower Cenomanian
DHEEB REDA 'UDAH	Masha	Salfit	Upper Beit Kahil/ Lower Beit Kahil	Upper Cenomanian
HARIS EXPLORATION	HarisARIS	Salfit	Upper Beit Kahil/	Lower Cenomanian

WELL			Lower Beit Kahil	
ARE'AIL	Marda	Salfit	Upper Beit Kahil/ Lower Beit Kahil	Lower Cenomanian
KAMEL AL SALEM & PARTNERS	Kufur Zeebad	Tulkarm	Upper Beit Kahil/ Lower Beit Kahil	Lower Cenomanian

- **The Cenomanian-Turonian aquifer**

Yatta, Jerusalem, Bethlehem and Hebron formations are the water bearing formations of the Cenomanian –Turonian aquifer with a thickness ranging between 320 and 350 m (Rofe and Rafty, 1965).

Lower Cenomanian (Yatta) Aquifer

Generally, Yatta Formation is to be the regional aquiclude of the West Bank, but a closer study of this formation will show that, mainly the middle part of this formation is of higher permeability than its top and bottom parts. The bluish-greenish clay, marl and chalk of the upper part of Yatta Formation are the actual parts of Yatta Formation that act as aquicludes. Dolomite and limestones of the middle part of the Yatta Formation are of higher permeability, which could assign this part as local regional aquifer. Wells discharging from this regional water table are illustrated in Appendix E.

Upper Cenomanian-Turonian aquifer

The Turonian-Cenomanian aquifer is divided into two aquifers:

1. The Turonian aquifer, including both Upper Bethlehem and Jerusalem Formation.

2. Cenomanian aquifer in the Hebron Formation, which shows two water tables.

• The upper, of which will be referred to as the Cenomanian upper aquifer, and

• The lower will be referred to as the Cenomanian lower aquifer. Wells discharging from this water table are illustrated in Appendix E and springs discharging from this water table are illustrated in Appendix F.

2.5 Water Supply

The West Bank overlies three groundwater basins jointly known as the Mountain Aquifer Basin: the Eastern Aquifer Basin, the Western Aquifer Basin and the Northeastern Aquifer Basin (Figure 2.2). Palestinians are currently denied the right to their share of water from the Jordan River and therefore groundwater is considered as the major source. Table 2.3 shows the amount of recharge to all of the three aquifers; it is important to note that these figures are based on values taken from the literature.

Table 2.3 Reported Aquifer Basin Recharge (Mimi, Z. and Aliewi, A., 2005)

Basin	Recharge (Mcm/ yr)
Eastern	100-197
North Eastern	130-200
Western	335-450
Total	565-822

2.5.1 Groundwater Resources

2.5.1.1 The Eastern Aquifer Basin

The Eastern Aquifer Basin (EAB) is an endogenous Palestinian basin since recharge and discharge are restricted to the West Bank. It covers the eastern half of the West Bank area, from the mountains down to the Jordan River. The recharge to the EAB as a whole occurs predominantly in the outcrop regions in the mountains where most of the rainfalls. The eastward dip of the eastern flank of the West Bank conducts most of the infiltrating water towards the Jordan Valley and the Dead Sea by gravity. Part of the groundwater emerges as springs and a yet unknown amount of groundwater is delivered to the Jordan Valley. The highest amount of well pumping occurs in Israeli settlement wells near the main fault in the Jordan Rift Valley (Palestine Water Authority, 2007).

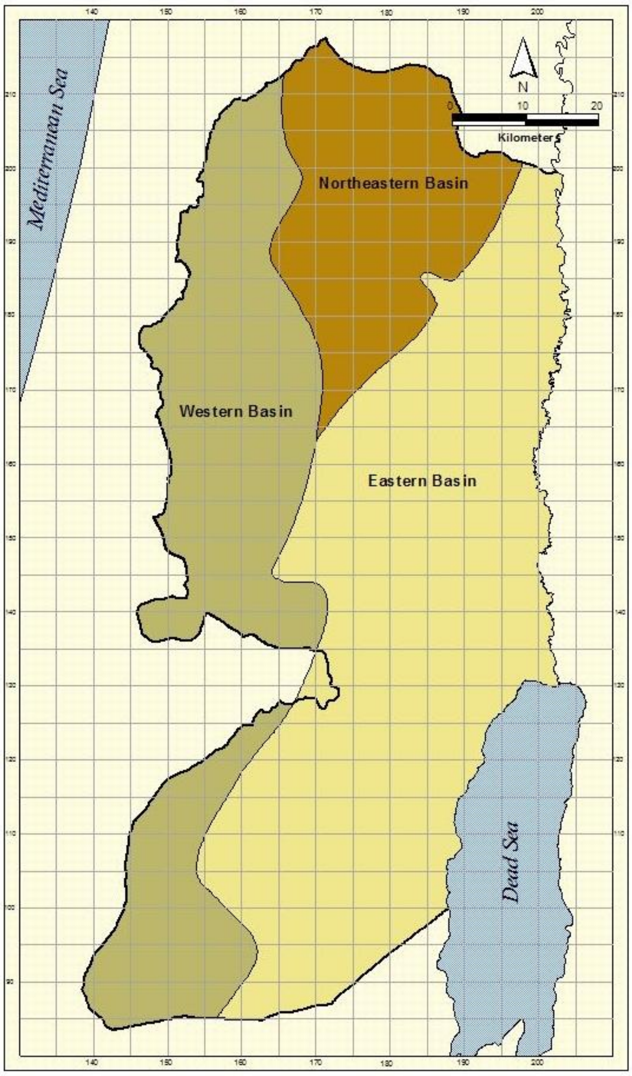


Figure 2.2 Groundwater Aquifer Basins (Palestine Water Authority, 2007)

The sustainable yield of the Eastern Aquifer is between 50 and 70 Mcm/yr. The average recharge to the EAB is about 197 Mcm/yr including approximately 21 Mcm/yr from flows (wadis, leaking pipes and sewer lines), and about 25 Mcm/yr from the Jericho and Auja spring systems. Palestinians pump 18.8 Mcm/yr from 197 abstraction wells while Israelis pump 36.7 Mcm/yr from only 38 wells in the EAB. Therefore, the theoretical average yield per Palestinian well is very low when compared to Israeli wells. Sixty six measured springs under Palestinian control yield 39.9 Mcm/yr on average. They are fresh water springs and are distributed all over the Eastern basin. However, in general it can be stated that a great number of Mountain springs have a low to very low discharge rate, while the strong springs are found in the Jordan Valley area. Israel controls a handful of mainly brackish to hyper saline springs along the Dead Sea. They discharge 88.5 Mcm/yr; this value is a rough approximation. Hence, Palestinians control the fresh water springs, and Israel controls the main, albeit saline, portion of spring flow (Palestine Water Authority, 2007).

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2.5.1.2 The North-Eastern Aquifer Basin

The North Eastern Aquifer Basin (NEAB) extends from the area south of Nablus towards the north beyond the borders of the West Bank. It is the smallest of the three basins and by that has the smallest portion of recharge as well. The area of Northeastern basin is about 1424 km2 of which 1053 km2 lies within the West Bank and 371 km2 lies within Israel. It is a classical shared aquifer in terms of use although most of the recharge originates within the West Bank. The total long-term average recharge from rainfall that reaches the groundwater body is expected to be approximately 165 Mcm/yr (excluding recharge that flows to springs of approximately 19 Mcm/yr). Currently, about 24.9 Mcm/yr of this recharge is being abstracted by wells, while the remainder flows to the Gilboa' area to the north or the Jordan Valley to the east. The flow to the Gilboa' area surfaces as springs flow, or is pumped from adjacent wells. Inside the West Bank, 85 Palestinian wells pump around 11.5 Mcm/yr (average period 1980-2004) while only 9 Israeli wells pump 13.4 Mcm/yr (average for the period 1980-2004). 74 Palestinian springs in the West Bank discharge 14.0 Mcm/yr. The rest of the spring discharge, more than 75 Mcm/yr, emerges from springs inside Israel (Palestine Water Authority, 2007).

2.5.1.3 The Western Aquifer Basin

The Western Aquifer Basin (WAB) is the largest of all groundwater basins in Historical Palestine. It includes the western part of the West Bank Mountains and extends to the coastal areas and from the north central mountains area to the Hebron Mountain in the south. Two main aquifers are present in this basin: the upper and the lower aquifers. The average thickness of these aquifers ranges between 600-900 meters.

The average annual natural recharge for the WAB is around 400-440 Mcm/yr. The mountains of the West Bank are the main recharge source to this basin. The average annual abstraction from the basin reaches to 338 Mcm/yr and most of these waters (317 Mcm/yr) are being pumped from the Israeli wells that are generally situated along the West Bank–Israeli border. An about of 760 Mcm/yr can be extracted from the basin WAB. The continuation of pumping at current levels till 2025 will lead to approaching the worst limit for the southern zone (current abstraction = 0.4 Mcm/yr) while the central and northern zones will marginally be affected (Palestine Water Authority, 2007).

Palestinians have a marginal share in groundwater pumping from this basin. There are 151 wells run at a comparably low average pumping rate. Therefore, their average pumping (20.9 Mcm/yr) is as low as 6% of the Israel. Where, Israel has more than 500 wells just inside and along its borders with the West Bank, in addition to only 5 abstraction wells within the West Ban (Palestine Water Authority, 2007).

2.5.2 Surface Water Resources

The surface water resources in the West Bank consist of three major components: the Jordan River Basin, the Dead Sea and the western wadis (the eastern wadis are all presented as part of the Jordan River and the Dead Sea). The Jordan River is the most important surface water resource in the West Bank. It is considered as a shared river between Lebanon and Syria and flows through Israeli, Palestinian and Jordanian lands which are all legal riparian with legitimate legal rights. The natural flow of the Jordan River in the absence of extraction ranges from 1485 to 1671 Mcm/yr at the entrance to the Dead Sea. Israel is the greatest user of the Jordan River water were its present use is around 58.7% of the total flow. Israel transfers huge quantities of surface water through the National Water Carrier from Upper Jordan to the Negev, where these quantities equal 420 Mcm/yr in addition to local consumption in the Tiberias Basin and the Huleh Valley which all sum up to the annual discharge of the three main tributaries of the Jordan River. At the same time Palestinians have been denied use of the Jordan River water by the Israeli occupation since the

1967 war while Jordan uses 23.4% of the flow, Syria uses 11%, Lebanon uses 0.3% and the remaining water without use is 6.6% (Palestine Water Authority, 2007).

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2.6 Water Demand

This section discusses both present and future municipal, industrial and agricultural demand levels. Population increase is the fundamental parameter affecting future water needs (Tables 2.4 and Table 2.5). This determines not only municipal demand, but also agricultural and industrial demand. Population projections have been based only on natural growth of the base populations. Future returnees have not been taken into account since the time table of their return previously agreed upon has not been implemented as a result of the political situation.

Table 2.4 Population Growth Rates (Palestine Water Authority, 2007)

Year	Population Growth Rate (%)
1997-1999	3.1
2000-2005	3.0
2006-2010	2.5
2011-2015	2.0

Table 2.5 Population Projection for the West Bank (Palestine Water Authority, 2007)

Year	1000s
1997	1600.1
1999	1699.3
2005	2005.2
2010	2255.8
2015	2481.4

The average total supply quantity in the West Bank is 159 Mcm/ yr (104 Mcm/yr is from wells and 54.5 is from springs), different sources. This quantity will be used to assess the supply-demand gap if it were to be kept constant in the future with no additional water resources.

2.6.1 Domestic and Municipal Water Demand

No accurate records of domestic water consumption rates are currently available, as quantities allocated to the various sectors (i.e. domestic, public, industrial, tourism and commercial) cannot be segregated. Domestic water consumption rates were grossly estimated to vary between 30 l/c/d and 70 l/c/d with an average of about 50 l/c/d. According to several studies, Projected Municipal Water Demand in the West Bank is (Table 2.6).

Table 2.6 Projected Municipal Water Demand in the West Bank (Palestine Water Authority, 2007)

Year	Demand (Mcm/ yr.)
2005	135
2010	156
2015	181

2.6.2 Industrial Water Demand

The existing situation of the industrial sector in Palestine (which consists mainly of light and small industries) does not represent the actual stable industry that could be achieved in Palestine. Types of existing Palestinian industries range between quarries, food processing and others. The present industrial water consumption is included in the total current domestic consumption. According to several studies, it was found that the present industrial water demand in Palestine represents about 8% of the total municipal water demand. Based on the World Health Organization (WHO) standard that the industrial sector should represent 16% of domestic water demand, Table 2.7 shows the projected industrial water demand for different planning years.

Table 2.7 Projected Industrial Water Demand in the West Bank (Palestine Water Authority, 2007)

Year	Demand (Mcm/ yr.)
2005	11
2010	25
2015	30

2.6.3 Agricultural Water Demand

The role of agriculture is particularly important in the economy of Palestine due to its high contribution to the Gross Domestic Product (GDP) and its role in employing Palestinian workers. In addition to forming about 30% of the GDP in the past decades agriculture’s contribution to employment has risen from 12.7% in 1995 up to 16% in 2004. Irrigated agriculture contributes to more than 37% of total agricultural production compared to only 24% from rainfed agriculture. Agriculture has a major role in national trade as agricultural products constitute 23% of the national commodities export. At present the total irrigated land area in the West Bank is 125,000 dunums with a total water supply for irrigated agriculture estimated to be about 68 Mcm/yr. It is important to note that water supplies are either shallow, old wells or natural springs. The total potential irrigable area in the West Bank is 612,000 (Palestinian Water Authority, 2007).

However, the required land area to be irrigated will depend on the availability of the natural resources of land and water. The irrigated area of 0.14 dunum per capita is used as the land share that should be irrigated, as it is nearly similar to the Jordanian per capita irrigated area, as Jordan is a country with similar conditions to Palestine. It is also assumed that the irrigation water requirement per dunum is 600 m^3 taking into account the projected improvement in irrigation methods and practices. Based on these assumptions the water requirements can be estimated as shown in Table 2.8.

Table 2.8 Future Water Requirements for Irrigation in the West Bank (Palestine Water Authority, 2007)

Year	Water Requirement (Mcm/ yr.)
2005	168
2010	190
2015	208

2.7 Future Water Deficit

Based on the previous demand projections Table 2.9 shows the future water deficit, assuming that the supply is constant.

Table 2.9 Supply-Demand Gap Estimation (Palestine Water Authority, 2007)

Year	Supply (Mcm/ yr.)	Demand (Mcm/ yr.)			Deficit (Mcm/ yr.)
		Municipal	Industrial	Agricultural	
2005	159	135	11	168	155
2010	159	156	25	190	212
2015	159	181	30	208	260

The numbers and data available in this section indicate that Palestinians are facing harsh and tragic water conditions. The available water volume is decreasing year after year, while the demand is continuously increasing due to population increase, the expansion of the inhabited areas and the industrial development. It is thus necessary to seek addition water resources and introduce non-conventional methods that provide water.

CHAPTER THREE

METHODOLOGY

Aquifer pollution vulnerability can be assessed using several approaches. In this research, two methods are used; the DRASTIC method which is applied on the Western Aquifer Basin located in the West Bank, and the PI method which is applied on Qalqilia governorate.

The DRASTIC methodology is a standardized system for evaluating groundwater pollution potential. The DRASTIC methodology is an index- based rating method whereby scores of groundwater vulnerability are assigned from hydrological attributes of an aquifer system. It considers seven hydrogeological factors: Depth to water, Net Recharge, Aquifer Media, Soil Media, Topography, Impact of the Vadose Zone Media, and Hydraulic Conductivity of the Aquifer

From these parameters, a DRASTIC Index or vulnerability rating can be obtained. The higher the value of the DRASTIC Index is, the greater the vulnerability of that location of an aquifer.

$$\mathbf{DI = D_R D_w + R_R R_W + A_R A_W + S_R S_W + T_R T_W + I_R I_W + C_R C_W}$$ **(Zwahlen, F., 2003).**

where,

DI = DRASTIC Index

D_R and D_W = Rating and weight assigned to the depth to water table

R_R and R_W = Rating and weight for range of aquifer re-charge

A_R and A_W = Rating and weight assigned to Aquifer media

S_R and S_W = Rating and weight for Soil media

T_R and T_W = Rating and weight assigned to Topography

I_R and I_W = Rating and weight assigned to Vadose Zone

C_R and C_W = Rating and weight given to Hydraulic conductivity

The higher the DRASTIC index is, the greater the relative pollution potential. The DRASTIC index can be further divided into four categories (CDM, 2004).

The PI-method takes two main factors into account: The Protective cover (P-factor) and the Infiltration conditions (I-factor). The P-factor considers: soil field capacity, subsoil type, lithology type and fracturing, aquifer type and recharge condition; while the I-factor considers the infiltration conditions and accordingly the flow concentration of the surface water. In this approach, the protective effectiveness of the rock cover, above the aquifer is determined by the point-counting system (Figure 3.1).

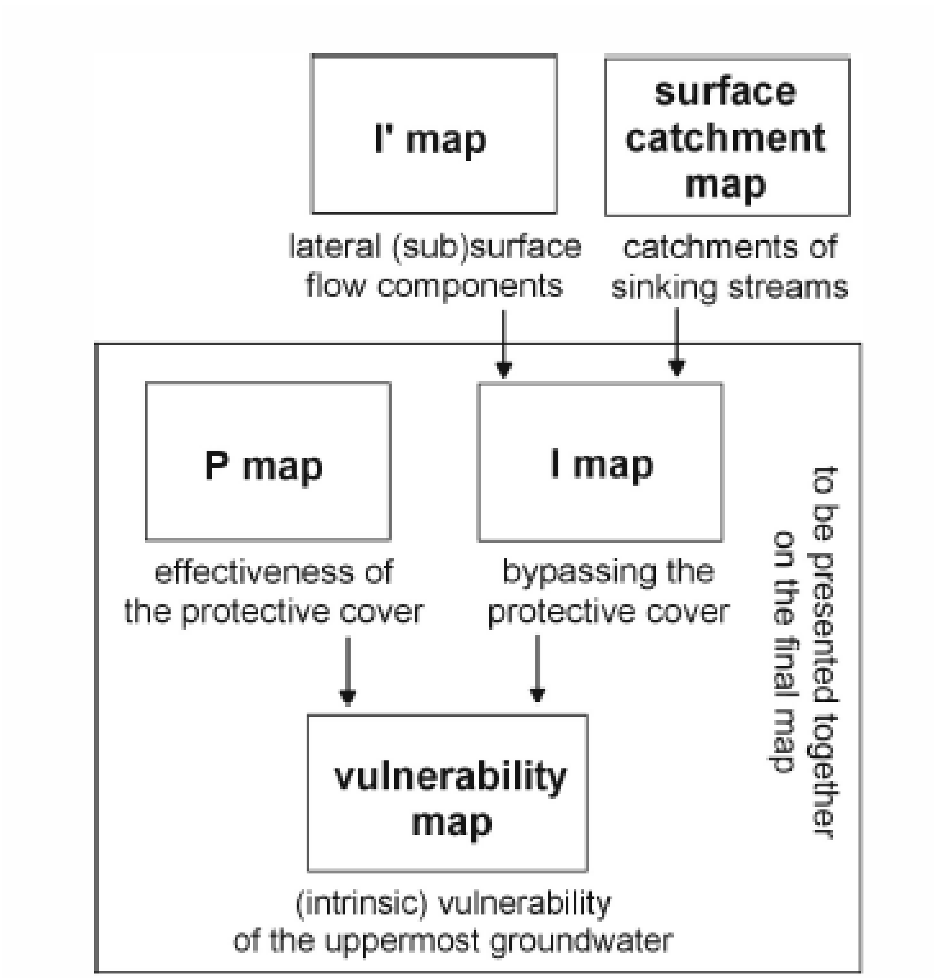

Figure 3.1 Simplified Flow Chart for the PI Method: The vulnerability map is obtained by intersecting the P map with the I map. The PI map shows the effectiveness of the protective cover as a function of the thickness and permeability of all the strata above the groundwater surface. The I map shows the degree to which the protective cover is bypassed. It is obtained by intersecting the map showing the catchment's areas of the sinking stream with the so-called I' map, which shows the distribution of lateral, surface and subsurface (Werz, H., and Hotzl, H.).

CHAPTER FOUR

VULNERABILITY ASSESSMENT USING THE DRASTIC METHOD

4.1 The Concept of Groundwater Vulnerability

The concept of groundwater vulnerability is based on the assumption that the physical environment may protect, to some degree, the groundwater against natural impacts, especially with regard to contaminants entering the subsurface environment. Consequently, some land areas are more vulnerable to groundwater contamination than others. The term "vulnerability to contamination" has the opposite meaning to the term "natural protection against contamination" where the two can be used alternatively. Thus, the term "vulnerability" means the sensitivity of a groundwater system to contamination. However, the term 'vulnerability' is not restricted to groundwater but is used in a wide sense to describe the sensitivity of whatever to any kind of stress, e.g. the vulnerability of global climate to human impacts. As this chapter deals with the vulnerability of groundwater to contamination, the term is used in that sense.

The vulnerability is a relative, non-measurable and dimensionless property. Two different types of vulnerability were distinguished: intrinsic vulnerability and specific vulnerability.

The intrinsic vulnerability of groundwater to contaminants takes into account the geological, hydrological and hydrogeologic characteristics of an area, but it is independent of the nature of the contaminants and the contamination scenario. The specific vulnerability takes into account the properties of a particular contaminant or group of contaminants in addition to the intrinsic vulnerability of the area.

The advantage of such qualitative and descriptive definitions is that the term 'vulnerability' is often intuitively understood, particularly by decision-makers in the planning process. Vulnerability is typically displayed as maps. Vulnerability maps are means of presenting various complex hydrogeologic properties in an integrated and comprehensible way. The map illustrates colored areas symbolizing different degrees of vulnerability (or natural protection respectively) where it is easy to be interpreted and can be used as a practical tool for land- use planning, protection zoning and risk assessment. The ultimate goal of vulnerability maps is showing zones subject to the risks of pollution. Risk can be assigned either numerically or qualitatively (extreme, high, medium, or low). However, there are also disadvantages of using only a qualitative approach where a property, which is not precisely defined, cannot be derived unambiguously through measurable quantities.

Vulnerability in this chapter is determined by the intrinsic characteristics of the aquifer. Different aquifer systems have different characteristics. It is distinct from pollution risk, which depends not only on vulnerability, but also on the existence of pollutant loading. The current chapter aims to develop a vulnerability map for the Western Aquifer Basin portion in the West Bank.

4.2 Method of Assessment

Aquifer pollution vulnerability can be assessed using several approaches. In this section of the research, the DRASTIC method, a standardized system for evaluating groundwater pollution potential is used. The DRASTIC method has been used in many countries because the inputs required for its application are generally available or easy to obtain from public agencies. The DRASTIC method makes four major assumptions (Nebraska Natural Resources Commission/ Data Bank, DRASTIC Methodology):

1. The contaminant is introduced at the ground surface.
2. The contaminant is flushed into the groundwater by precipitation.
3. The contaminant has the mobility of water.
4. The area evaluated is 100 squared acres or larger.

The DRASTIC methodology is an index- based rating method whereby scores of groundwater vulnerability are assigned from hydrological attributes of an aquifer system. It considers seven hydrogeologic factors:

- D: Depth to water–Shallow water tables are more susceptible to contamination than deep water table. The shallower water depth is, the more vulnerable the aquifer.

- R: Net Recharge–Recharge is considered the principle mechanism that transports a contamination to the groundwater. The greater the recharge is, the greater the chance of the contaminant to be transported to the water table is.
- A: Aquifer Media–The aquifer media determines the rate of movement and attenuation of the contaminant. In the West Bank, aquifers mainly comprise carbonates rocks (limestone, dolomite, and marl), while many are of karst ones.
- S: Soil Media–The thickness and type of soil determines the amount of water that reaches the water table. A thick soil layer, and/ or soils with clays and silts, will increase the travel time of contaminants.
- T: Topography–A high slope results in rapid runoff, thus lowering the pollution potential.
- I: Impact of the Vadose Zone Media –The vadose zone is the unsaturated zone above the water table. The thickness and matrix of the vadose zone determines the travel time and attenuation of a contaminant. A lower vulnerability rating is typically assigned if the aquifer media is overlain or comprises a less permeable layer such as clay.
- C: Hydraulic Conductivity of the Aquifer–The hydraulic conductivity of the aquifer determines the amount of water percolating through the aquifer. The higher the conductivity is, the more vulnerable the aquifer is. In the case of karstic aquifers, such as those in this study, hydraulic conductivities can be several orders of magnitude higher than predicted by "conventional" hydrogeologic principles.

From these parameters, a DRASTIC Index or vulnerability rating can be obtained. The higher the value of the DRASTIC Index is, the greater the vulnerability of that location of an aquifer.

The following definitions are useful:

Rating: Each range for each DRASTIC factor has been evaluated with respect to the others to determine the relative significance of each range with respect to pollution potential. The rating is from 1 to 10.

Range: Each DRASTIC factor has been divided into either ranges or significant media types which have an impact on pollution potential.

Weight: The weighting represents an attempt to define relative importance of each factor in its ability to affect pollution transport to and within the aquifer. The weight is from 1 to 5.

Table 4.1 provides the weight for each parameter. Tables 4.2 through 4.8 provide the ranges and ratings for each parameter. The rating is multiplied by the weight to get a score for the parameter. These scores are then summarized to arrive a pollution index, called the DRASTIC index (Appendices C, and D):

$$\mathbf{DI = D_R D_w + R_R R_W + A_R A_W + S_R S_W + T_R T_W + I_R I_W + C_R C_W}$$ **(Zwahlen, F., 2003).**

where,

DI = DRASTIC Index

D_R and D_W = Rating and weight assigned to the depth to water table

R_R and R_W = Rating and weight for range of aquifer re-charge

A_R and A_W = Rating and weight assigned to Aquifer media

S_R and S_W = Rating and weight for Soil media

T_R and T_W = Rating and weight assigned to Topography

I_R and I_W = Rating and weight assigned to Vadose Zone

C_R and C_W = Rating and weight given to Hydraulic conductivity

The higher the DRASTIC index is, the greater the relative pollution potential. The DRASTIC index can be further divided into four categories (CDM, 2004):

1. Extreme: DRASTIC index (DI) is greater than 175.
2. High: DRASTIC index (DI) is greater than 151 and less than 175.
3. Moderate: DRASTIC index (DI) is greater than 126 and less than 150
4. Low: DRASTIC index (DI) is equal to or less than 125.

The sites with extreme, high, and moderate index values are more vulnerable to contamination and consequently need to be managed more carefully. The weights assigned are related. Therefore a site with low pollution potential may still be vulnerable to groundwater contamination while it is less when compared to the sites with high DRASTIC ratings.

Table 4.1 Assigned Weights for DRASTIC Parameters (Zwahlen, F., 2003)

Feature	DRASTIC Weights
Depth to Water	5
Net Recharge	4
Aquifer Media	3
Soil Media	2
Topography	1
Impact of Vadose Zone	5
Hydraulic Conductivity	3

Table 4.2 Ranges and Rating for the Depth to Water (Zwahlen, F., 2003)

Depth to Water (meter)	
Range	**Rating**
< 50	10
50 - 150	3
> 150	1

Table 4.3 Ranges and Rating for the Net Recharge (Zwahlen, F., 2003)

Net Recharge		
Range (inch/year)	**Range (mm/year)**	**Rating**
0-2	0-50	1
2-4	50-100	3
4-7	100-175	6
7-10	175-250	8
> 10	>250	9

Table 4.4 Ranges and Rating for the Aquifer Media (Zwahlen, F., 2003)

Aquifer Media		
Range	**Rating**	**Typical Rating**
Massive Shale	1-3	2
Metamorphic/igneous	2-5	3
Weathered metamorphic/igneous	3-5	4
Thin bedded sandstone/limestone/shale	5-9	5
Massive Sandstone	4-9	6
Massive Limestone	4-9	6
Sand and Gravel	4-9	8
Basalt	2-10	9
Karst limestone	9-10	10

Table 4.5 Ranges and Rating for the Soil Media (Zwahlen, F., 2003)

Soil Media	
Range	**Rating**
Clay	1
Muck	2
Clay loam	3
Silty loam	4
Sandy loam	5
Peat	8
Sand	9
Gravel	10
Thin or absence	10

Table 4.6 Ranges and Rating for the Topography (Zwahlen, F., 2003)

Topography	
Range (% slope)	**Rating**
0-2	10
2-6	9
6-12	5
12-18	3
>18	1

Table 4.7 Ranges and Rating for the Impacts of Vadose Zone (Zwahlen, F., 2003)

Impact of Vadose Zone		
Range	**Rating**	**Typical Rating**
Silty/clay	1-2	1
Shale	2-5	3
Limestone	2-7	6
Sandstone	4-8	6
Bedded Limestone/Sandstone/Shale	4-8	6
Sand and gravel with significant	4-8	6
silt/clay	2-8	4
Metamorphic/Igneous	6-9	8
Sand and gravel	2-10	9
Basalt	9-10	10
Karst limestone		

Table 4.8 Ranges and Rating for the Hydraulic Conductivity (Zwahlen, F., 2003)

Hydraulic Conductivity (gallon/ day. ft^2)	
Range	**Rating**
1 – 100	1
100 – 300	2
300 – 700	4
700 – 1000	6
1000 – 2000	8

4.3 Thematic Maps

4.3.1 Depth to Water

Maps showing the depth to water in the Western Basin portion located in the West Bank where not found in literature. However, those showing the locations of wells and springs and water level were found in numerous resources. The following steps illustrate the procedure adopted to estimate the depth to water for wells and springs in the Western Basin portion located in the West Bank:

1. A map illustrating the wells and springs in the Western Basin portion located in the West Bank was extracted from one covering the whole Palestinian area through GIS applications. (Figure 4.1).

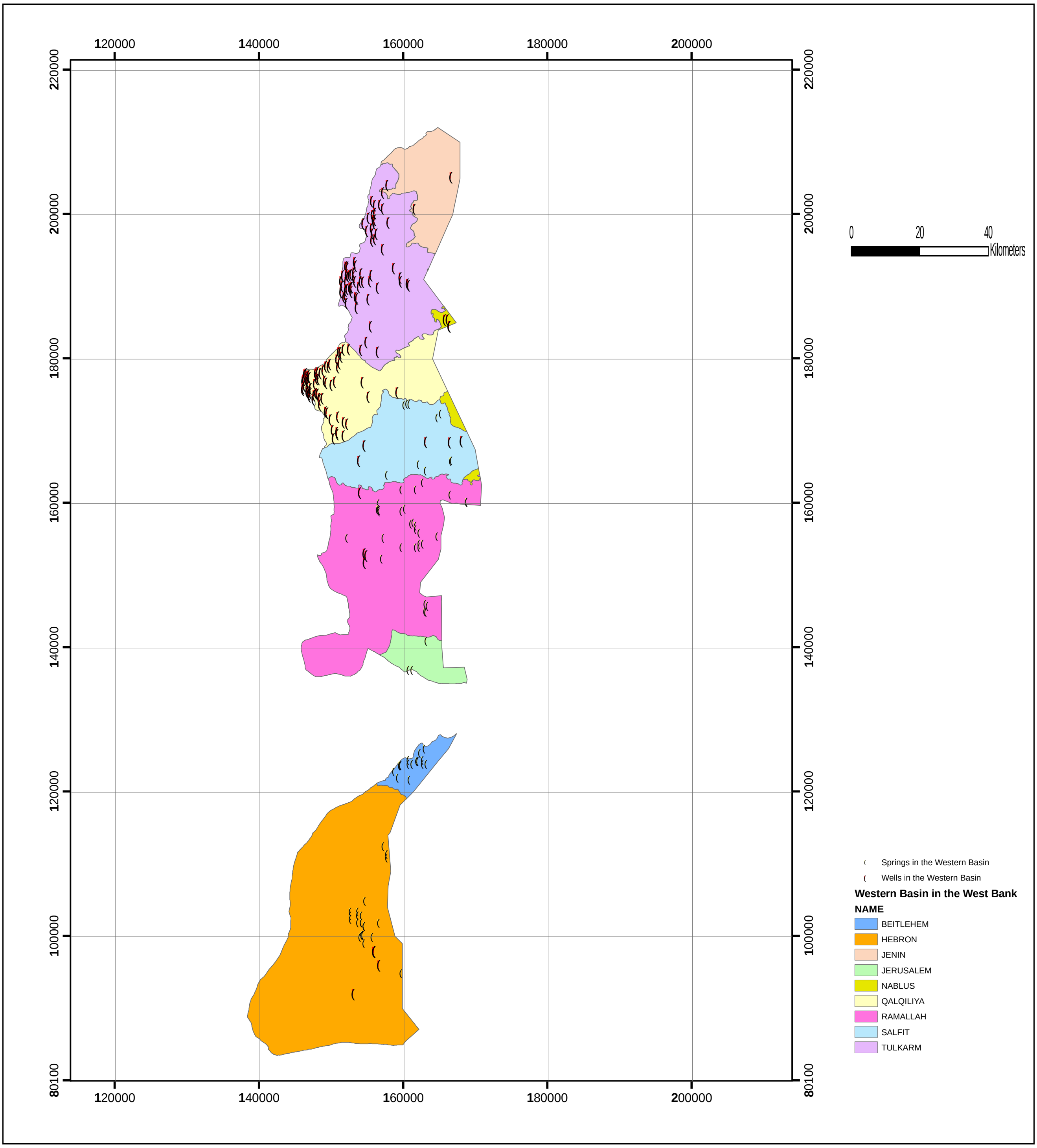

Figure 4.1 Wells and Springs (SUSMAQ, 2005)

2. A map illustrating the water level in the Western Basin portion located in the West Bank was extracted from one covering the whole Palestinian area through GIS applications (see Figure 4.2).

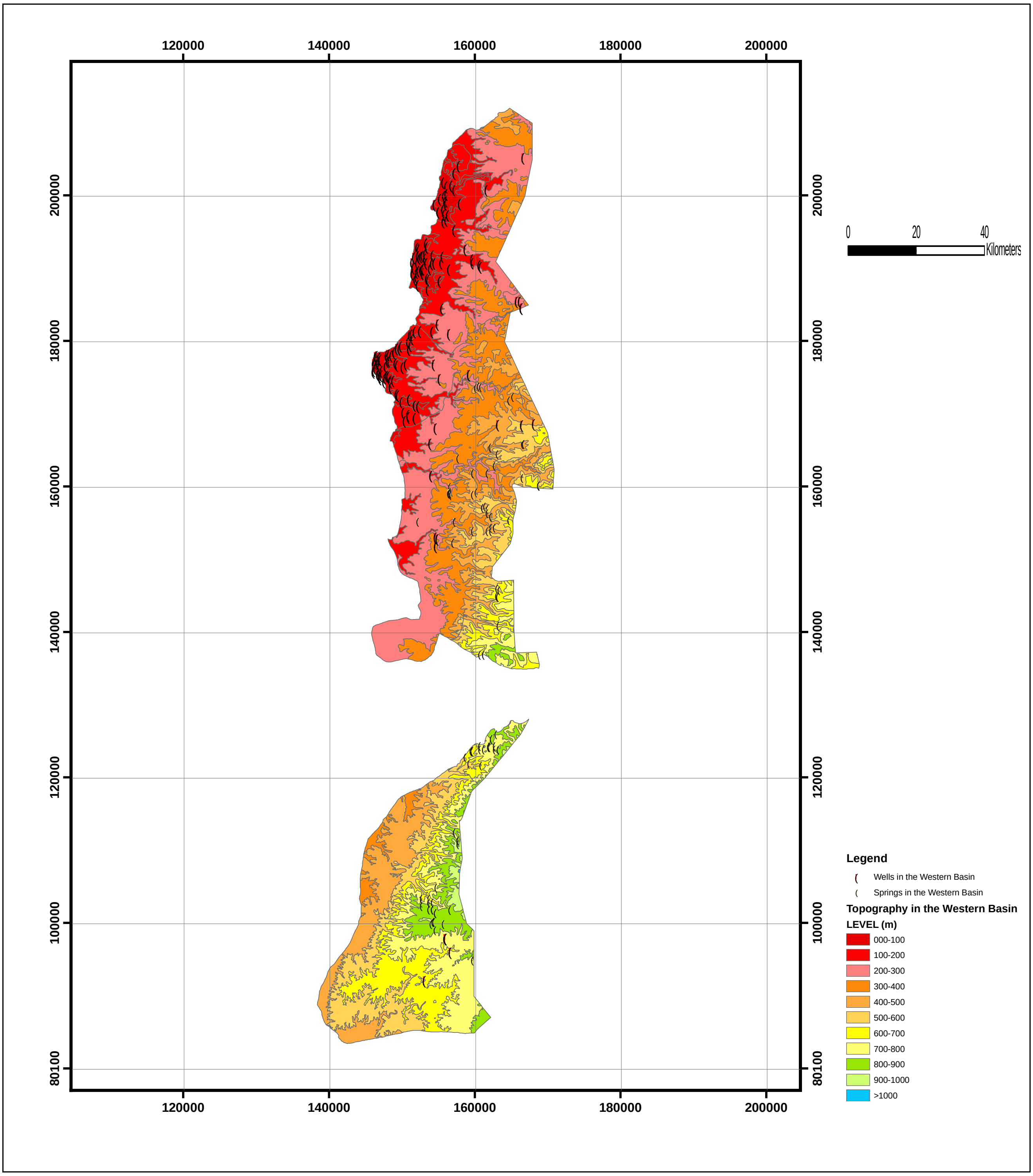

Figure 4.2 Water Level Map (SUSMAQ, 2005)

3. Estimate the water level for each well and spring based on their locations on water level map.
4. From the locations of the wells and springs, get the z- coordinate for each.
5. For each well and spring, subtract the z-coordinate from the water level value, to obtain the depth to water as shown in Appendix A for the wells, and in Appendix B for the springs.

Most of the wells were assigned low D-factors (3 and 1) as shown in Appendix C due to the large depth to water in the study area (50-250 meter) as shown in Appendix A. Springs were assigned high D-factors (10) as shown in Appendix D due to the no depth to water in the study area as shown in Appendix B.

4.3.2 Net Recharge

A map illustrating the rainfall in the Western Basin portion located in the West Bank was extracted from one covering the whole Western Basin area (SUSMAQ, 2005) through GIS applications (Figure 4.3).

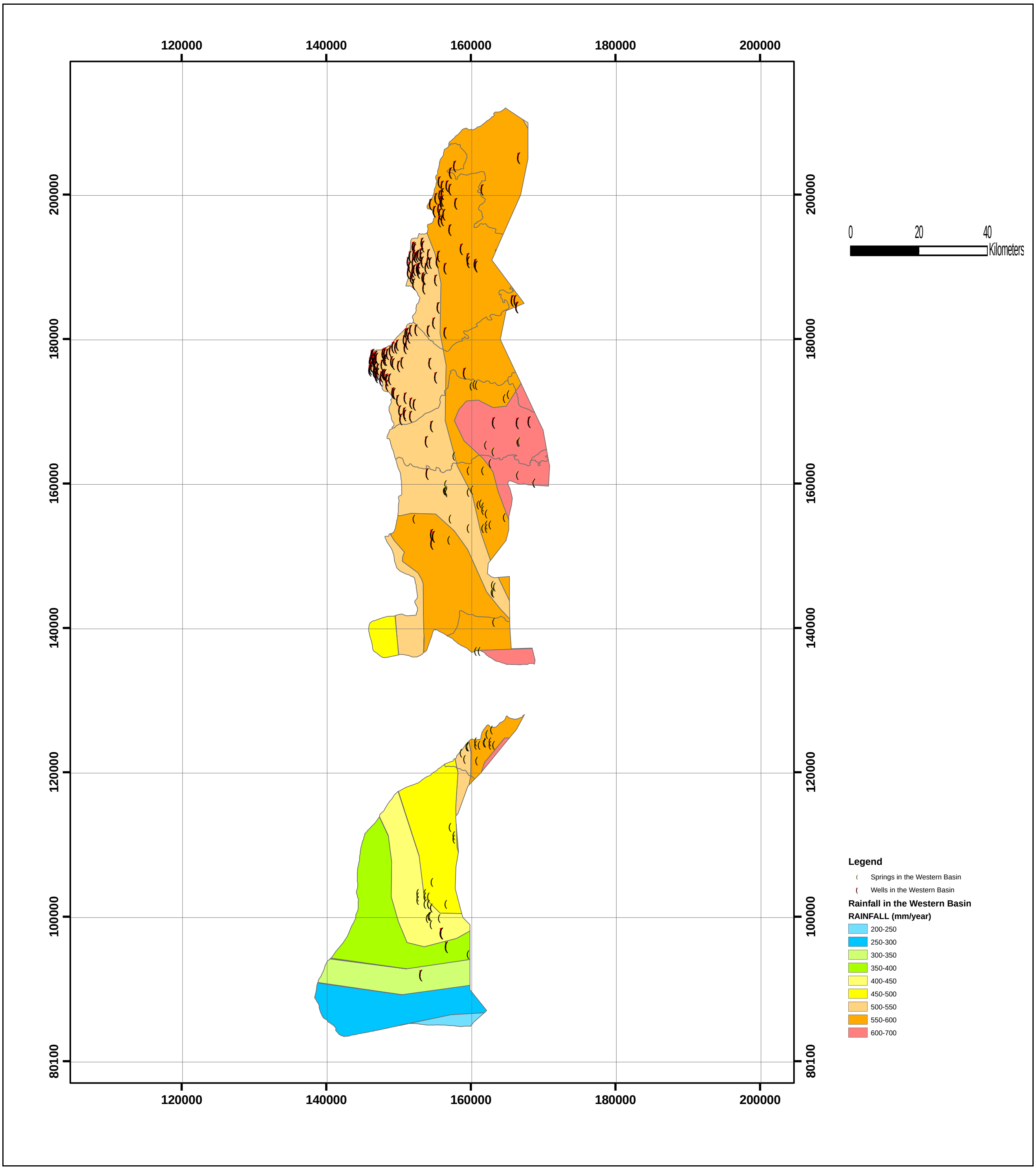

Figure 4.3 Rainfall Map (SUSMAQ, 2005)

This map was used to calculate the net recharge using the following equation:

R = 0.46 [P-159] (Wiley, J., and Sons, L., 2006).

Where:

- P = Precipitation (mm).
- R = Recharge (mm).

Net recharge results are illustrated in Figure 4.4.

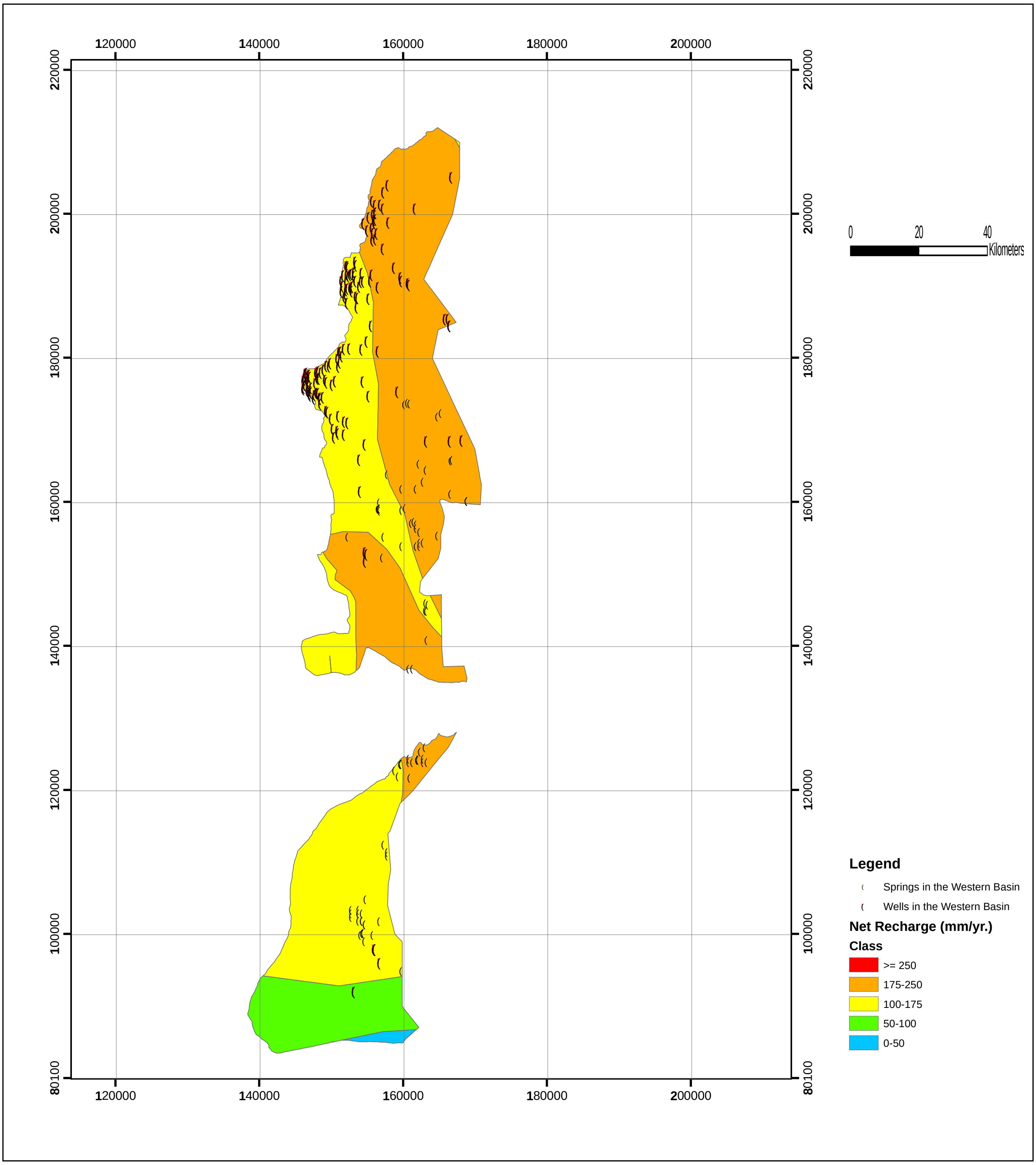

Figure 4.4 Net Recharge Map (SUSMAQ, 2005)

The net recharge value for each well and spring located in the study area was estimated according to its location as follows:

1. Endorse the wells and springs locations map on the net recharge map.
2. Find the net recharge zone that each well or spring is located in.
3. Give the zone net recharge value for well or spring that located in.

The net recharge value for each well and spring located in the study area was displayed in Appendices A, and B. In this study, supervisor experience to rate the net recharge parameter is illustrated in Table 4.9.

Table 4.9 Ranges and Rating for the Net Recharge of the Research Area.

Net Recharge	
Range (mm/year)	**Rating**
≤ 100	1
100-150	5
≥ 150	10

Most of the wells and springs have recharge areas located in areas with rainfall > 500 mm/ year, hence high R-factors were assigned to most wells and springs. The net recharge parameter and rating are presented in Appendices A, and C for wells and in Appendices B and D for springs.

4.3.3 Aquifer Media

All wells and springs in the research area pump water from carbonate rocks (a massive bedded limestone aquifer media) and the typical rating for this aquifer type is 6, however the local experience suggests parameters such as those in Table 4.10.

Table 4.10 Ranges and Rating for the Aquifer Media of the Research Area

Aquifer Media	
Range	**Rating**
Turonian (T)	10
Turonian/ Upper Cretaceous (T/UC)	8
Upper Cretaceous (UC)	6
Lower Cretaceous (LC)	3

The properties of the aquifer media and their corresponding ratings for the wells and springs are presented in Figure 4.5. Most of the Tulkarem, Qalqilia, and Salfit areas pump water from Upper Cretaceous aquifer media while Jenin area pumps water from both Turonian/ Upper Cretaceous, and Upper Cretaceous, Hebron area pumps water from both Turonian, and Upper Cretaceous, and Ramallah and Bethlehem areas pump water from the Lower Cretaceous.

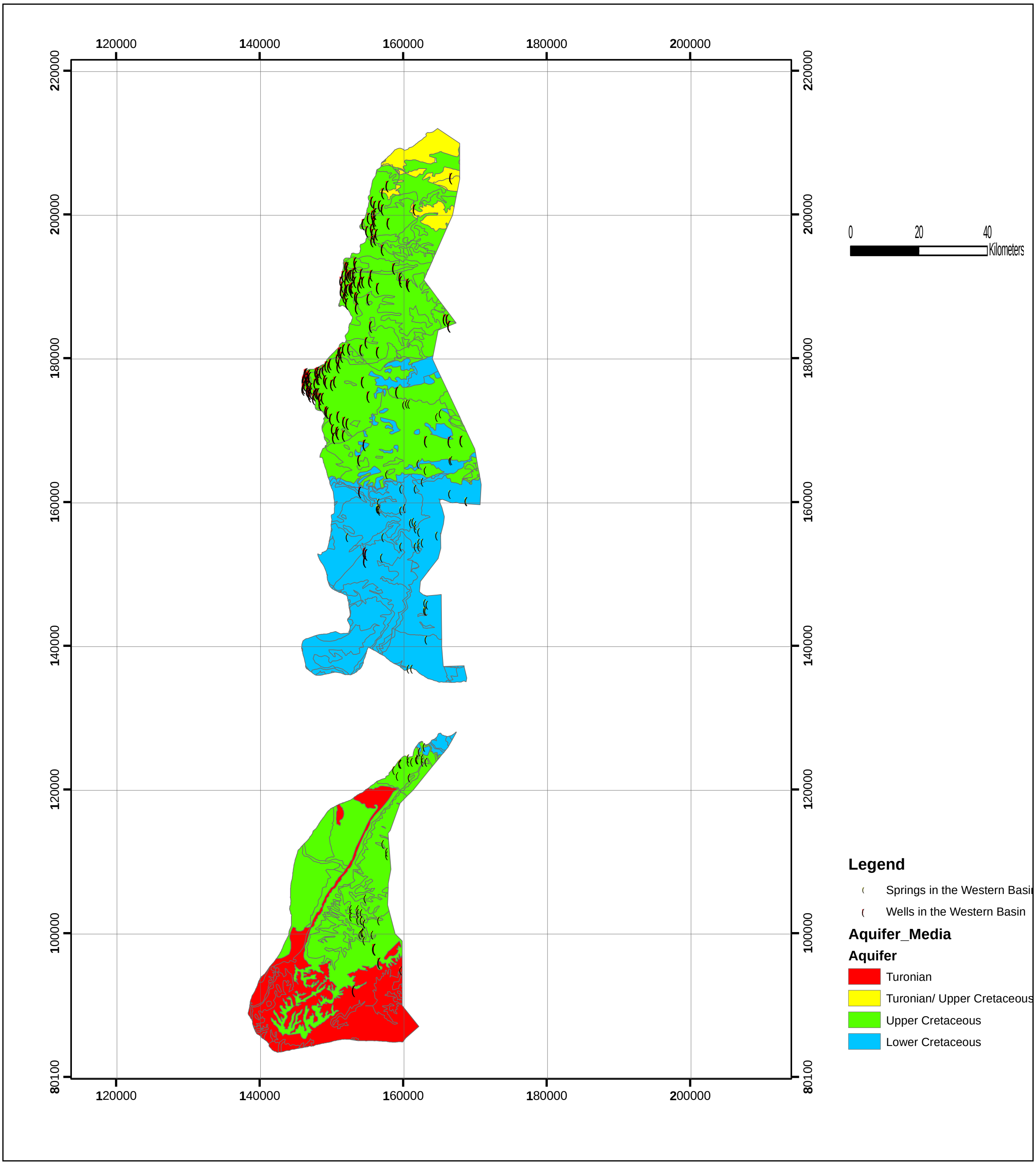

Figure 4.5 Aquifer Media (SUSMAQ, 2005)

4.3.4 Soil Media

Soil media values were strictly assigned on the basis of whether or not any significant areas of soil thickness > 2 m are present at the wells and springs locations. Soils in the study area are mostly thin or absent, or occur in small pockets, and where present are of relatively consistent nature (clayey loams). Wells and springs that have significant soil profiles in pockets are assigned higher S-rating than wells and springs without significant soil profiles. Table 4.11 illustrates the rating for the soil media parameter**.**

Table 4.11 Ranges and Rating for the Soil Media of the Research Area (CDM, 2004)

Soil Media	
Significant Area of Soil Cover (≥ 2 m) / No, Partly, Yes	**Rating**
No (thin/ absent soil)	10
Partly (low elevation - pockets of thin soils)	6
Yes (thick soil)	3

The soil media parameter for each well and spring was estimated and are included in Appendices A, and B.

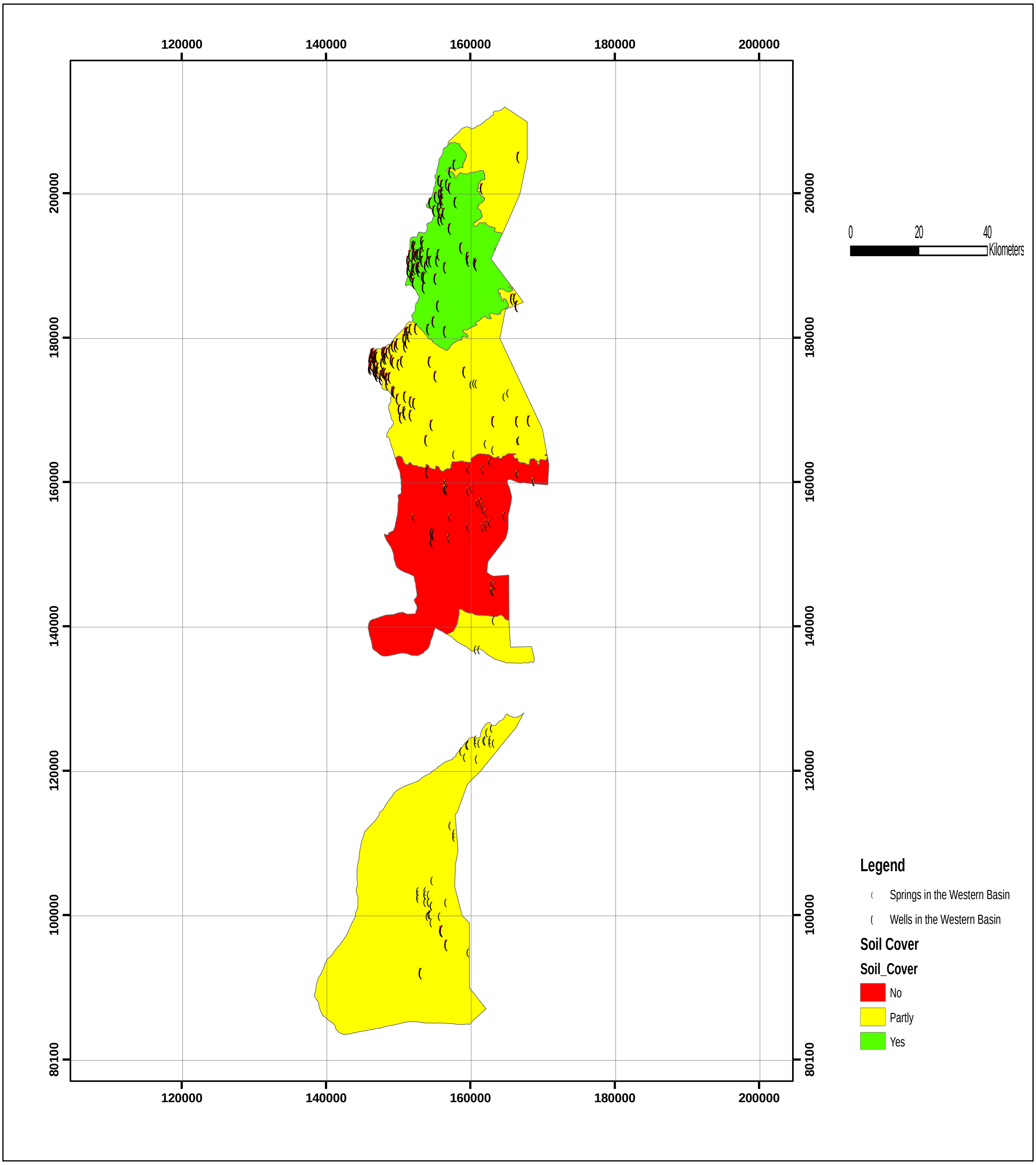

Figure 4.6 Significant Area of Soil Cover (SUSMAQ, 2005)

4.3.5 Topography

Unfortunately, there is no quantitative data for the slope in the direct recharge areas. Estimation of slopes as Low/ Moderate, and Moderate for each well and spring (Table 4.12) is taken from previous studies (CDM, 2004). It was interesting to note that most of the northern part of the research area has low/ moderate topography whereas the southern part is characterized with a moderate slope trend (Figure 4.7).

Table 4.12 Ranges and Rating for the Topography of the Research Area (CDM, 2004)

Topography	
Range (% slope)	**Rating**
Low/ Moderate	7
Moderate	5

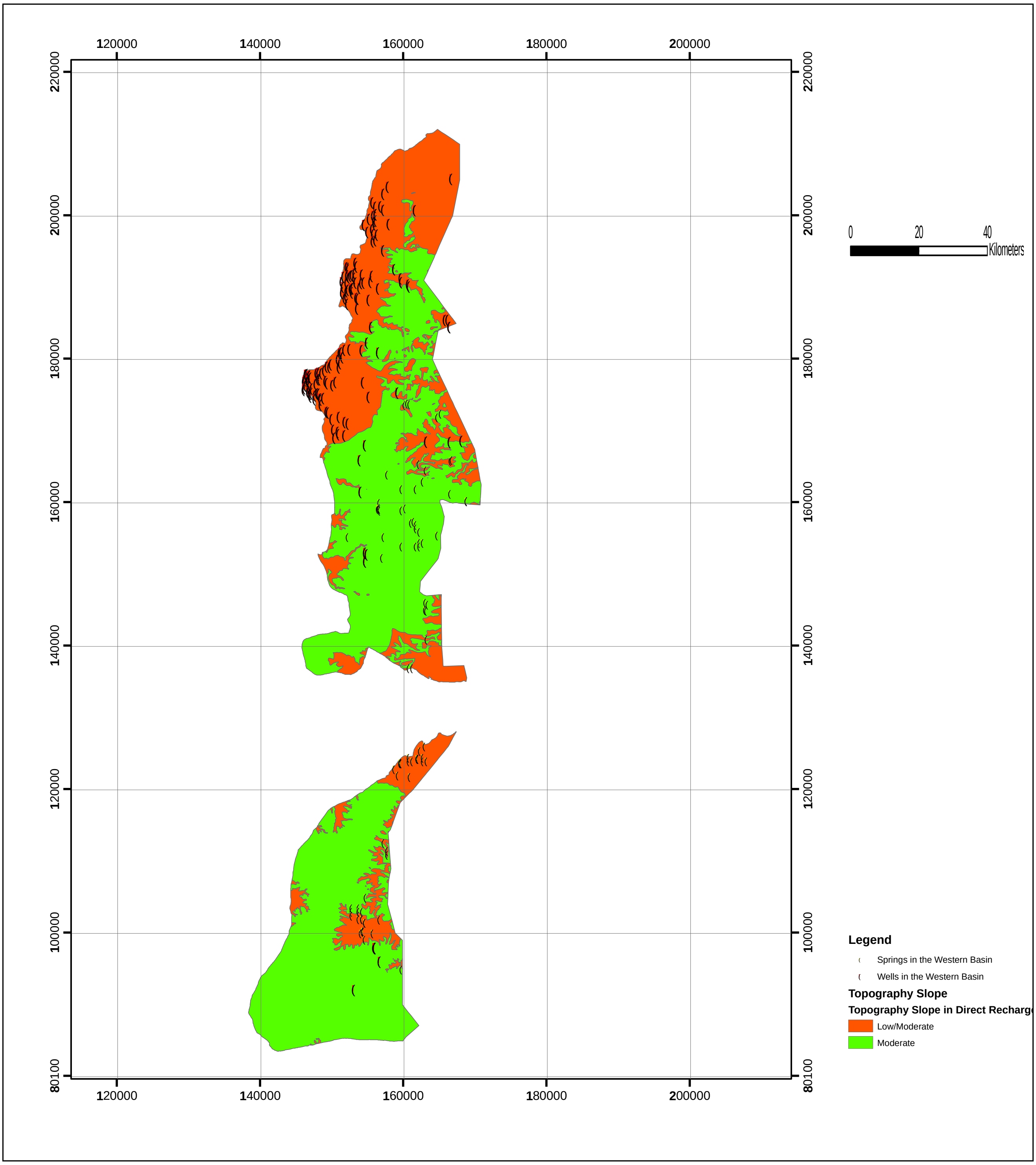

Figure 4.7 Topograhy (SUSMAQ, 2005)

4.3.6 Impacts of Vadose Zone

The Impacts of vadose zone rating is assigned on the basis of whether or not a protective subsurface aquitard is deemed present within the unsaturated zone (Table 4.13).

Table 4.13 Ranges and rating for the Protective Aquitards in Subsurface of the Research Area (CDM, 2004)

Protective Aquitards in Subsurface	
Range	**Rating**
No	10
Others (Partly, Yes, No data)	6

Data shows that protective subsurface aquitards aren't deemed present in the unsaturated zone for most of the wells and springs (Figure 4.8). Protective aquitards in the subsurface for each well is illustrated in Appendix A whereas protective aquitards in the subsurface for each spring is illustrated in Appendix B. Protective aquitards in the subsurface rating for each well is assigned as shown in Appendix C whereas its rating for each spring is assigned as shown in Appendix D.

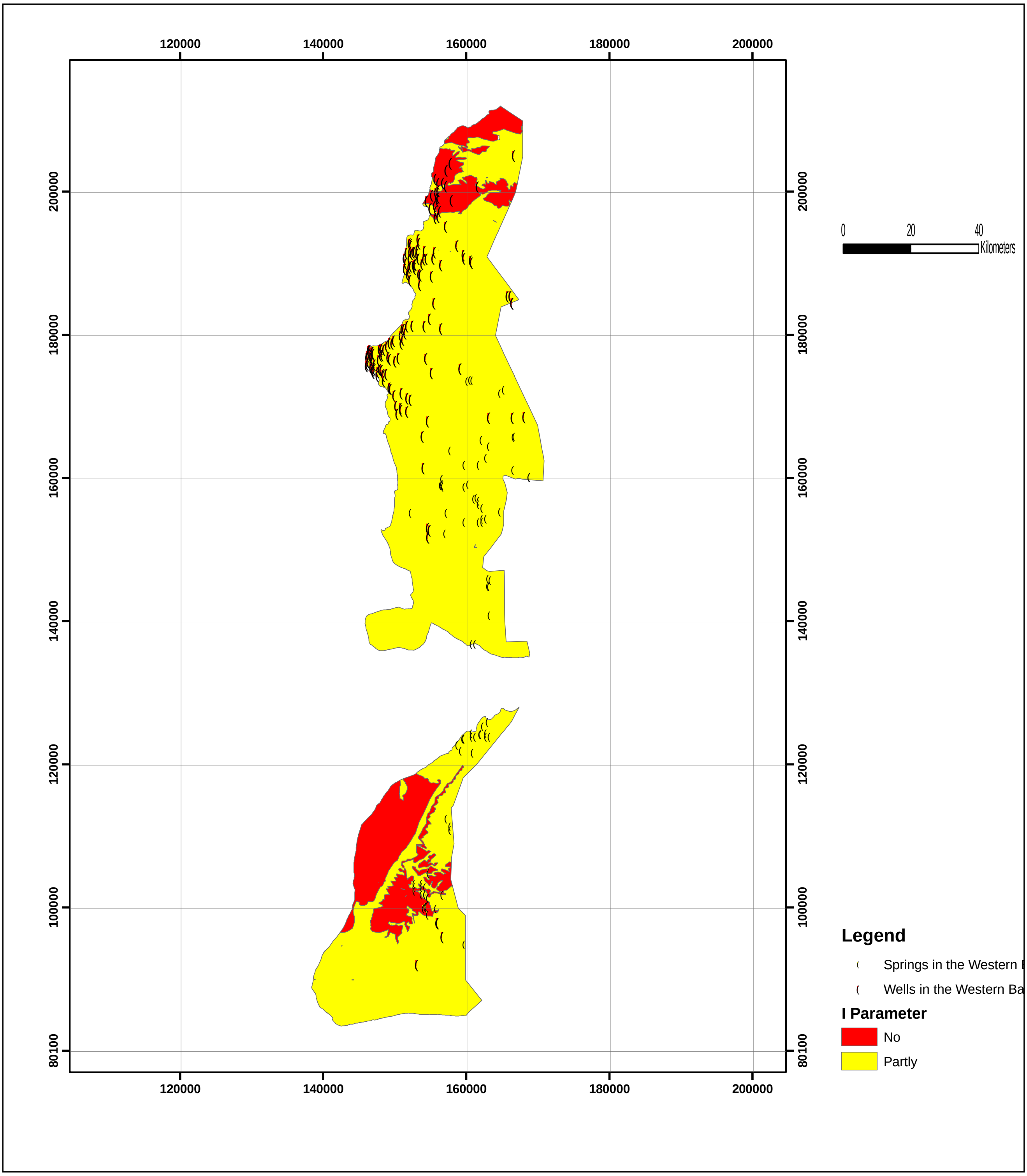

Figure 4. 8 Protective Aquitards Subsurface (SUSMAQ, 2005)

4.3.7 Hydraulic Conductivity

The C-factor in the DRASTC guidelines is modified to K-factor (K for "karst"). Most of the research area is characterized by karst hydrogeology, which has great implications on recharge, groundwater flow rates, and transport of pollutants to and in groundwater. Most of the wells and springs are located in, and pump from, karst aquifers. Hence, high K-ratings are assigned for most of the wells and springs (Table 4.14). In cases were data is absent, and the significance of karst is not well mapped or understood, a lower K-rating is assigned.

Table 4.14 Ranges and Rating for the Karst Feature observed of the Research Area (CDM, 2004)

Karst Feature observed	
Range	**Rating**
Yes	10
No data	6

Karst features observed for the research area as shown in Figure 4.9. Karst features observed for each well and spring is shown in Appendices A, and B while its rating is assigned in Appendices C, and D.

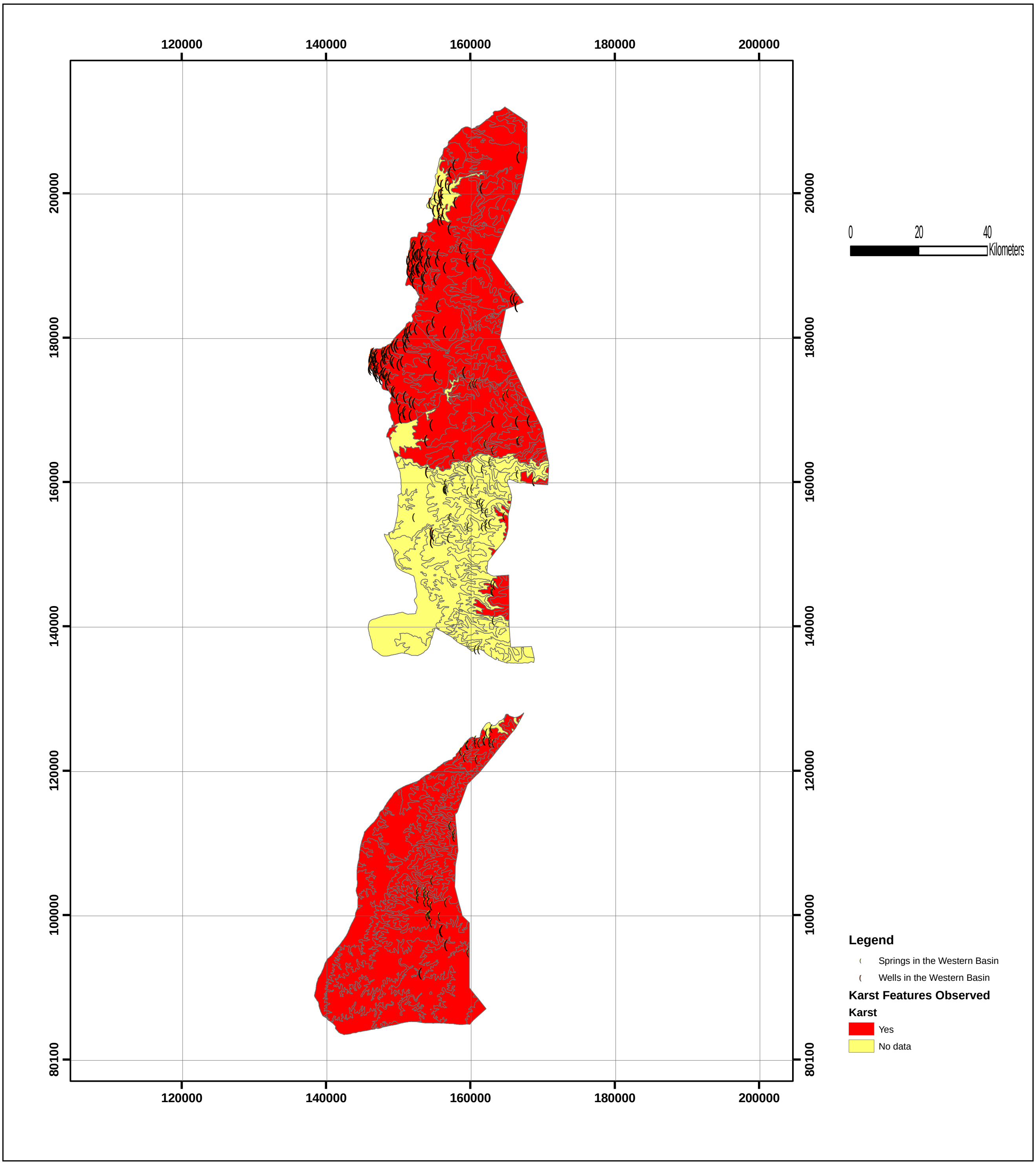

Figure 4. 9 Karst Features Observed (SUSMAQ, 2005)

4.4 Vulnerability Map

Appendices C and D illustrate ratings for seven DRASTIC parameters for each well and spring in the research area. The vulnerability index for each well and spring was found by applying the Equation. The vulnerability for wells and springs is divided into four categories regarding to previous vulnerability classification studies (CDM, 2004):

5. Extreme: DRASTIC index (DI) is greater than 175.
6. High: DRASTIC index (DI) is greater than 151 and less than 175.
7. Moderate: DRASTIC index (DI) is greater than 126 and less than 150
8. Low: DRASTIC index (DI) is equal to or less than 125.

By using GIS technique, the vulnerability map for the research area was endorsed as illustrated in Figure 4.10.

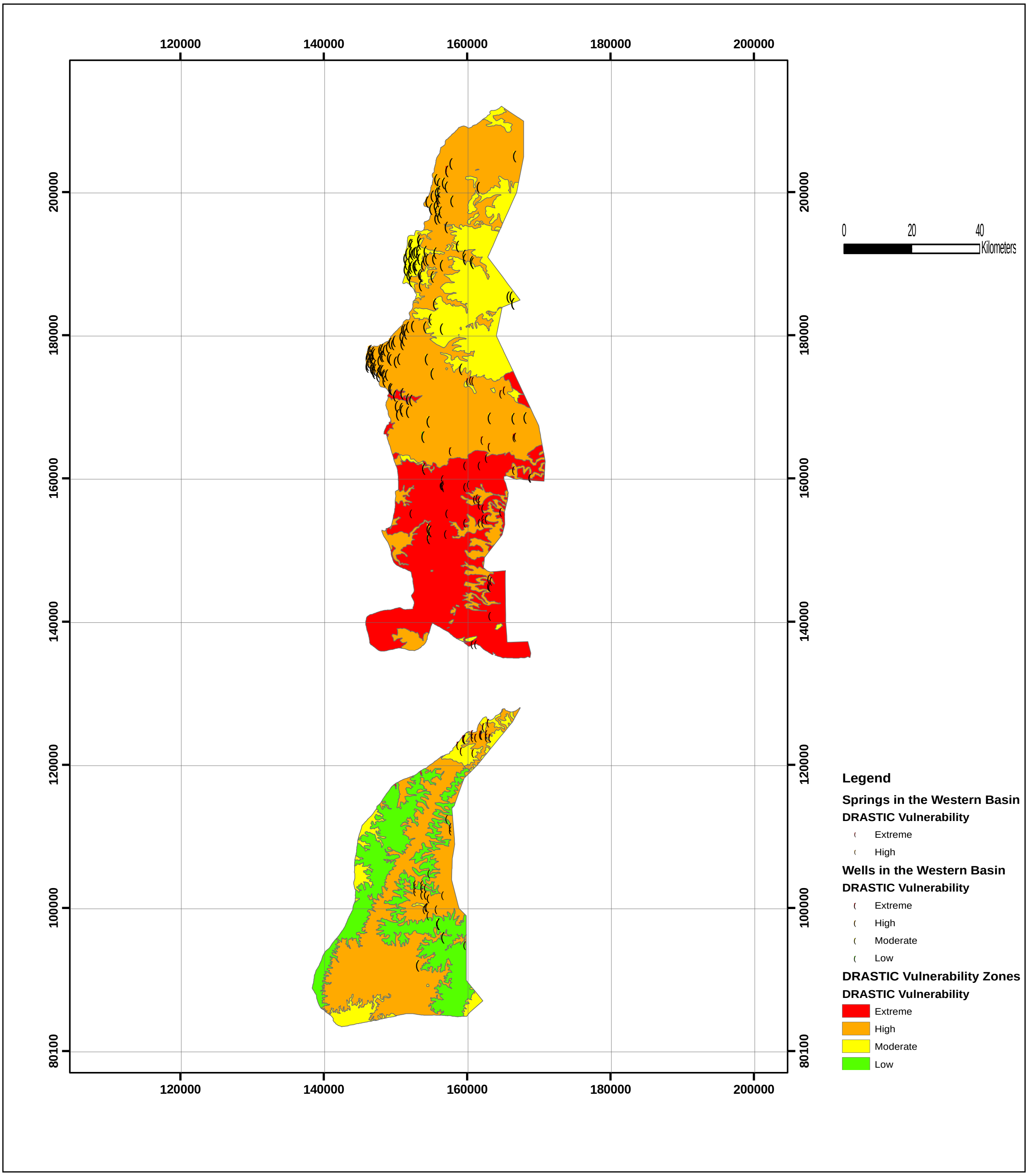

Figure 4.10 Vulnerability Map (SUSMAQ, 2005)

4.5 Results

As it is shown in vulnerability map, "Extreme" vulnerability is assigned in Ramallah and Jerusalem since there are many springs located near the surface in those two areas. "High" vulnerability is assigned to rocks, which make up the regionally Turonian/ upper cretaceous, and upper cretaceous like in some parts of Jenin, west side of Tulkarem, Qalqilia, Salfit, Bethlehem and Hebron. "Moderate" vulnerability is assigned to upper cretaceous like in east side of Tulkarem and parts of Bethlehem. "Low" vulnerability is assigned in parts of Hebron district**.** Note that there are no wells located in the Jerusalem or Bethlehem Governorates. The distribution of wells among the various governorates, according to vulnerability assessment, is described in Table 4.15.

Table 4.15 Vulnerability Index for Wells

Governorate	Wells	Vulnerability	Governorate	Wells	Vulnerability
Jenin (3 Wells)	1	Extreme	Tulkarem (67 Wells)	0	Extreme
	1	High		6	High
	1	Medium		61	Medium
	0	Low		0	Low
Governorate	**Wells**	**Vulnerability**	**Governorate**	**Wells**	**Vulnerability**
Nablus (4 Wells)	0	Extreme	Qalqilia (72 Wells)	0	Extreme
	0	High		69	High
	4	Medium		3	Medium
	0	Low		0	Low
Governorate	**Wells**	**Vulnerability**	**Governorate**	**Wells**	**Vulnerability**
Salfit (5 Wells)	0	Extreme	Ramallah (4 Wells)	0	Extreme
	0	High		0	High
	5	Medium		4	Medium
	0	Low		0	Low

Governorate	Wells	Vulnerability
Hebron (6 Wells)	0	Extreme
	0	High
	5	Medium
	1	Low

CHAPTER FIVE

AQUIFER VULNERABILITY ASSESSMENT IN QALQILA GOVERNORATE USING PI METHOD

5.1 Introduction

Although groundwater from karst aquifers is an important drinking water resource, it is particularly vulnerable to contamination. Karst aquifers, consequently, need a special protection strategy. In this chapter, a new method of groundwater vulnerability mapping is proposed: the PI method. It could be applied for all types of aquifers, but it provides special tools for karst (Werz, H., and Hotzl, H.). The Western Aquifer Basin located in Qalqilia, will be taken as a Case Study (Figure 5.1), results will then be compared with those from the DRASTIC method. The results obtained from the two methods will be discussed and an outlook on the role of vulnerability maps within an overall groundwater protections scheme will be given.

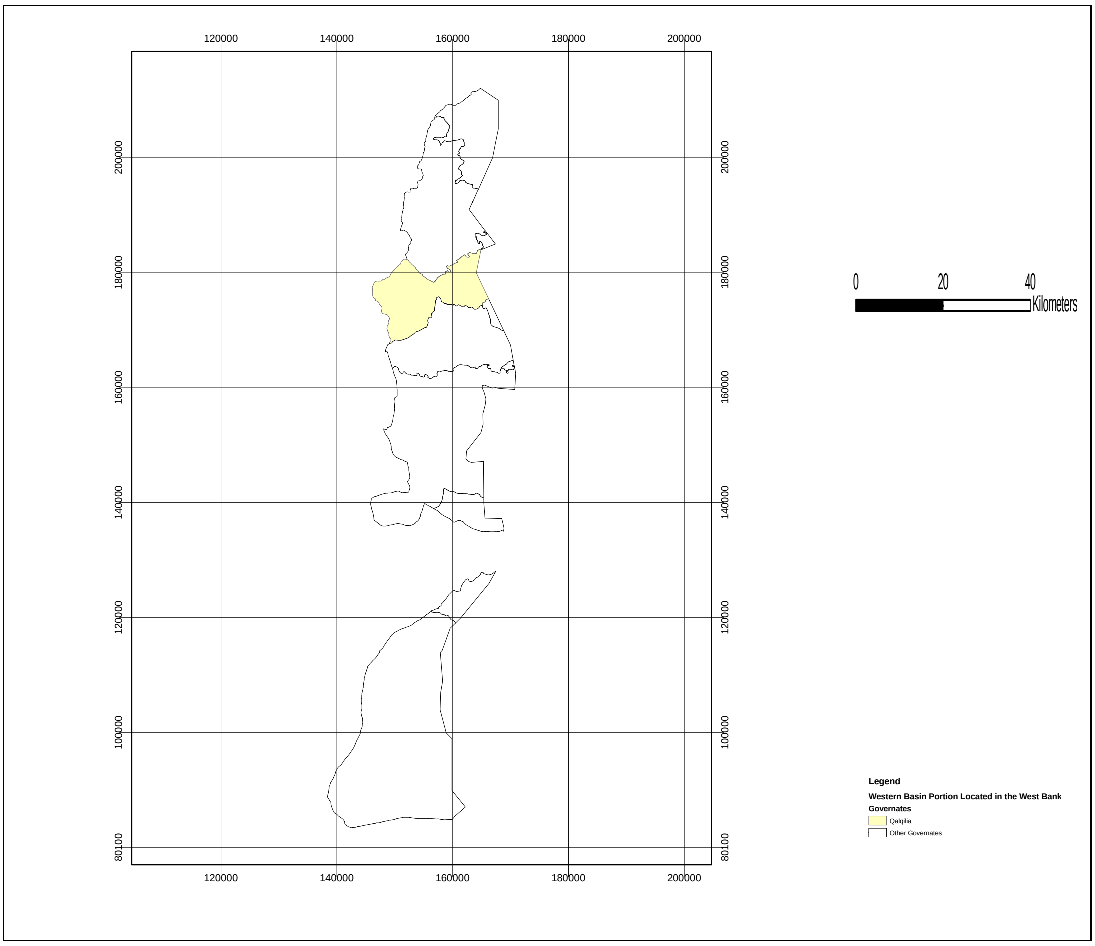

Figure 5.1 Case Study Area (SUSMAQ, 2005)

5.2 Background of the Case Study Area – Qalqilia Governorate

The Palestinian city of Qalqilia, that is located in the northwest of the West Bank, has its roots and origins in the Canaaite era. The name "Qalqilia" goes back to the Roman times, where European Mediaeval sources refer to it as "Kalkelie", which is the name that is still in use (Wildlife-Palestine, 2006).

5.2.1 Location

Qalqilia is situated about 12 km from the Mediterranean coast. The city's altitude ranges from 45 to 125 m above sea level, and it covers approximately 3.5 km^2 (Wildlife-Palestine, 2006).

5.2.2 Population

Qalqilia inhabitants reach about 45,000 Palestinians while the annual growth rate reaches approximately 3.8% (Wildlife-Palestine, 2006).

5.2.3 Climate

Qalqilia has a temperate Mediterranean climate; rainy, warm in the winter, and hot in the summer with humidity levels reaching 70% during July and August. Annual average rainfall is 550 mm (Wildlife-Palestine, 2006).

5.2.4 Agriculture

The area of agricultural lands in the governorate reaches about 74274 Donums (4% of the total area of Palestinian farmed lands) of which 60726 donums are rain fed while the rest are irrigated (Table 5.1).

Table 5.1 The Farmed Areas and Method of Plantation in Qalqilia Governorate in the Years 1997/ 98 (Wildlife-Palestine, 2006)

Type of Plantations	Method of Plantation		Total
	Rain-fed	Irrigated	
Fruit Trees	50606	7947	58553
Vegetables	741	5346	6084
Field Crops	9379	255	9634
Total	60726	13548	74274

The amount of plant production in Qalqilia Governorate was about 73179 tons in the years 1997/ 98 (about 7.1% of total plant production in the Palestinian lands). The financial value of this product was about 42.772 million US Dollars (about 7% of plant production value in the Palestinian lands).

5.2.5 Local Economy

The City of Qalqilia is dependent on the Israeli market. The majority of Qalqilia labor force (skilled and unskilled) works in the construction, agriculture and other sectors within the Israeli labor market. Additionally, 20% of Qalqilia population is engaged in trade and commerce

(Wildlife-Palestine, 2006). Israelis and Palestinian citizens of Israel in the villages across the borders are an important source of income for this sector.

The recurrent Israeli closures of the West Bank, during which the movement of goods and persons between Israel and the West Bank (and at sometimes within the West Bank, as well) is prohibited, has had a devastating impact on Qalqilia economy. Workers are prevented from reaching their workplaces and the agricultural products cannot be marketed and as a consequence, the local commercial sector is negatively affected as well. On several occasions, the Israeli military force has sealed off Qalqilia from the outside world for prolonged periods, preventing any movement into or out of the city.

5.3 General Concept of the PI Method

The PI Method is a GIS-based approach to mapping intrinsic groundwater vulnerability with special consideration of karst aquifers. It is based on an origin-pathway-target model (Figures 5.2 and 5.3): The origin of the assumed hazard is the ground surface; the groundwater table in the uppermost aquifer is the target; the pathway includes the layers between the ground surface and the groundwater surface. Thus, the PI method can be used for resource vulnerability mapping.

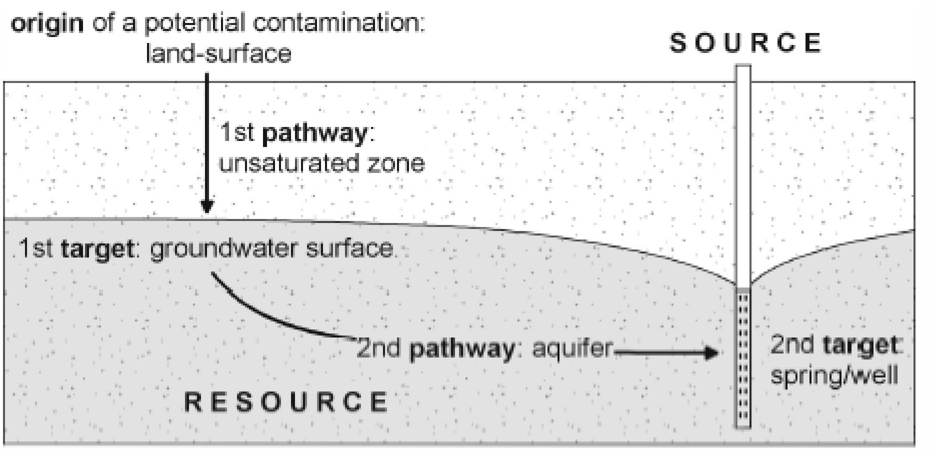

Figure 5.2 The European Approach to Groundwater Vulnerability Mapping: is based on an origin-pathway-target conceptual model. The possible contamination event is assumed to originate at the land-surface. For resource protection, the groundwater surface in the aquifer is the target; for source protection, the spring or well is the target. For resource protection, the pathway consequently consists of the passage through the unsaturated zone (also referred to as the overlying layers); for source protection, it includes the passage through the aquifer (Werz, H., and Hotzl, H.).

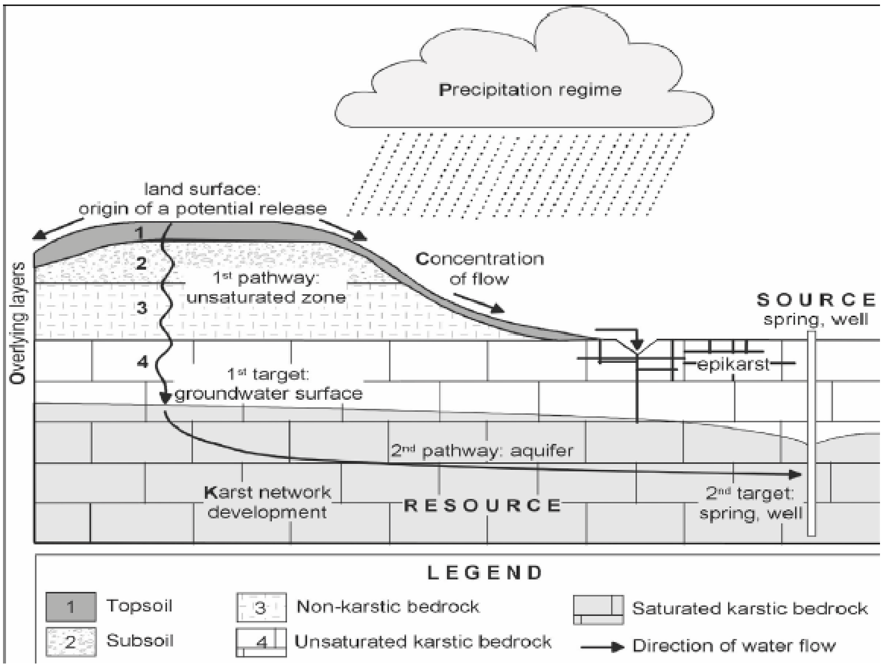

Figure 5.3 Origin-Pathway-Target Model (Werz, H., and Hotzl H.)

5.4 Method of Assessment

5.4.1 Determination of Protective Cover (P-Factor)

The P factor indicates the effectiveness of the protective cover. The calculation scheme is shown in Figure 5.4. The score B for the bedrock is obtained by multiplying the factor L for the lithology and the factor F for the degree of fracturing and karstification. The F factor was modified in order to describe the development of the epikarst and its influence on groundwater vulnerability.

The epikarst is defined as the uppermost zone of karstified rock outcrops, in which permeability due to fissuring and karstification is substantially higher and more uniformly distributed than in the rock below. Its thickness ranges between a few decimeters and several tens of meters. The possible functions of epikarst are storage and concentration of flow. If the epikarst is developed in a way that leads to extreme concentration of flow, e.g., a bare karrenfield connected with hidden, karstic shafts, the structural factor is assigned a value of zero, expressing that the protective cover of the unsaturated zone below this epikarst is completely bypassed.

Surface karst features are only one expression of epikarst, but most of it cannot be seen at the surface. The epikarst zone can be highly developed without any visible karst features. As a consequence, it is assumed that epikarst is present (even if it is not visible) if there are conditions that are favorable for epikarst development, such as pure limestone with widely spaced fractures, or if there are geomorphologic indicators of extensive development of epikarst, such as dolines and karrenfields.

It can be misleading to assign a low vulnerability to an area where the aquifer under consideration is overlain by a higher aquifer–in this case, the higher aquifer needs protection. Therefore, the PI method always takes the groundwater table in the uppermost aquifer as the target. As a consequence, a higher aquifer is not considered to be protection for the underlying aquifer. Consideration of artesian pressure (A) in the aquifer by an additional score of A is 1500 points was not modified.

The scores for the subsoil and the bedrock are multiplied by the respective thickness in M (factor M). Thin, low permeability strata can be bypassed if they are not laterally extensive, but occur in form of lenses. As a consequence, the lateral continuity of each layer should be taken into account in order to avoid overestimation of the protective function. The score for the total effectiveness of the protective cover PTS is calculated as shown in Figure 5.4.

The range of possible scores for the total protective function PTS is subdivided into five classes, which are the final P factors in the PI method. Each class covers a score range of one magnitude. The classes allow a description of the high natural variation of protective cover: PTS ≤ 10 (e.g., < 2 m of gravel) is considered to provide a very low degree of protection and to be extremely vulnerable (P = 1), while a very high degree of natural protection and a very low vulnerability (P = 5) is assigned to PTS > 10000 (e.g., > 20 m of clay). The spatial distribution of the P factor is shown on a P map (Werz, H., and Hotzl, H.). For flat areas with a high infiltration capacity, the P factor is multiplied by an I factor of 1. Consequently, the final vulnerability map will be identical to the P map for this area.

A P factor of 5 is assigned to areas outside the considered aquifer from which recharge enters the aquifer by surface and lateral surface or subsurface flow; these areas can be subdivided and classified according to different I values.

Topsoil - T

eFC [mm] up to 1 m depth	T
> 250	750
> 200-250	500
> 140-200	250
> 90-140	125
> 50-90	50
< 50	0

Recharge - R

Recharge [mm/y]	R
0-100	1.75
>100-200	1.50
>200-300	1.25
>300-400	1.00
>400	0.75

Subsoil - S

Type of subsoil (grain size distribution)	S	Type of subsoil (grain size distribution)	S
clay	500	very clayey sand, clayey sand, loamy silty sand	140
loamy clay, slightly silty clay	400		
slightly sandy clay	350	sandy silt, very loamy sand	120
silty clay, clayey silty loam	320	loamy sand, very silty sand	90
clayey loam	300	slightly clayey sand, silty sand, sandy clayey gravel	75
very silty clay, sandy clay	270		
very loamy silt	250	slightly loamy sand, sandy silty gravel	60
slightly clayey loam, clayey silty loam	240	slightly silty sand, slightly silty sand with gravel	50
very clayey silt, silty loam	220	sand	25
very sandy clay, sandy silty loam, slightly sandy loam, loamy silt, clayey silt	200	sand with gravel, sandy gravel	10
		gravel, gravel with breccia	5
sandy loam, slightly loamy silt	180	non-lithified volcanic material (pyroklastica)	200
slightly clayey silt, sandy loamy silt, silt, very sandy loam	160	peat	400
		sapropel	300

Lithology - L

Lithology	L
claystone, slate, marl, siltstone	20
sandstone, quarzite, volcanic rock plutonite, metamorphite	15
porous sandstone, porous volcanic rock (e.g. tuff)	10
conglomerate, breccia, limestone, dolomitic rock, gypsum rock	5

Fracturing - F

Fracturing	F
non-jointed	25.0
slightly jointed	4.0
moderately jointed, slightly karstified or karst features completely sealed	1.0
moderately karstic or karst features mostly sealed	0.5
strongly fractured or strongly karstified and not sealed	0.3
Epikarst strongly developed, not sealed	0.0
not known	1.0

Thickness of each stratum in [m] - M

Bedrock - B
$B = L \cdot F$

Artesian pressure A
1500 points

Total protective function P_{TS}

$$P_{TS} = \left[T + \left(\sum_{i=1}^{m} S_i \cdot M_i + \sum_{j=1}^{n} B_j \cdot M_j \right) \right] \cdot R + A$$

score P_{TS}	effectiveness of protective cover	P-factor	example
0-10	very low	1	0-2 m gravel
>10-100	low	2	1-10 m sand with gravel
>100-1000	medium	3	2-20 m slightly silty sand
>1000-10000	high	4	2-20 m clay
>10000	very high	5	> 20 m clay

P-map

Figure 5.4 Determination of the P Factor (Werz, H., and Hotzl H.)

5.4.2 Determination of Infiltration Conditions (I-Factor)

5.4.2.1 General Concept

The overlying layers can protect the groundwater only if the precipitation infiltrates directly into the ground without significant concentration of flow. However, the disappearance of an intermittent or perennial surface stream into a swallow hole is common in karst areas. In this case, the protective cover is completely bypassed at the swallow hole and bypassed in part by the surface runoff in the catchment's area of the sinking stream.

Therefore, the I factor was introduced. It expresses the degree to which the protective cover is bypassed as a result of lateral, surface and subsurface concentration of flow, especially within the catchment's area of a sinking stream. If the infiltration occurs directly on a flat surface without significant concentration of flow, the I factor is 1.0, indicating that the protective cover is not bypassed and is 100% effective. On the other hand, the protective cover is completely bypassed by a swallow hole through which surface water directly enters the karst aquifer. In such a case, the I factor is 0.0 (Werz, H., and Hotzl H.). The catchment's area of a sinking stream is assigned for a value between 0.0 and 1.0 according to the extent of surface and subsurface flow.

It has to be emphasized that the I factor is not precisely defined in terms of hydrology. It is a half quantitative tool to express the vulnerability of groundwater resulting from bypassing of the protective cover by lateral surface and subsurface flow. The I factor is used for further GIS operations to generate the vulnerability map.

5.4.2.2 Hydrological Basis

The vulnerability of an area to groundwater contamination is dependent on the pathway of a possible contaminant from the ground surface to the groundwater table. As contaminants are usually transported in water, it is necessary to describe the possible flow paths of the water. We can distinguish between three relevant processes: infiltration with subsequent percolation, surface flow, and subsurface flow. Which of these processes predominates depends on both the properties of the site and the characteristics of the rainfall event, as well as the previous precipitation history and the degree of saturation of the soil (Werz, H., and Hotzl H.).

Diffuse infiltration of rain water from the surface into the soil and the subsequent downward percolation through the soil is the dominant hydrological process if the rainfall intensity is less than the capacity of the soil to absorb the water and if the hydraulic conductivity of the total soil profile is high enough to allow downward movement of the water. Gentle slopes, dense vegetation–especially forest cover–and coarse-textured soils with thick organic horizons and stable peds favour infiltration (Werz, H., and Hotzl H.).

Surface flow occurs when not all of the rainwater is able to penetrate the soil surface. There are two main types: Hortonian runoff and saturated surface flow (Werz, H., and Hotzl H.).

Hortonian runoff occurs when the intensity of a rainfall event exceeds the infiltration capacity of the topsoil and the surplus rainwater flows away on the surface. The necessary condition for Hortonian runoff is that the intensity of the rain is significantly higher than the hydraulic conductivity of the topsoil. The amount (depth) of surplus water, which is sufficient to produce surface runoff, is dependent on the slope of ground surface (Werz, H., and Hotzl H.).

Saturated surface flow occurs when a rainfall event is sufficiently long and intense to saturate the soil and exhaust it's through flow capacity or if the soil was saturated due to previous precipitation and the additional precipitation cannot infiltrate but flows away on the surface. This process is favored when lower permeability layers are present below thin, relatively highly permeable topsoil. The necessary condition for this type of flow is that the total amount of precipitation is more than the effective porosity; similar to Hortonian runoff, the amount of surplus water that is sufficiently high to produce surface runoff depends on the ground surface gradient (Werz, H., and Hotzl H.).

Subsurface flow occurs when the hydraulic conductivity of the topsoil is high enough for the infiltration of rainwater while lower permeability layers in or below the soil does not allow the further downward percolation to continue. In this case, the layers above the low permeability zone become temporarily saturated, allowing movement parallel to the slope. The velocity of the subsurface flow is strongly dependent on the slope gradient, the hydraulic conductivity of the topsoil, and on preferential flow paths. We can distinguish between two relevant types (Werz, H., and Hotzl H.):

Subsurface storm water flows in diffuse pathways and is a fast flow process, which occurs in very highly permeable soils. The flow velocity depends on the hydraulic conductivity and the slope gradient.

Subsurface storm water also flows in preferential pathways which is another fast flow process. Soil pipes, desiccation fissures, worm holes and mouse holes are usually dry but become filled with water during intensive rain events, enabling very fast flow.

5.4.2.3 Determination of the I Factor

The I factor expresses the degree to which the protective cover is bypassed by lateral surface and subsurface flow. The spatial distribution of the I factor is displayed on the I map. Such flow is considered to be especially dangerous within the catchment's area of a sinking stream because contaminants can directly enter the karst groundwater. Therefore, the I factor (the I map) is obtained using the following two components (Werz, H., and Hotzl H.):

- The I' factor expresses the estimated direct infiltration relative to surface and lateral subsurface flow. The controlling factors are soil properties, slope and vegetation. The spatial distribution of the I' factor is shown on the I' map.

- The surface catchment's map shows the surface catchment's areas of sinking streams disappearing into a swallow hole and buffer zones of 10 m and 100 m on both sides of the sinking streams.

The amount of surface and subsurface flow is dependent on rainfall intensity and site properties. Characteristics of single events, like precipitation rate, cannot be included in the concept of vulnerability–otherwise a different vulnerability map for each rain event have been to draw. Therefore, the proportion of surface and subsurface flow is estimated only on the basis of the site properties and assuming average storm rainfall, which might occur several times per year.

The critical values for hydraulic conductivity and thickness (Figure 5.5) were calculated using data and theoretical approaches from the hydrological literature as follows (Werz, H., and Hotzl H.):

- Infiltration is the dominant process when the hydraulic conductivity of the topsoil is greater than 10^{-5} m/ s and the thickness is more than 100 cm (Werz, H., and Hotzl H.).

- Fast subsurface storm-water flow is the dominant process when the thickness is between 30 and 100 cm and the conductivity is greater than 10^{-5} m/ s; if it exceeds 10^{-4} m/ s, very fast subsurface flow of more than 50 m/ d is to be expected; macro pores favour this process (Werz, H., and Hotzl H.).

- Saturated overland flow is the dominant process if we find low permeable layers at depths of less than 30 cm and if the conductivity of the topsoil is greater than 10^{-5} m/s (Werz, H., and Hotzl H.).

- Hortonian flow occurs rarely (rainfall intensity of 30 mm/ h on steep slopes and 50 mm/ h on gentle slopes) if the conductivity of the topsoil is between 10^{-5} and 10^{-6} m/s (Werz, H., and Hotzl H.).

- Hortonian flow occurs frequently (rainfall intensity of 3 mm/h on steep slopes and 30 mm/ hr on gentle slopes) if the conductivity of the top soil is less than 10^{-5} m/ s (Werz, H., and Hotzl H.).

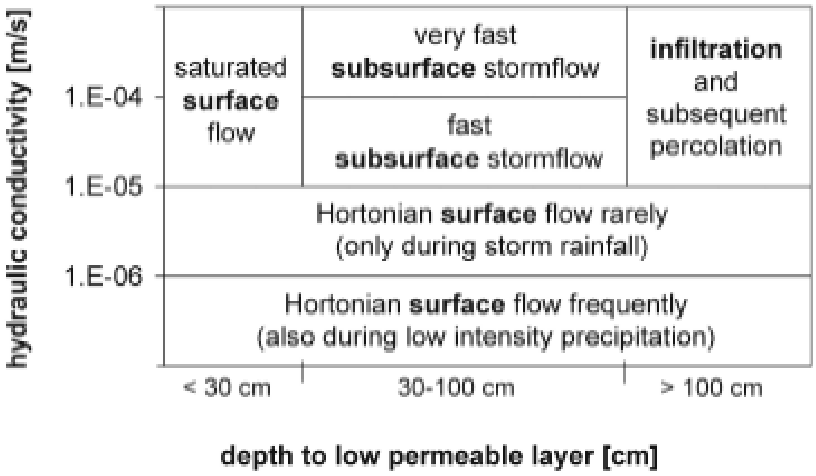

Figure 5.5 Determination of the Predominant Flow Process as a Function of the Saturated Hydraulic Conductivity and the Depth to Low Permeability Layers: If it is not possible to distinguish all the six processes, it is often sufficient to differentiate between infiltration, subsurface flow and surface flow. This can be done on the basis of direct field observations and geological data (Werz, H., and Hotzl, H.).

This system makes it possible to delineate areas with different flow processes predominate. However, there are often not enough detailed data to distinguish between the six different processes described above. In this case, it is sufficient to differentiate between the three processes infiltration, subsurface flow and surface flow. This can often be done on the basis of geological data, information on the soil type and/ or direct field observations. For example: Infiltration has to be expected on highly permeable rendzina soil on karst rocks, subsurface flow predominates on coarse rock debris covering low permeability formations, and surface flow takes place on outcrops of marl and clay stone formations.

The proportion of each of these flow processes depends on the factors vegetation (land use) and slope of the ground surface (Werz, H., and Hotzl H.). In general, forest cover favors infiltration, whereas agricultural areas are more likely to produce surface runoff. The flow velocity of subsurface flow can be estimated using the Darcy equation (except for preferential flow) and is directly proportional to the slope gradient. Hortonian runoff and saturated flow can occur even on very gentle slopes if the precipitation exceeds infiltration or if the topsoil is saturated, but steep slopes favour surface flow and increase its flow velocity.

A system to assess the proportion of lateral surface and subsurface flow was developed, based on the dominant flow process and the factors vegetation and slope. The slope was done using the divisions of the German soil mapping guidelines. The proportion of lateral flow is expressed by the so-called I' factor. Its spatial distribution is shown on the I' map. However, for vulnerability mapping in karst areas, it is indispensable to distinguish whether this flow occurs inside or outside the catchment's area of a sinking stream as well as to take into account the distance of the evaluated site to the stream. With respect to groundwater vulnerability, the most dangerous situation is lateral flow close to a swallow hole or sinking stream, while the least dangerous situation is flow that leaves the system under consideration without sinking or seeping underground. Therefore, the final I map is obtained by the intersection of the I'-map with a map showing the catchment's areas of sinking streams. Five zones (Figure 5.6) are delineated on this “surface catchment's map” in order to decrease risk. Shows the five zones with the following definitions:

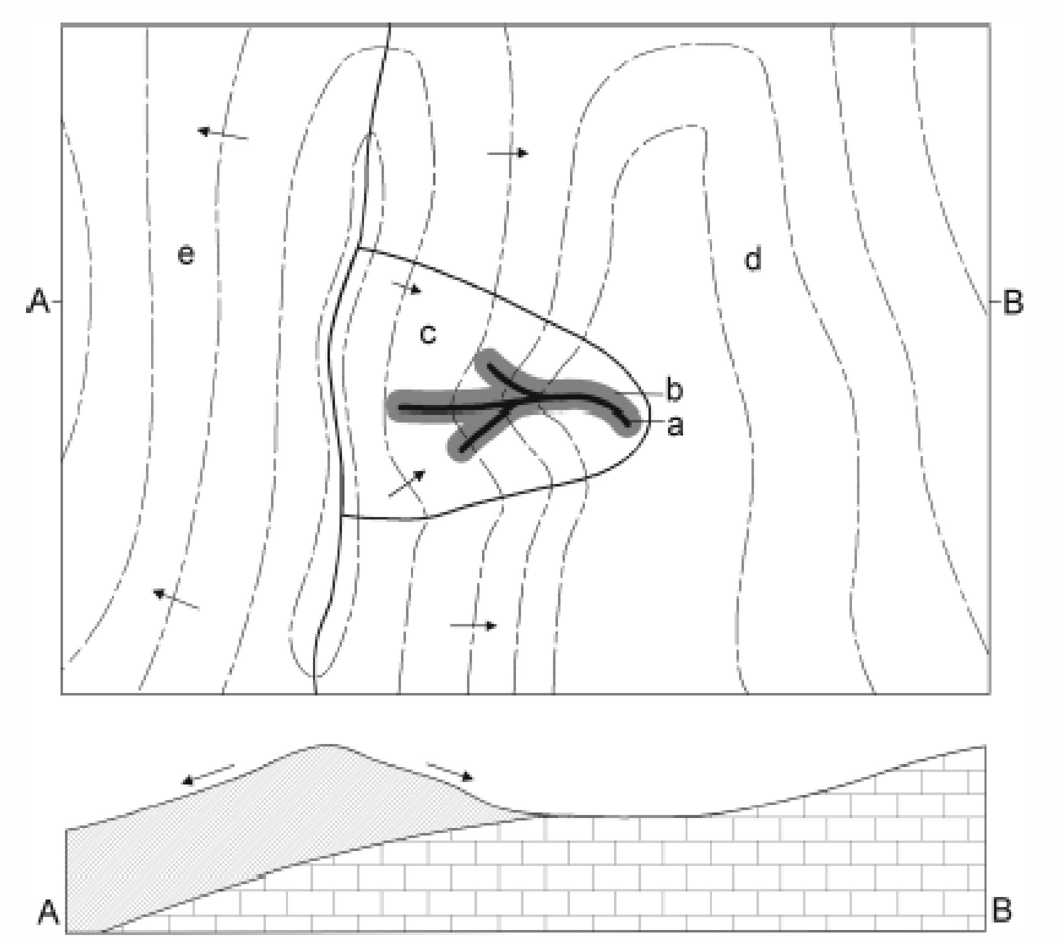

Figure 5.6 Topographical Sketch and Geological Profile Illustrating the Five Zones of the "Surface Catchment's Map" (Werz, H., and Hotzl, H.).

a Swallow holes, the sinking streams and 10 m buffer zones on both sides of these streams.

b 100 m buffer zones on both sides of the swallow holes and sinking streams.

c The rest of the surface catchment's areas of the sinking streams.

d Areas outside the catchment of sinking streams but inside the topographic catchment of the (karst) system under consideration; surface and subsurface flow cannot enter a swallow hole but can infiltrate somewhere else, e.g. at the base of a slope or in a closed depression.

e Areas that discharge by surface or subsurface flow out of the (karst) system under consideration. In that zone, surface and subsurface flow can never reach the groundwater.

The I' map and the map of the surface catchment's area are intersected according to the scheme presented in Figure 5.7. The I-map shows the degree to which the protective cover is bypassed by lateral surface and subsurface flow.

1st Step: Determination of the dominant flow process

Saturated hydraulic conductivity [m/s]	Depth to low permeability layer < 30 cm	30-100 cm	> 100 cm
> 10^{-4}	Type D	Type C	Type A
> 10^{-5}-10^{-4}	Type D	Type B	Type A
> 10^{-6}-10^{-5}	Type E		
< 10^{-6}	Type F		

2nd Step: Determination of the I'-factor

Forest

dominant flow process		Slope < 3.5 %	3.5 - 27 %	> 27 %
infiltration	Type A	**1.0**	**1.0**	**1.0**
subsurface flow	Type B	1.0	0.8	0.6
	Type C	**1.0**	**0.6**	**0.6**
surface flow	Type D	0.8	0.6	0.4
	Type E	1.0	0.6	0.4
	Type F	**0.8**	**0.4**	**0.2**

Field/Meadow/Pature

dominant flow process		Slope < 3.5 %	3.5 - 27 %	> 27 %
infiltration	Type A	**1.0**	**1.0**	**0.8**
subsurface flow	Type B	1.0	0.6	0.4
	Type C	**1.0**	**0.4**	**0.2**
surface flow	Type D	0.6	0.4	0.2
	Type E	0.8	0.4	0.2
	Type F	**0.6**	**0.2**	**0.0**

3rd Step: Determination of the I-factor

	Surface Catchment Map	I' factor 0.0	0.2	0.4	0.6	0.8	1.0
a	swallow hole, sinking stream and 10 m buffer	0.0	0.0	0.0	0.0	0.0	0.0
b	100 m buffer on both sides of sinking stream	0.0	0.2	0.4	0.6	0.8	1.0
c	catchment of sinking stream	0.2	0.4	0.6	0.8	1.0	1.0
d	area discharging inside karst area	0.4	0.6	0.8	1.0	1.0	1.0
e	area discharging out of the karst area	1.0	1.0	1.0	1.0	1.0	1.0

→ I-map

Figure 5.7 Calculation and Assessment of the I Factor: If it is not possible to distinguish six different dominant flow processes, it is sufficient to distinguish between infiltration (white), subsurface flow (light grey) and surface flow (dark grey). In this case, the bold numbers can determine the I' factor (Werz, H., and Hotzl, H.).

5.4.3 Construction of Vulnerability Map

The vulnerability map shows the intrinsic vulnerability and the natural protection of the uppermost aquifer. The map shows the spatial distribution of the protection factor π, which is obtained by multiplying the P and I factors:

$$\pi = P \cdot I$$ **(Zwahlen, F., 2003).**

The π factor ranges between 0.0 and 5.0, with high values representing a high degree of natural protection and low vulnerability. Small maps of the protective cover and the infiltration conditions are also printed as insets on the vulnerability map so that it can be determined whether the vulnerability of a particular area is due to a thin protective cover or to surface and subsurface concentration of flow. The areas on each of the three maps are assigned to one of five classes, symbolized by five colours: from red for high risk to blue for low risk. Consequently, one legend can be used for all three maps (Table 5.2).

As the information on the vulnerability map is always for the uppermost aquifer, a thick line indicates graphically the presence of aquifer above the main aquifer under consideration.

Table 5.2 Legend for the Vulnerability Map, the P and the I map (Werz, H., and Hotzl, H.).

	vulnerability map vulnerability of groundwater		**P-map** protective function of overlying layers		**I-map** degree of bypassing	
	description	π-factor	description	P-factor	description	I-factor
red	extreme	0-1	very low	1	very high	0.0-0.2
orange	high	>1-2	low	2	high	0.4
yellow	moderate	>2-3	moderate	3	moderate	0.6
green	low	>3-4	high	4	low	0.8
blue	very low	>4-5	very high	5	very low	1.0

5.5 Thematic Maps

5.5.1 Thematic Maps Used for Calculating the P-Factor

The protective cover map depends on the following factors:

1. Topsoil (T).

2. Recharge (R)

3. Subsoil (S)

4. Lithology (L)

5. Fracturing (F).

5.5.1.1 Topsoil (T)

In the Qalqilia Governorate portion located of Western Basin, there are two types of topsoil: Terra Rossas, brown rendzinas and pale rendzinas located in the east portion from the research area, and Brown rendzinas and pale rendzinas in the remaining area (Figure 5.8).

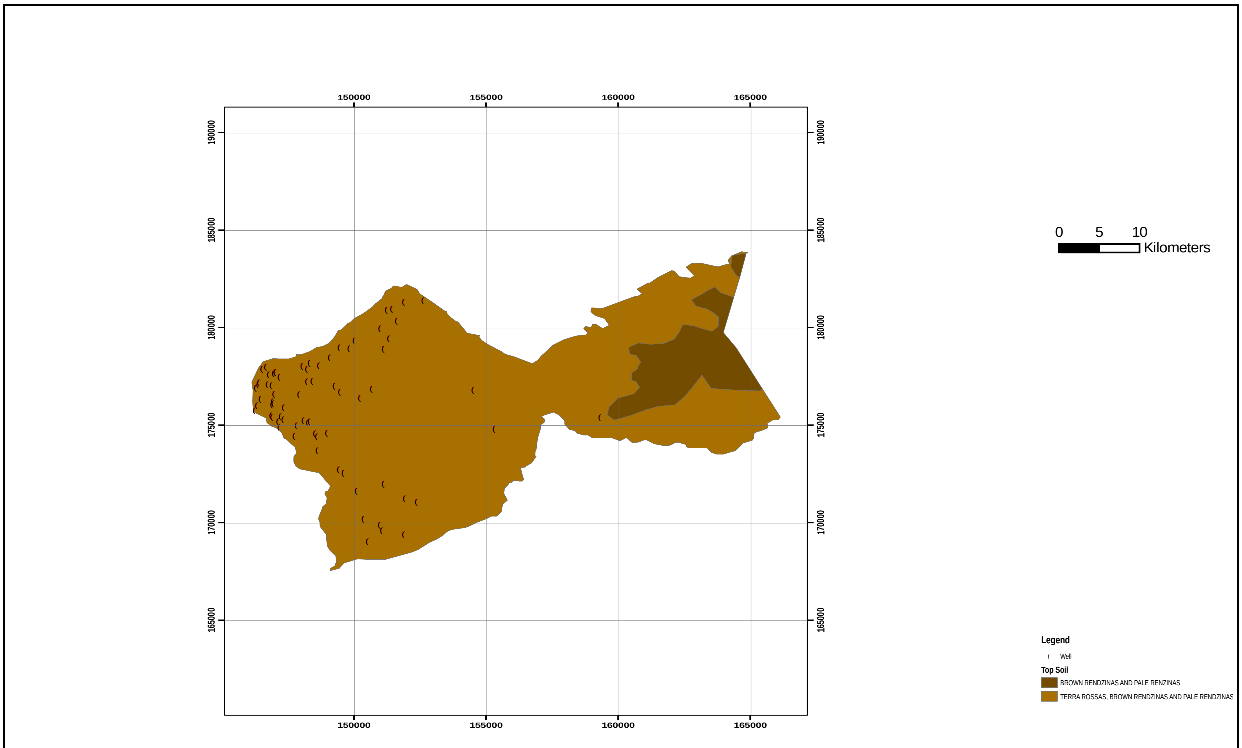

Figure 5.8 Top Soil in Qalqilia Governorate Located on the Western Basin (SUSMAQ, 2005)

The T factor which is suitable for each type of top soil found in the literature is illustrated in Table 5.3.

Table 5.3 Qalqilia Topsoil Factors	
eFC (mm) up to 1 m depth	**T**
Terra Rossas, brown rendzinas and pale rendzinas	750
Brown rendzinas and pale rendzinas	750

5.5.1.2 Recharge (R)

The available data related to recharge is rainfall, Figure 5.9 shows that rainfall in the research area ranges from 500 to 550 mm/year in the western part of Qalqilia Governorate while the eastern area of Qalqilia Governorate has a 550 to 600 mm/year range of rainfall.

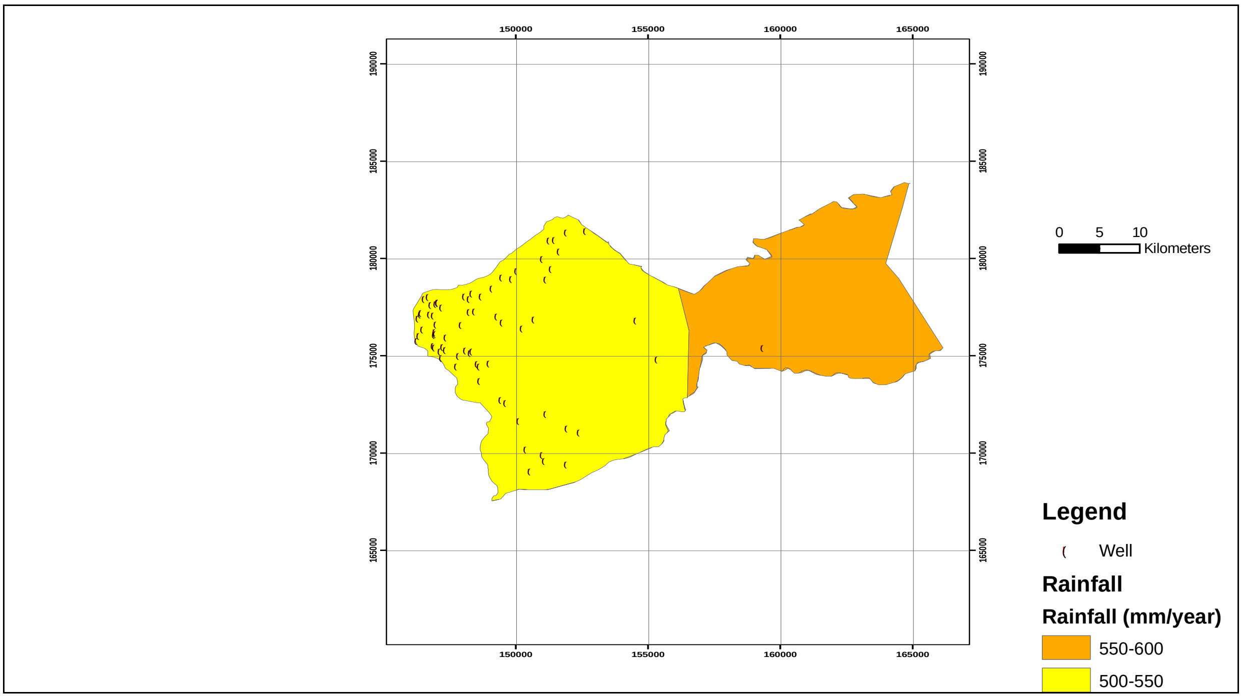

Figure 5.9 Rainfall in Qalqilia Governorate Located on the Western Basin (SUSMAQ, 2005)

Recharge values were obtained from rainfall by applying the following relationship between rainfall and recharge:

R = 0.46 [P-159] (Wiley, J., and Sons, L., 2006).

Where:

- P = Precipitation (mm).

- R = Recharge (mm).

Results of the calculation process are shown in Figure 5.10and Table 5.4.

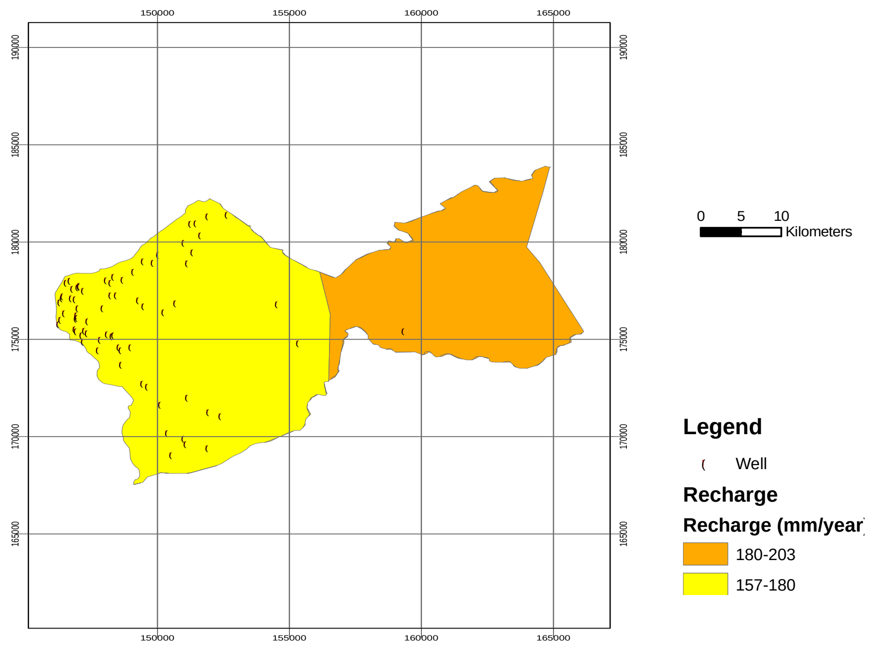

Figure 5.10 Recharge in Qalqilia Governorate Located on the Western Basin (SUSMAQ, 2005)

Table 5.4 Qalqilia Recharge Factor

Rainfall (mm/yr)	Recharge (mm/yr)	R
500 - 550	157 – 180	1.5
550 – 600	180 – 203	1.5

5.5.1.3 Subsoil (S)

The S factor depends on the soil type, as mentioned before; there are two types of topsoil in Qalqilia: Terra Rossas, brown rendzinas and pale rendzinas in the east, and Brown rendzinas and pale rendzinas in the remaining area. Table 5.5 illustrates the suitable subsoil factors (S) according to the Type of Subsoil (Grain Size Distribution).

Table 5.5 Qalqilia Subsoil Factor

Type of Subsoil (Grain Size Distribution)	S
Terra Rossas, brown rendzinas and pale rendzinas	500
Brown rendzinas and pale rendzinas	300

5.5.1.4 Lithology (L)

Four types of lithology can be found in Qalqilia district (Figure 5.11);

1. Turonian
2. Upper cenomanian
3. Senonian,
4. Quaternary.

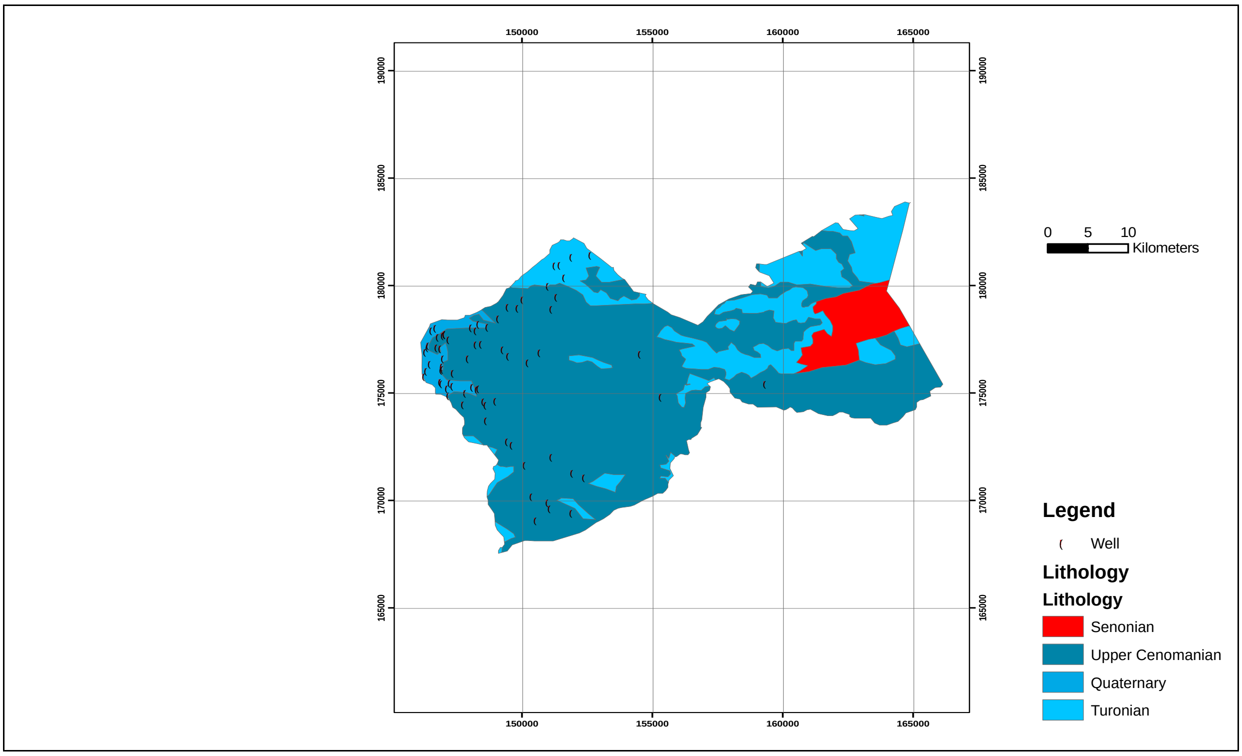

Figure 5.11 Lithology in Qalqilia Governorate Located on the Western Basin (SUSMAQ, 2005)

Table 5.6 illustrates the lithology factors (L) according to the Type of lithology.

Table 5.6 Qalqilia Lithology Factors

Lithology	L
Turonian	5
Upper cenomanian	5
Senonian	20
Quaternary	5

5.5.1.5 Fracturing (F)

Table 5.7 shows the fracturing factors (F) corresponding to the different lithology: Turonian, Upper cenomanian, Senonian, Quaternary.

Table 5.7 Qalqilia Fracturing Factors

Fracturing	F
Turonian	0.3
Upper cenomanian	0.3
Senonian	4.0
Quaternary	0.3

By applying the P_{TS} function the protective cover map shown in Figure 5.12 can be obtained.

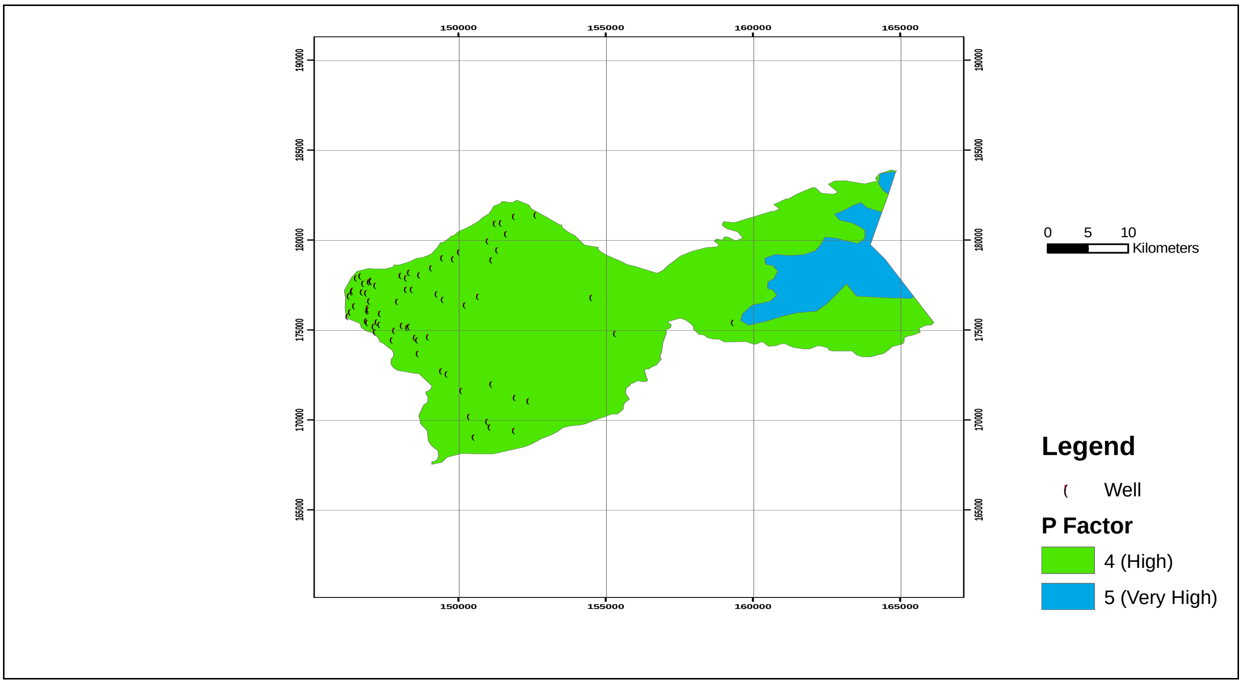

Figure 5.12 Qalqilia Protective Cover Map (SUSMAQ, 2005)

5.5.2 Thematic Maps Used for Calculating the I-Factor

The spatial distribution of the I factor is shown on the I map. The I factor (I map) is obtained using the following two components:

1. The I' factor: The controlling factors are soil properties, slope and vegetation.

2. The surface catchment's map.

5.5.2.1 Determination of the I' Factor

In Qalqilia district, there are two types of soil with the following saturated hydraulic conductivity values as shown in Table 5.8.

Table 5.8 Qalqilia Hydraulic Conductivity

Type of Soil	Saturated Hydraulic Conductivity (m/s)
Terra Rossas, brown rendzinas and pale rendzinas	$2.78 * 10^{-7}$
Brown rendzinas and pale rendzinas	$1.67 * 10^{-6}$

Table 5.9 Qalqilia Dominant Flow Process

Type of Soil	Saturated Hydraulic Conductivity (m/s)	Dominant Flow Process
Terra Rossas, brown rendzinas and pale rendzinas	$2.78 * 10^{-7}$	Type F
Brown rendzinas and pale rendzinas	$1.67 * 10^{-6}$	Type E

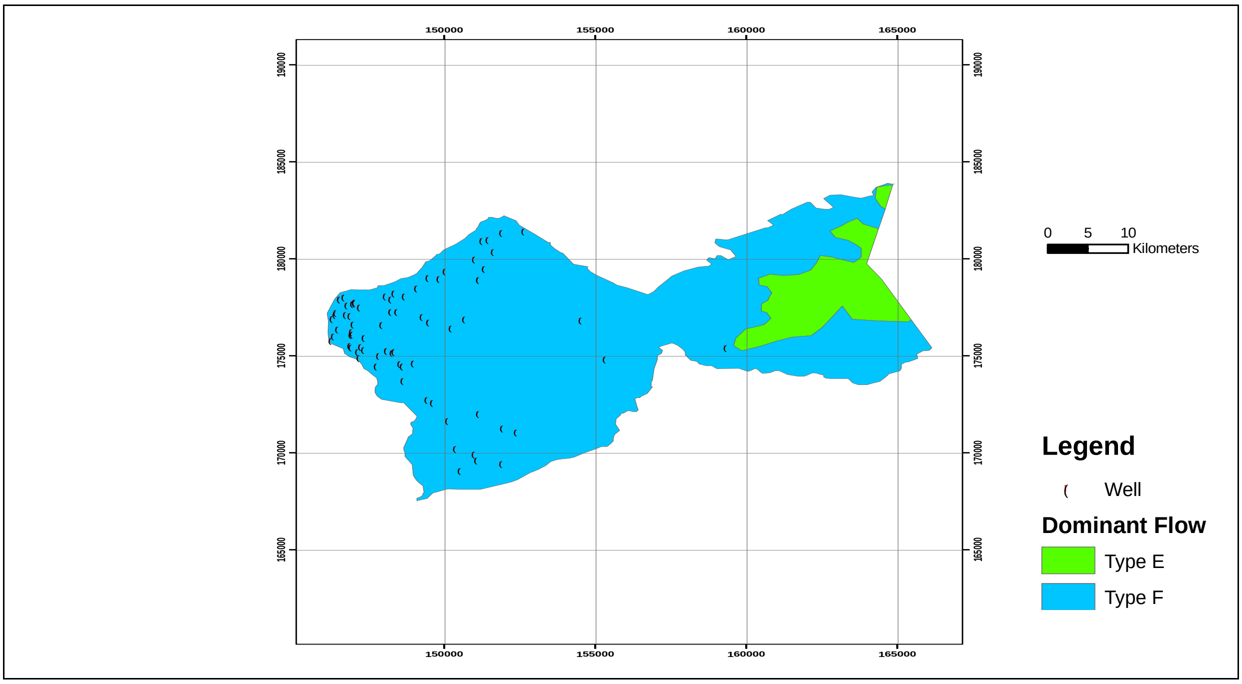

Figure 5.13 Qalqilia Dominant Flow Process (SUSMAQ, 2005)

Unfortunately, there are no quantitative data for the slopes in the research area have been found. Slopes have been estimated from the topography. In this study, it is assumed that the region with ≤ 200 m level has a < 3.5% slope, and region with > 200 m level has a 3.5-27% slope (Table 5.10, and Figure 5.14).

Table 5.10 Qalqilia Slope

Slope	
Level (m)	**Slope (%)**
≤ 200	< 3.5%
> 200	3.5-27%

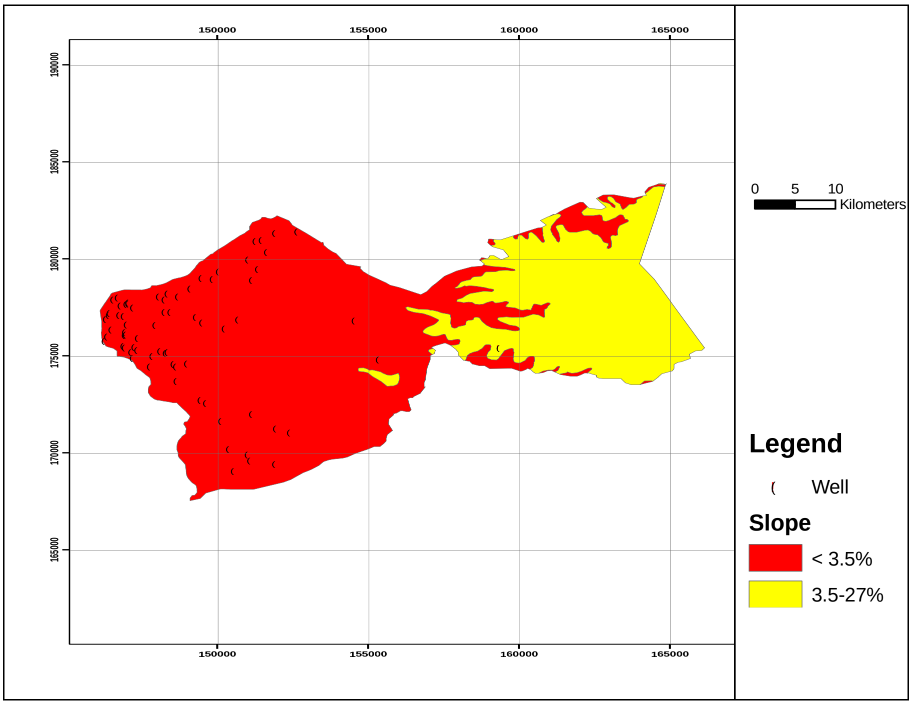

Figure 5.14 Qalqilia Slope Map(SUSMAQ, 2005)

According to step 2 in Figure 5.7, the I' factor will then be found as shown in Figure 5.15.

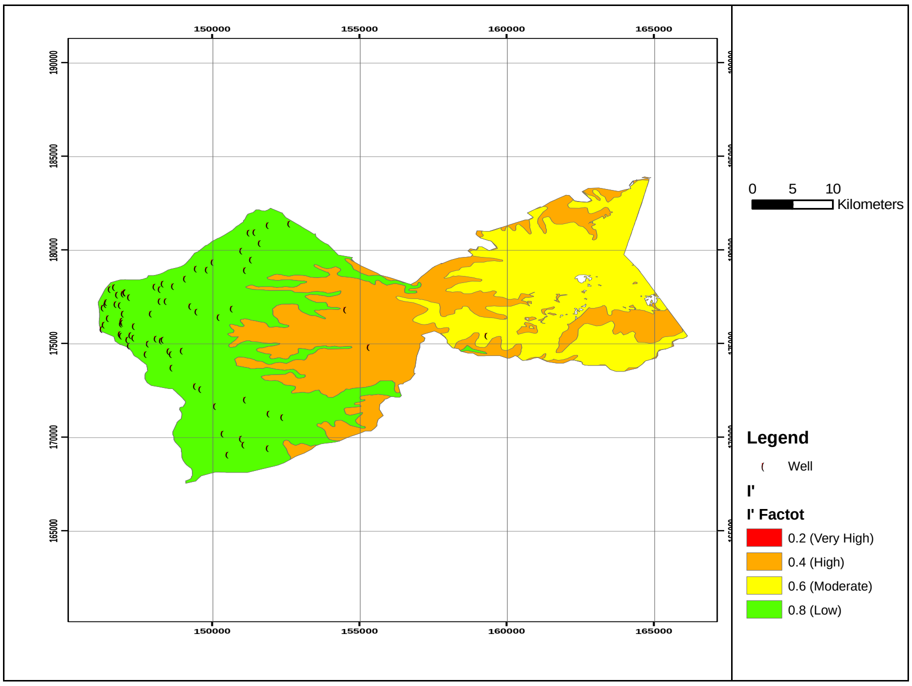

Figure 5.15 Qalqilia I' Map (SUSMAQ, 2005)

To get the surface catchment's map: a map of sinking streams in the research area should be obtained, then a 10 m, and a 100 m buffer zone on both sides of these streams should be drawn using GIS applications (Figure 5.16).

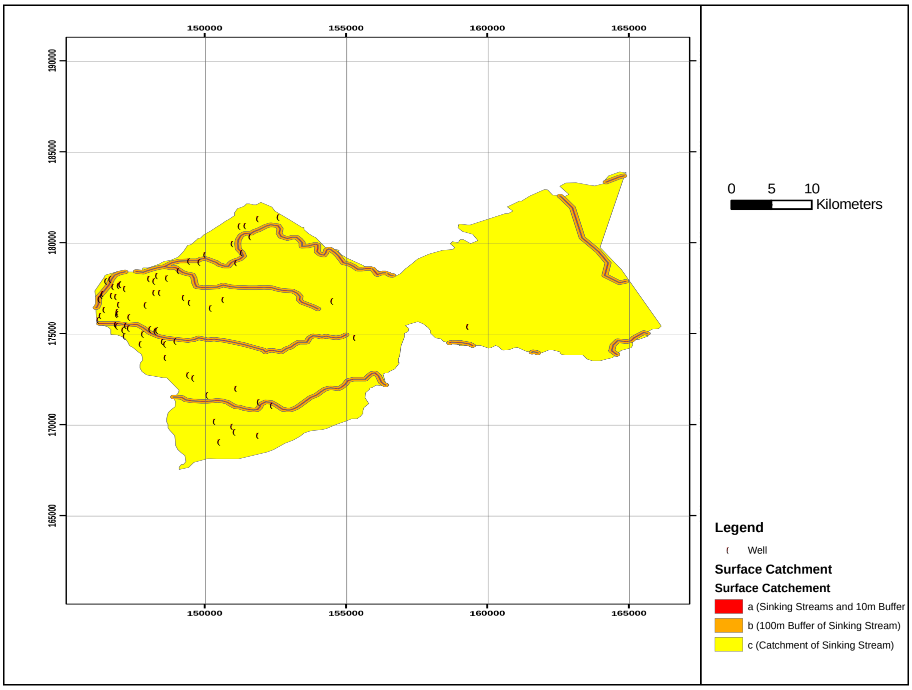

Figure 5.16 Qalqilia Surface Catchment's Map (SUSMAQ, 2005)

According to step 3 in Figure 5.7, the I factor can be calculated as shown in Figure 5.17.

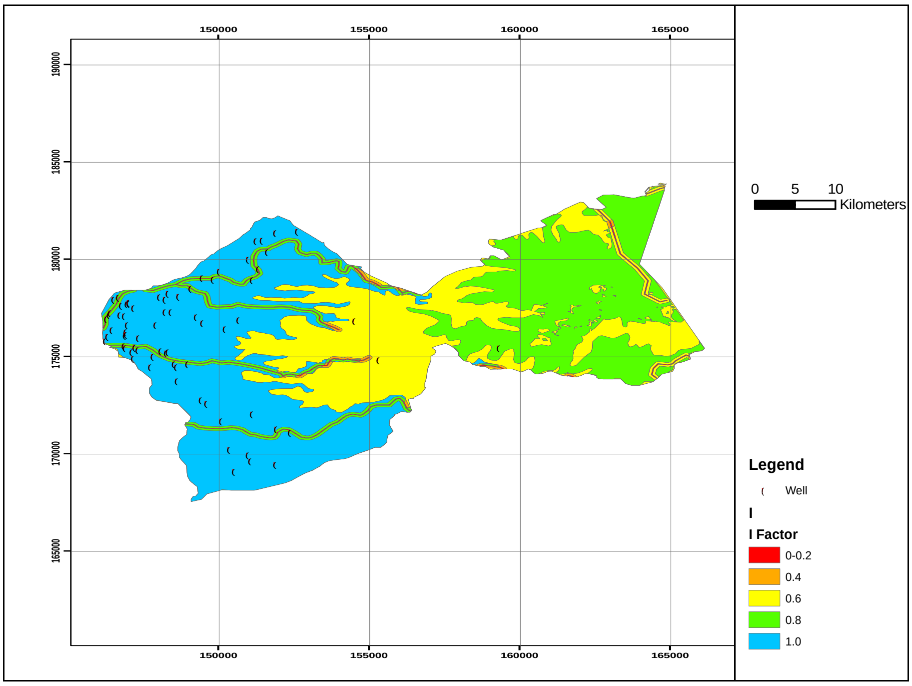

Figure 5.17 Qalqilia I Map (SUSMAQ, 2005)

5.6 Vulnerability Map

From the P and I maps the overall vulnerability map for the research area can then be elaborated using GIS applications (Figure 5.18).

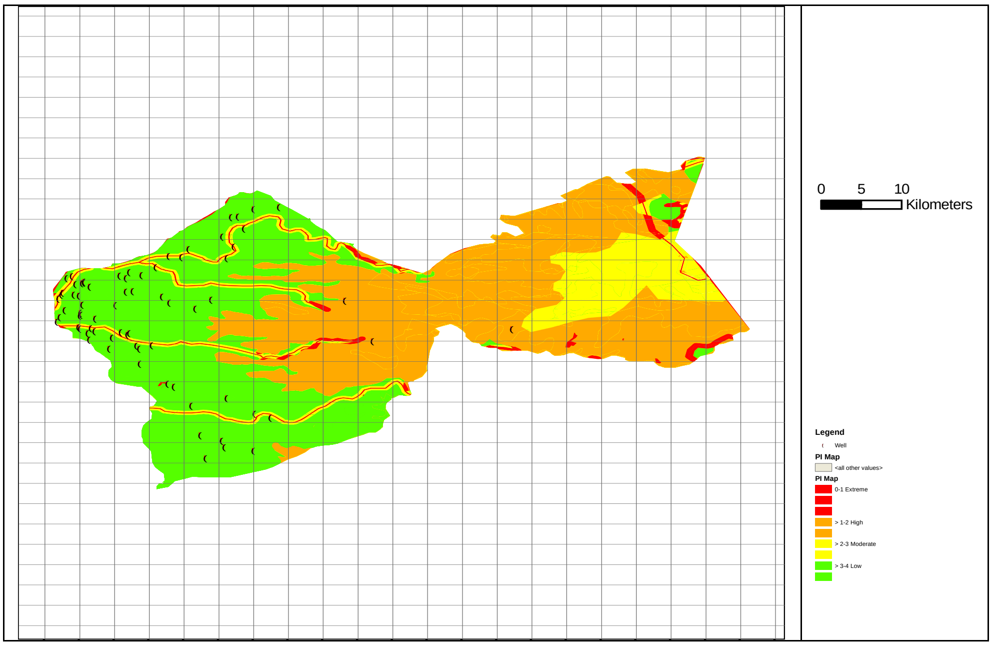

Figure 5.18 Qalqilia PI Map-Vulnerability Map (SUSMAQ, 2005)

As it is shown in Figure 5.18, "extreme" vulnerability assess around sinking streams in Qalqilia governorate, "high" vulnerability is located in the middle and in the majority of eastern part of the governorate, "moderate" vulnerability is assigned in the areas of brown rendzians and pale renzians top soil, and the low vulnerability is assigned in the western part.

CHAPTER SIX

POTENTIAL GROUNDWATER POLLUTION SOURCES

6.1 Introduction

Current access to fresh water only barely meets the domestic, industrial and agricultural demand. If industry is to be developed, or agricultural output is to be maintained, recycled water will have to be used. But currently, only 20% of the West Bank is part of a sewer system: all rural and suburban areas rely on onsite cesspits (CDM, 2004). Cesspits themselves constitute a threat to freshwater: if they overflow, as frequently happens, they contaminate the soil and groundwater with raw sewage. If they are pumped out, the sewage is usually dumped into the nearest body of water. So not only freshwater is declining due to population growth, it is also under threat from pollution.

Sources of Potential groundwater pollution in the West Bank are numerous and can be divided into the following four categories:

- Wastewater
- Solid waste
- Industrial and hazardous waste, and
- Agricultural waste

This chapter provides a brief description of potential pollution sources and places on the groundwater vulnerability map.

5.2 Wastewater Sources

Wastewater is considered one of the largest sources for groundwater pollution in the West Bank. Wastewater collection and treatment facilities are restricted to few cities/ towns. Existing sewer systems are generally in poor physical state and leakage rates from sewage networks are as high as 50%. It is estimated that only 20-30% of the Palestinian population benefits from sewer collection systems (PWA, 2002). Locations of wastewater disposal wadies are shown in Figure 6.1

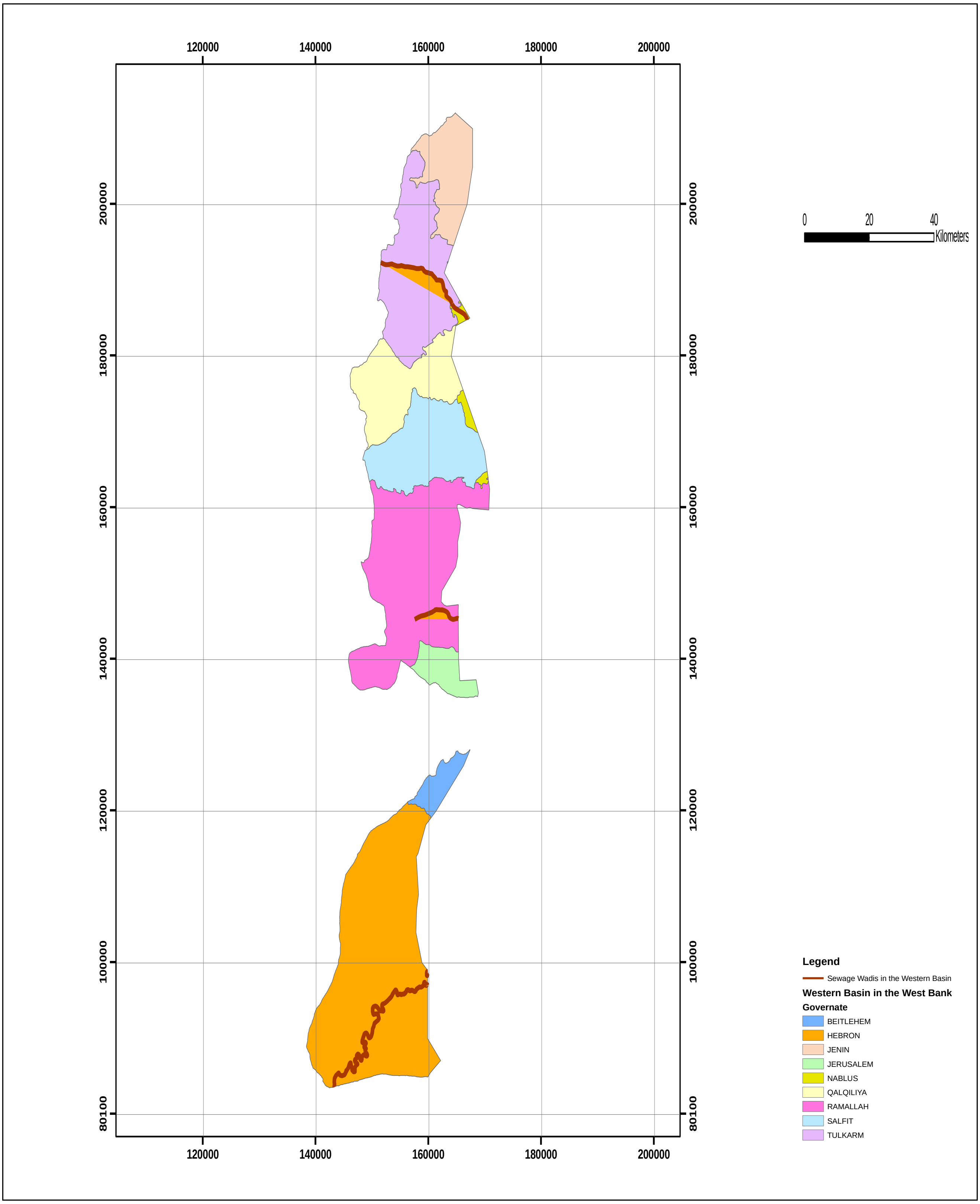

Figure 6.1 Locations of Wastewater Disposal Wadies (SUSMAQ, 2005)

6.2.1 Industrial Wastewater

Industrial pollution is considered one of the major issues in environmental protection. Industries contribute to the pollution of the environment, especially in the absence of enforcement regulations on manufacturers to reduce their hazardous impact. Industrial Wastewater is generated by both Palestinian and Israeli settlement industries mainly in the industrial zones. Israeli settlements in the West Bank host several polluting industries which produce hazardous waste. These industries include aluminum, batteries, leather tanning, textile dyeing, fiberglass and other chemical industries. Waste generated from these industries affects various areas in the West Bank. According to surveys conducted by the Palestinian Central Bureau of Statistics, sewers receive only about 50% of Palestinian industrial discharges.

Israel has moved many of its polluting industries from places inside Israel to areas near the 1967 border or inside colonies. The wastewater from these factories has damaged the citrus trees and polluted the soil in the area located in, in addition to the pollution that it may cause to the groundwater (ARIJ, 1998).

The generated industrial wastes contain toxic elements such as aluminum, chromium, lead, zinc and nickel. For example aluminum industry produces aluminum and acidic wastes. Electroplating produces nickel, chrome and acidic wastes (ARIJ, 1998).

6.2.2 Effluent from Olive Mills

There are presently about 250 olive oil mills in production in the West Bank (PCBS, 2003). 54 olivemills are located in the research area (SUSMAQ, 2005). During the short winter processing period, olive mill waste (zebar) is mainly discharged to cesspits. Yields and zebar production can vary significantly from one year to another, and the largest mills may produce upward of 1,000 m^3 per day (PCBS, 2003). Locations of olivemills in the study area are shown in Figure 6.2.

This wastewater is extremely high in BOD, COD, TSS, fats and phenols.

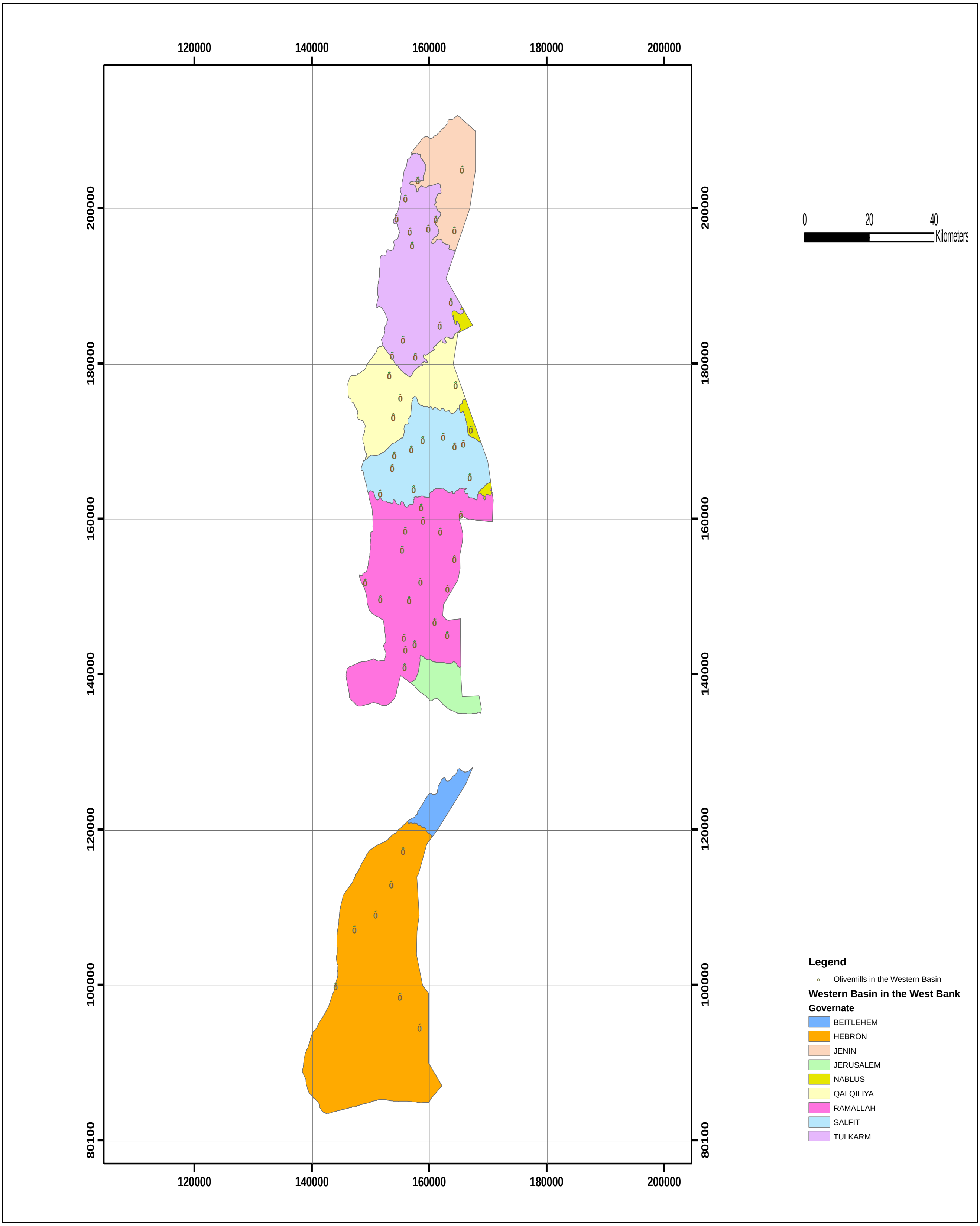

Figure 6.2 Locations of Olivemills (SUSMAQ, 2005)

6.3 Solid Waste

Solid wastes are generated from houses, farms, factories, and hospitals. Related studies indicate that 27% of the West Bank inhabitants do not have proper areas for disposing of the solid waste or programs for solving this problem on the medium or long term. Moreover, privatization in the issue of containing the solid waste is found only in three governorates: Jerusalem, Jenin, and Tulkarem.

Table 6.1 Solid Waste Production in the West Bank (PCBS, 2006)

Item	Average Amount of Solid Waste Production (Kg/ Day)
Palestinian Household	4.6
Rural Palestinian	0.4-0.6
Refugee Camps Palestinian	0.5-0.8
Israelis living in Settlements in the West Bank	2.21
Town/ Village Dwellers	0.6-0.8
City Dwellers	0.9-1.2

Dumping sites are considered to be sources of insects for 272 localities in the Palestinian area and sources of bad odor for 258 localities (Figure 6.3). Dumping sites are believed to be more of a local source of groundwater pollution, but there are presently no suitable or adequate monitoring systems to measure liquid wastes (e. g., leachates) from such facilities (PCBS, 2006). It is estimated that the total number of disposal sites ha drastically increases, and that the total number of dump sites may exceed 400 (EQA, 2002).

Israeli contractors smuggled thousands of tons of solid waste into Palestinian lands and buried them in the Shoffa village of Tulkarem. This practice has been extended to include Kuffer Jammal and Flameya villages. Waste from Israeli settlements and the Green Line areas contain hazardous chemical, herbicides, leather, aluminum batteries, cement, plastic, food, wool, health, alcohol, marble, nickel and acids substances, which are harmful to both environment and public health.

Some of the laws relevant to solid waste in the West Bank can be traced back to Ottoman or British eras and these are complemented by some recently issued orders from Palestinian Governors and heads of municipal health departments. It will take some time until a unified Palestinian Law is in place. The future Environmental Law is now in its second draft and under discussion in the Palestinian Legislative Council. The Environmental Planning Directorate has also undertaken some preparatory studies and initiated debate in this field, with regard to a general environmental framework law and special regulations concerning solid wastes. Several municipalities report that attempts has been made to obtain necessary permits to construct sanitary landfills, but these have been denied on the ground that locations mostly fall within Area C (EQA, 2002).

While there are no engineered sanitary landfills in operation in the West Bank, the World Bank and KfW have financed initiatives in Jenin and Ramallah/ Al-Bireh, while similar initiative for Hebron is on hold (EQA, 2002).

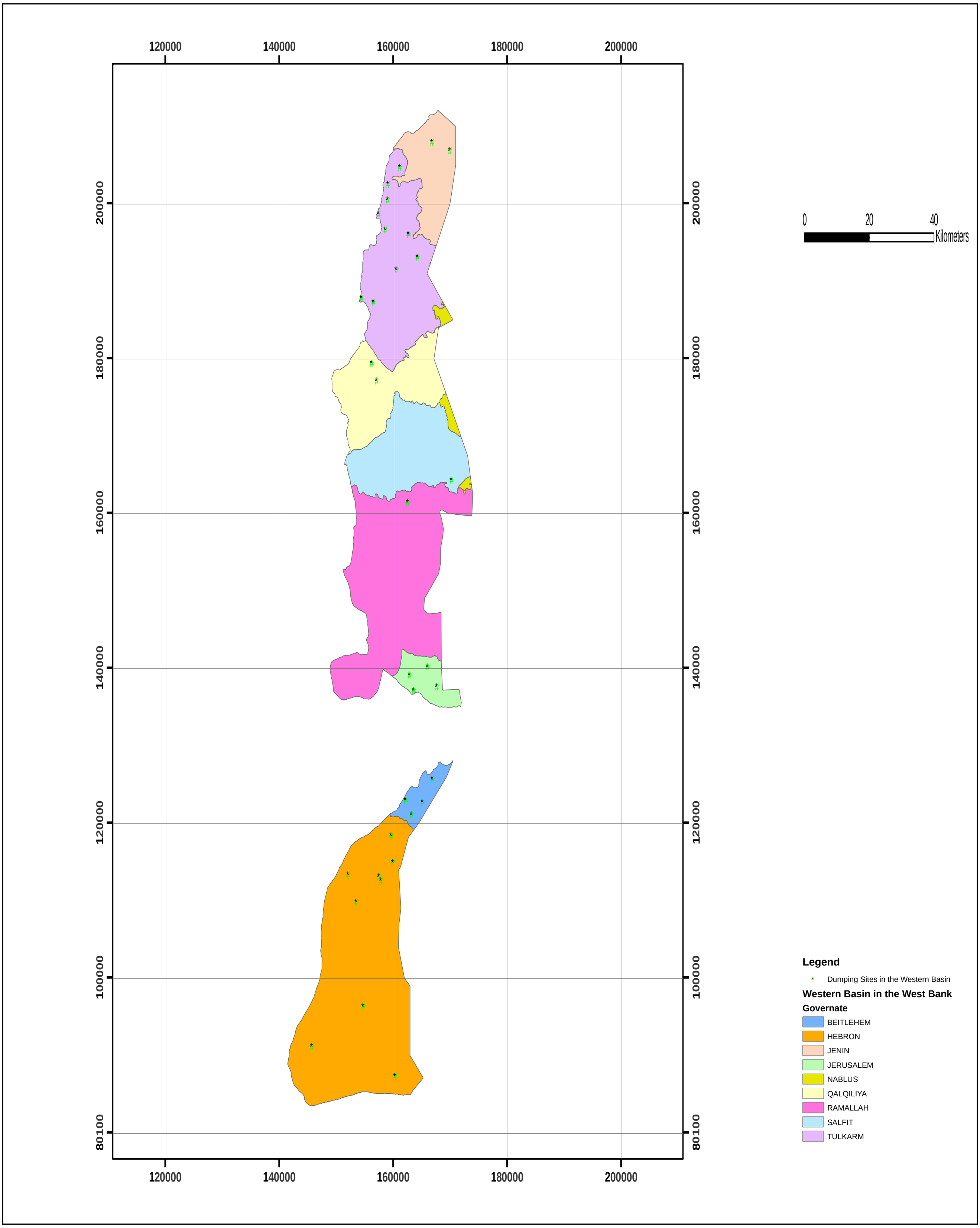

Figure 6.3 Locations of Dumping Sites (SUSMAQ, 2005)

6.4 Industrial and Hazardous Waste

There are at least seven industrial zones in the West Bank colonies. These industrial zones occupy an area of approximately 302 hectares.

A'tarot, Mishor Adumim, and Barqan industrial zones are the largest in the West Bank. They are mainly located on the tops of hills, which often results in the flow of industrial wastewater into adjacent downstream Palestinian lands. Recently, Israel has given permits to four new Israeli industrial zones to be established in the West Bank. These industrial zones are to be located in Area C near Ramallah, Nablus, Hebron and the Jordan Valley. Table 6.2 lists the Israeli industrial zones in the West Bank and the area each one of them occupies.

Clear evidence that Israeli factories operating in the Occupied Territories do not follow pollution prevention measures is provided by the Barqan industrial zone, which hosts factories producing aluminum, fiberglass, plastic, electroplating, and military items. Industrial wastewater from this zone flows untreated to the nearby valley, damaging agricultural land belonging to the Palestinian villages of Sarta, Kufr Al-Deek, and Burqin, while polluting the groundwater with heavy metals.

Table 6.2 Industrial Zones in Settlements in the West Bank (ARIJ, 1998)

Industrial Zone	District	Area (hectare)
Hinnanit	Jenin	10.99
Barqan	Nablus	14.87
Ariel	Nablus	14.84
Ma'ale Efrayim	Nablus	2.58
Atarot	Jerusalem	145.78
Mishor Adummim	Jerusalem	109.92
Qiryat Arba'	Hebron	3.35
Total		302.00

It is estimated that at least 200 Israeli industrial factories are located within the West Bank. These factories are either located in the Israeli industrial zones or inside Israeli settlements. Information about Israeli industrial activities in the West Bank is scarce. Some of their products are identified, but detailed information on quantities produced, labors and waste generated is unavailable. The major industries within these industrial zones include: aluminum, leather tanning, textile dyeing, batteries, fiberglass, plastics, and other chemical industries. Table 6.3 lists the Israeli industries in the West Bank.

Table 6.3 Israeli Industries in the West Bank (ARIJ, 1998)

District	Industrial Location	Industry
Nablus	Barqan	Aluminum, fiberglass plastic, electroplating
	Allon Morieh	Aluminum, food canning and textile dyeing
	Shilo	Aluminum and leather tanning
Ramallah	Halmeesh	Fiberglass and leather tanning
	Givout hadasha	Rubber
	Nili	Aluminum
	Shelta	Fiberglass and plastic
	Atarot	Aluminum, cement, plastic, food canning and others
Hebron	Qiryat Arba'	Winery, building blocks, tiles and plastic
Jerusalem	Mishor Adummim	Plastic, cement, leather tanning, detergents, textile dyeing, aluminum, electroplating and several others
Jenin	Homesh	Batteries, aluminum, detergents
Tulkarm	Near 1967 border, inside the West Bank	Pesticide, fiberglass and Dixon gas

Palestinian lands located at the foothills of industrial zones are highly vulnerable to the flow of industrial waste. Evidence shows that measures of pollution prevention are not followed inside the Israeli industrial facilities. Also, the generated industrial solid waste is often collected and dumped at areas near Palestinian villages. Table 6.4 shows some Palestinian villages affected by industries in some of the Israeli industrial zones.

Table 6.4 Palestinian Locations Affected by Israeli Industry in the West Bank (ARIJ, 1998)

Israeli industrial location	Affected Palestinian location
Halmeesh	Al-Nabi Saleh village
Mishor Adummim	Jerusalem Desert
Homesh	Silat Al-Thahir
Barqan	Kafr Al-Deik, Sarta, and Bruqin villages
Shilo	Qaryout and Turmus 'Ayya
Allon Moreh	Nablus- Wadi Badan road
Atarot	Bir Nabala and Judeira
Qiryat Arba’	Bani Na’im
Israeli Industrial zone on 1967 border near Tulkarm	Tulkarm city, nearby agricultural areas

6.5 Agriculture

It is estimated that the total quantity of pesticides used in the West Bank may exceed 700 tons per year. Organic and inorganic fertilizers are commonly used in Palestine. Tulkarm, Jericho, and Jenin represent the major agricultural areas in the West Bank, and are also the largest generators of agricultural waste products. A total of 123 pesticides are currently used in Palestine, including 15 that are internationally suspended or banned such as Aldicarb, Chlordane, DDT, Lindane, Paraquate, Parathion and Pentachlorophenol. Most pesticides arrive in the Palestinian lands with Hebrew labels, which most farmers cannot read. The total use is estimated to be 730 tons in the West Bank (ARIJ, 1998).

Many of wells and springs in the research area have nitrate concentrations greater than 50 mg/ L. The World Health Organization (WHO) drinking water standard for nitrate of 50 mg/ L is used as a marker for comparative purposes. Important sources of water with current concentrations above the WHO standard are located in Jenin, Tubas/ Wadi Fari'a, Hebron, Tulkarm, and Qalqilia.

Exceedances of the nitrate standard appear to be concentrated near Palestinian towns, but this observation is somewhat skewed by the fact that most supply wells are located close to urban areas (CDM, 2004). Use of pesticides and fertilizers in irrigated areas is of particular concern, as return flows may carry associated pollutants to underlying aquifers.

6.6 Quarries and Urban Storm Water

Quarrying and stone-cutting are the largest industries in the West Bank and an estimated 100,000 tons/ year of slurry is disposed of in wadis and dumping sites (CDM, 2004). The rocks nearby the Dead Sea are considered one of the natural resources in Palestine that is used in the field of construction and for other purposes in both Palestine and Israel. Beit Fajjar's main source of livelihood is its stone-cutting factories, because of its proximity to the major quarries in the West Bank and its easy access to Israel through Gush Etzion checkpoint on Route 60. Unlike the neighbouring villages of Sair and Shuyukh, agriculture in Beit Fajjar is limited to local consumption.

Israel developed 6 quarries and originated many others, most of which are adjacent to the residential areas and agrarian lands. These quarries cause harmful effects to the environment because they are places allocated for the disposal of solid and liquid wastes. These quarries give the emission of heavy dusts that are detrimental to the public health. Table 6.5 demonstrates the Israeli quarries in the West Bank nearby the populated Palestinian Territories. Figure 6.4 shows the Locations of Quarries in the study area.

Table 6.5 Israeli Quarries in the West Bank (ARIJ, 1998)

No.	Quarries	Governorate	Notes
1.	Quarry in Al-Zahiryya	Hebron	All these quarries exist near the populated areas. Consequently, causing the following harms: 1. Noisy explosions. 2. Heavy emission of dust. 3. Serious disturbance due to the continuous process of transportation.
2.	Quarry in Dura	Hebron	
3.	Quarry nearby Al-Dihaisha	Bethlehem	
4.	Quarry in Ya'bid	Jenin	
5.	Quarry nearby Giyos	Qalqilya	
6.	Tzufim Quarry near Qalqilya	Qalqilya	

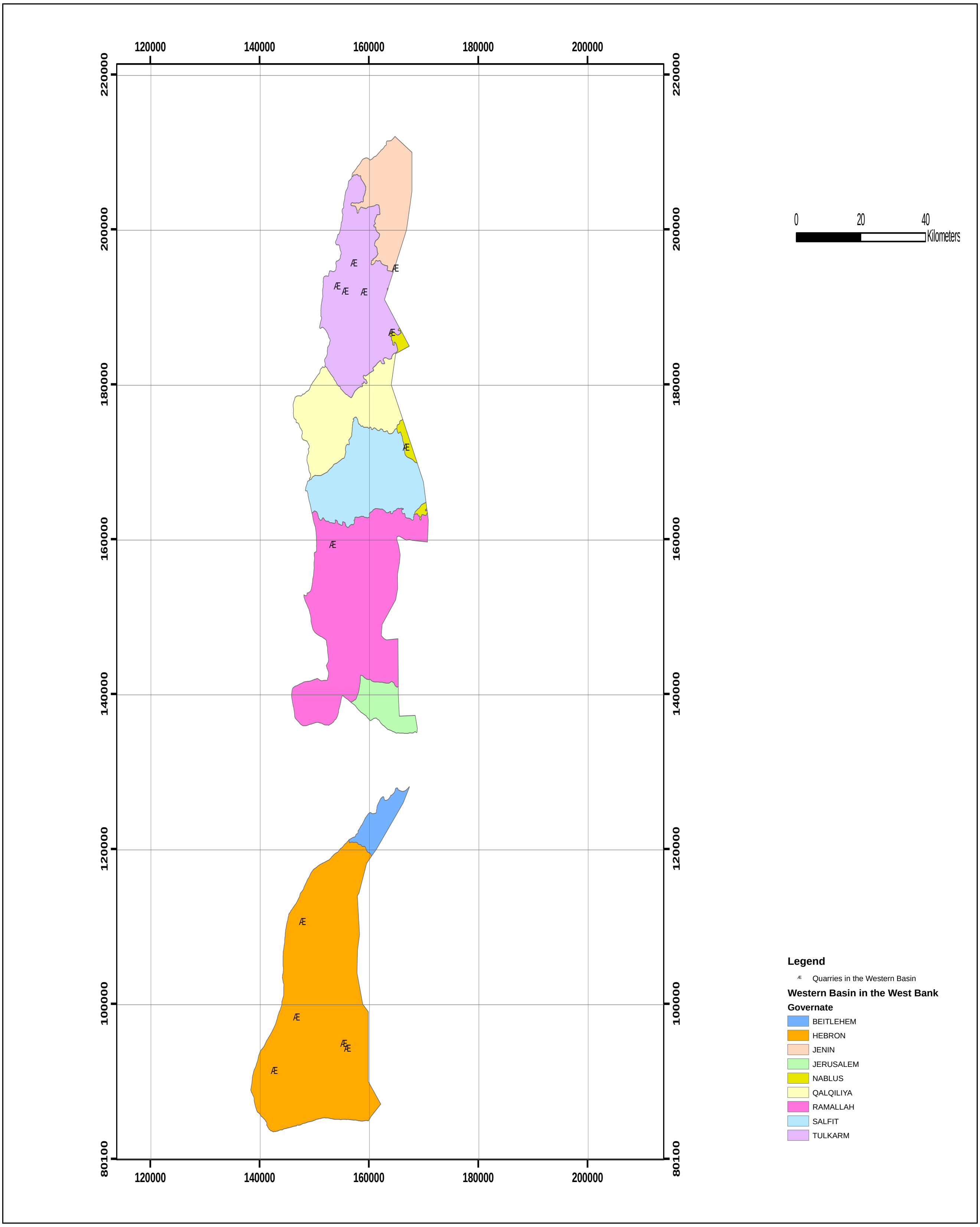

Figure 6.4 Locations of Quarries (SUSMAQ, 2005)

In terms of urban areas, car service areas, petrol stations, and other mechanical facilities are potential sources of pollution. Gas stations in the West Bank are responsible for selling the gasoline in addition to changing the motor oil (Figure 6.5). From an environmental point view, practices in these gas stations are threatening to the environment as they give little consideration to the safety of individuals or to the natural environment. Oil storage tanks and the used motor oil at these stations are threatening the air and the water resources in the area.

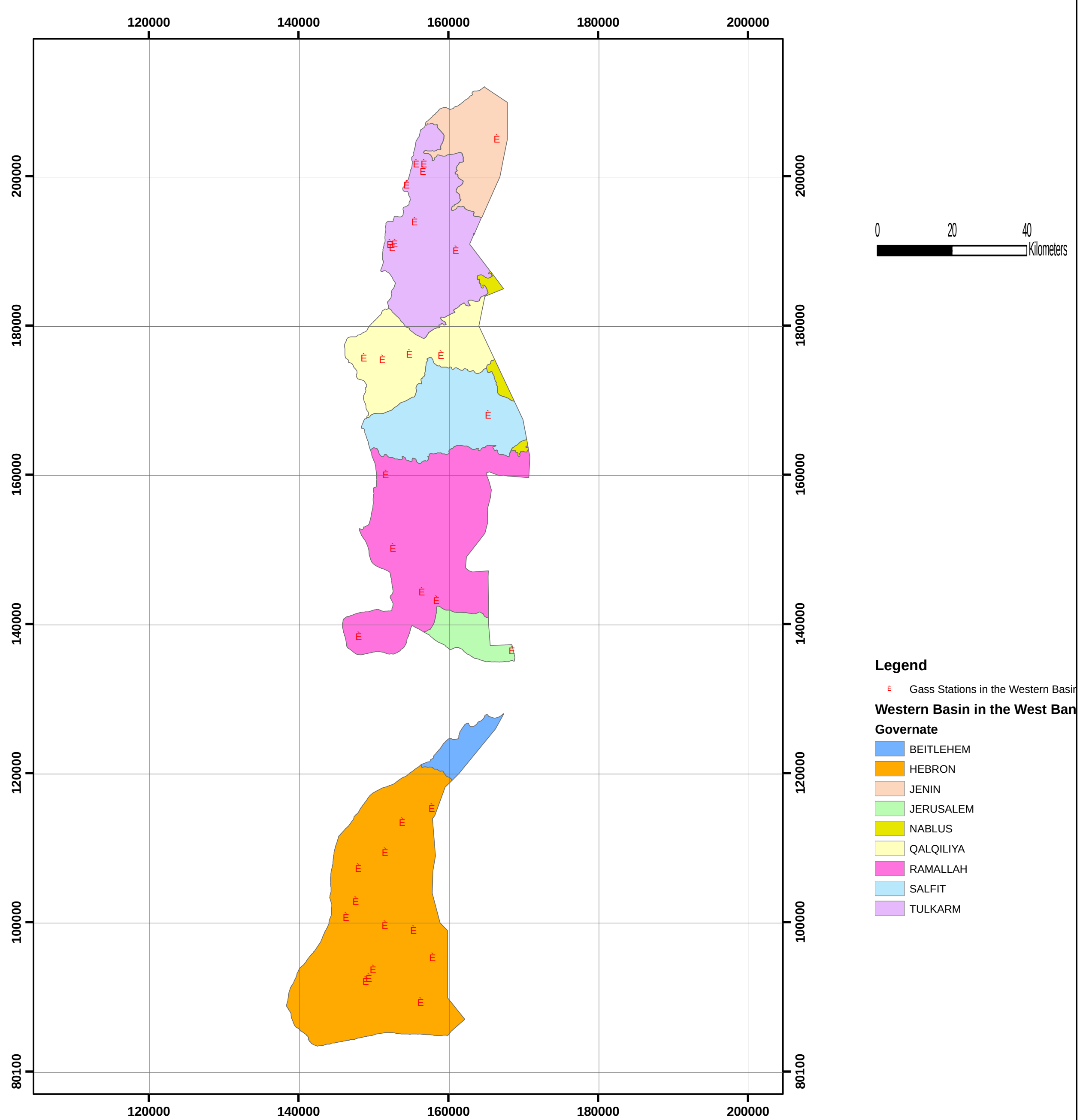

Figure 6.5 Locations of Gas Stations (SUSMAQ, 2005)

The disposal of waste products (e. g., motor oils) to sewers, cesspits and directly to the ground takes place in these stations (Figure 6.6). Also, underground storage tanks without containment structures pose potential problem.

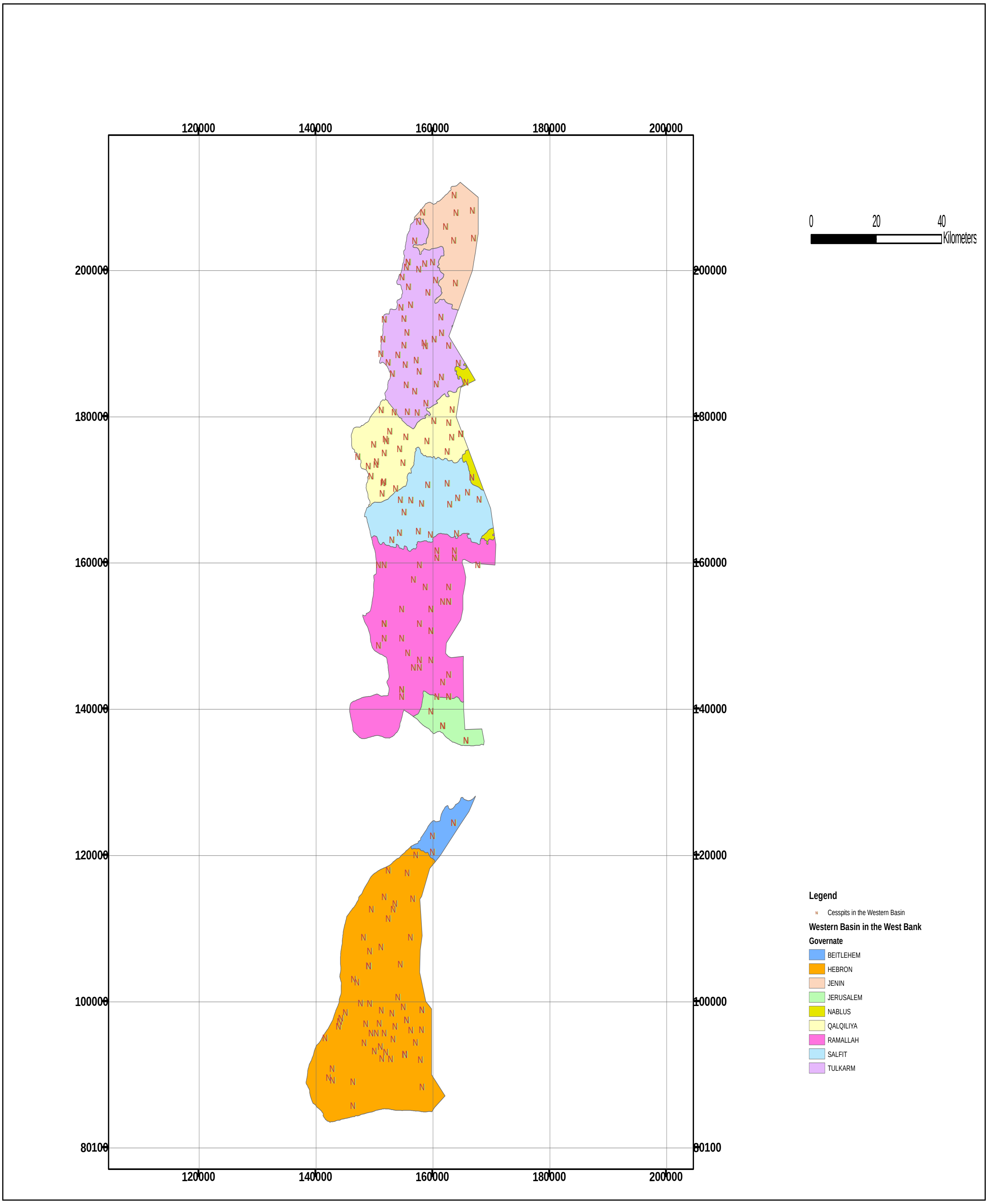

Figure 6.6 Geographical Locations in the Study Area that Contains Cesspits (SUSMAQ, 2005)

6.7 Pollution Sources Map

Using GIS applications, the water pollution sources are asseemboled in one map. Figure 6.7 shows the spatial distribution of water pollution sources.

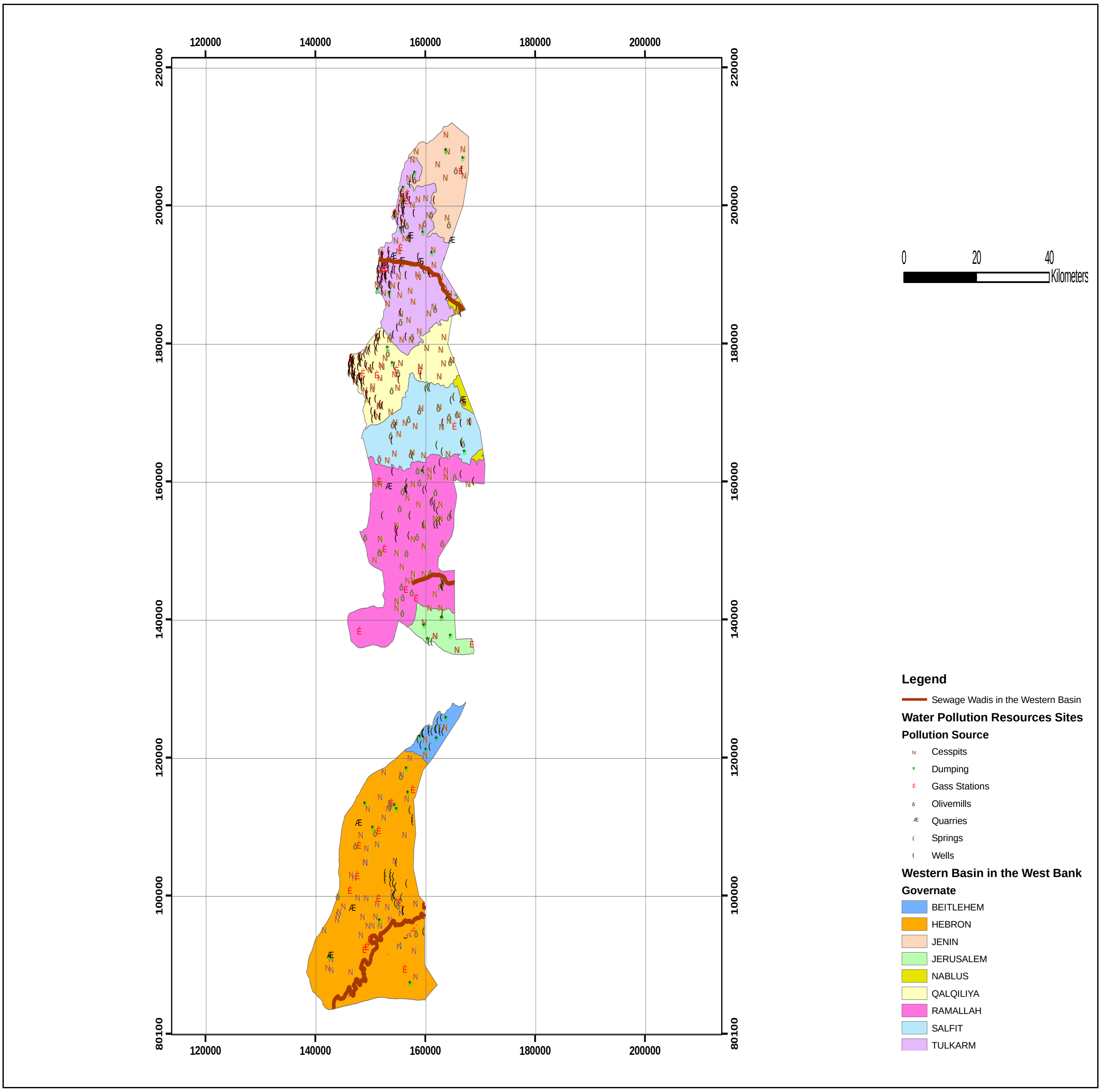

Figure 6.7 Water Pollution Sources Sites (SUSMAQ, 2005)

It is clear that large number of water pollution sources is found in the research area, there are 339 water pollution sources located in the research area, there are distributed as: 141 water pollution sources located in the extreme vulnerability zone, 219 water pollution sources located in the high vulnerability zone, 21 water pollution sources located in the Moderate vulnerability zone, and 58 water pollution sources located in the low vulnerability zone. Water quality concerns with regard to water pollution in the West Bank have been a major source of contention (CDM, 2004). Finding a solution to the pollution problem should be a fundamental component of the water section of a final peace agreement between the Palestinians and Israelis.

Using GIS applications, both Vulnerability Map and pollution sources are connected together in order to appear as a one map as in Figure 6.8.

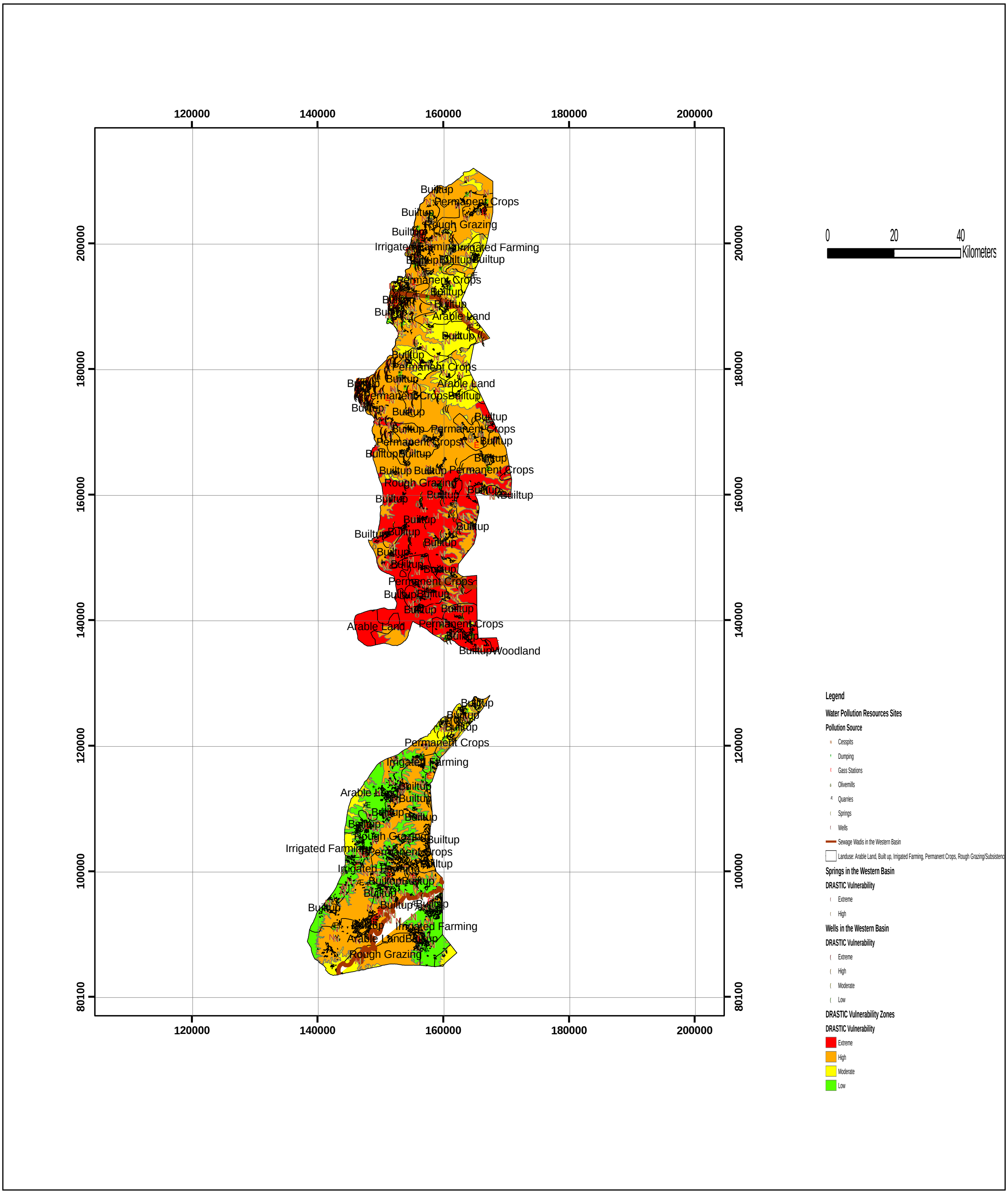

Figure 6.8 Water Pollution Sources, Wells, Springs Sites on Vulnerability Map

(SUSMAQ, 2005)

CHAPTER SEVEN

CONCLUSIONS AND RECOMMENDATIONS

7.1 Conclusions

A groundwater vulnerability map for the study area is presented in Figure 4.10. This map is based on the geology and hydrogeologic features of the different aquifer formations in the study area.

- "Extreme" vulnerability is assigned in Ramallah and Jerusalem since they have many springs which are located near the surface. These areas display highly developed karst features.
- "High" vulnerability is assigned given to rocks which make up the regionally important turonian/ upper cretaceous, and upper cretaceous (most of Jenin, west of Tulkarem and Qalqilia, Salfit, areas in Bethlehem and Hebron) while these rocks also display karstic features.
- "Moderate" vulnerability is assigned to upper cretaceous (east of Tulkarem, parts in Bethlehem). These deposits are not typically used for drinking water purposes but are important sources of water for agriculture.
- "Low" vulnerability is assigned to parts in Hebron district.

The karst hydrogeology of the studied area has far reaching impacts on the ability to monitor, respond to, and predict the fate and transport of pollution in the western basin part located in the West Bank. Karst is a term used to describe the presence of cavities and solution openings in limestone terranes (such as the studied area), whereby cavities and solution openings act as preferential flow paths for groundwater and contamination.

Groundwater flow in karst terranes is notoriously unpredictable. Therefore, devising ranking schemes for pollution sources and protective measures is difficult and subjective, and in some case misleading, since a pollution source that is several kilometers from a well or spring could be as important as pollution source that is close to the same well or spring.

In theory, vertical movement to deep water tables should be on the order of years given the large depth to water across much of the studied area. However, because of the presence of karst features, fractures and fissures this facilitates rapid infiltration to groundwater.

By applying PI method on Qalqilia Governorate, it is concluded that "extreme" vulnerability assess around sinking streams, "high" vulnerability is located in the middle and most of east part from Qalqilia, "moderate" vulnerability covers the area which has brown rendzians and pale renzians top soil, and the western part of Qalqilia has "low" vulnerability.

If the results obtained from applying PI method compare with those obtained from applying DRASTIC method on the same area "Qalqila Governorate", High vulnerability is assigned given to rocks which make up the regionally important turonian/ upper cretaceous, and upper cretaceous (west of Qalqilia) while these rocks also display karstic features. Moderate vulnerability is assigned to upper cretaceous (some east parts of Qalqilia).

It is concluded that the results obtained from the first method is more accurate than the later. PI method takes into account the land use while this factor is not used in the DRASTIC method. Also, applying PI method is more suitable for karst features than DRASTIC method.

More protection of source waters in Qalqilia district should be implemented from a lot of water pollution sources which are observed in it. A major source for pollution in the Qalqilia area wells is sewage from outfalls associated with Palestinian communities and several large settlements in the area, and potentially the Barkan industrial zone. Industrial effluents and wastewater from Barkan flows along Wadi Qana and partly infiltrates to groundwater. In addition, settlements such as Ariel, Imanuel, Elqana, Share Tiqva, Alfeh Menashe, and Karnei Shamron discharge wastewater to wadies located immediately and hydraulically upgradient of the impacted Qalqilia wells, so that appropriate implementation of sewage treatment projects should be formulated.

Within the town of Qalqilia, water supply wells are likely impacted by both sewage return flows from the city boundaries as well as return flows in agricultural areas. Some groundwater samples in Qalqilia have reported concentrations of potassium which are higher than other parts of the West Bank (PWA, unpublished data). The potassium may originate from fertilizers.

7.2 Recommendations

It is recommended for who want to continue this work that:

- Study other aquifer basins (Easter Aquifer Basin, and Northeastern Aquifer Basin) in order to have a complete groundwater vulnerability assessment to pollution from human beings activities in the region.
- Take updated data which are required for analysis since there is a variety in data from time to another according to our special political situation.

In a region such as the research area, with limited available water resources, considerable logistical obstacles, a poor economy, and an uncertain political environment, source water protection may by some be considered secondary in importance to improving the overall water supply situation. Nonetheless, pollution prevention measures should be considered part of good aquifer management practices because long-term treatment of contaminated groundwater can be costly, and remediation may not be practical or feasible (logistically, financially or technically).

Recommended mitigation measures fall into these broad categories:

- Engineering (e.g., source controls to reduce sewage and pollutant loading).
- Land use planning (e.g., zoning).
- Regulations and enforcement of laws.
- Public awareness and community outreach.
- Institutional capacity-building.
- Improved monitoring (physical system, water quality, and watershed attributes such as land use, demographics).

Based on observed and suspected groundwater pollution, the following goals are considered "drivers" of aquifer protection in the studied area:

- Sewage loads to surface and ground water should be reduced.
- Other potential pollutant loads to surface and ground water must be investigated to further reduce them.
- Mitigation measures must be sustainable, both from water resources and institutional perspectives (i. e., capacity-building).
- Measures should be defined and implemented with specific attention to local conditions in the studied area, using low-cost technologies, and should allow for the highest possible benefit at the lowest possible costs.
- Stakeholders and the public should be engaged in the definition and implementation of measures (i. e., public participation).

7.2.1 Reduce Sewage Loads to Groundwater

Available data indicate that lack of adequate sewage systems and widespread use of cesspits are primary causes. A sanitation intervention strategy is therefore needed to protect groundwater resources, which addresses both urban areas and rural communities.

7.2.2 Reduce Other Pollutant Loads to Groundwater

Leachates, return flows, and effluents from solid waste dump sites, agricultural areas, and industries are all believed to contribute to pollution, but are expected to be more localized than sewage issues.

7.2.3 Inventory Industries, Hazardous Raw Materials and Industrial Wastes

There is presently only a cursory understanding of Palestinian industries in terms of raw materials used and hazardous waste quantities generated. Industrial licensing laws exist which call for reporting and monitoring of industrial wastes, but these are not enforceable under the current political situation. An inventory of industrial facilities is required to identify the potential types of waste products that are generated and disposed of. Inventories of raw materials and hazardous waste should include the agricultural sector.

It is recommended that data from inventories be used to examine pollution prevention opportunities in the industrial sector. A good basis for such an assessment is represented by the industrial wastewater pilot studies conducted under the USAID-funded Water Resources Program Phase III (CH2MHill, 2002c) and similar studies carried out for KfW in Tulkarm (1999). It is expected that such work would lead to smaller, specific, local-scale mitigation measures.

7.2.4 Public Awareness

It is recommended that public awareness be adopted as a core aquifer protection strategy. An active community who understands the link between water quality and public health will more likely take "ownership" and will be more understanding of protection measures.

7.2.5 Watershed Protection Plans

Watershed protection plans should be developed and implemented for all watersheds in the studied area., especially those watersheds that are associated with the major Palestinian drinking water sources. The objectives would be to define and design manageable protective actions that will both mitigate existing water quality problems and prevent future pollution.

7.2.6 Aquifer Management Plans

Water levels in some parts of the studied area are decreasing as a result of current pumping operations. As a part of aquifer protection planning, it is recommended that attention be given to aquifer management as well. The latter would address quantities of water rather than just quality. Combined aquifer management and water quality protection measures are considered crucial to aquifer sustainability. Hence, aquifer management plans that integrate watershed studies and water quality measures should be formulated and implemented for all of the major Palestinian drinking water sources.

7.2.7 Improve Monitoring Programs and Practices

Monitoring related to aquifer protection involves quantification of changes in water quantity and quality, as well as human activities and socio-economic factors. It is recognized that practical groundwater monitoring is resource-driven, the current monitoring practices by Palestinian authorities are severely hampered by travel restrictions, it is important to try to maintain monitoring activities high on the priority list of aquifer management and protection activities.

7.2.8 Israeli Activities-Data Collection and Monitoring

The understanding of Israeli settlement activities that pertain to aquifer vulnerability and water quality deterioration is very incomplete. It is recommended to develop a better understanding of the potential impacts of settlement activities on groundwater quality in the studied area.

7.2.9 Management of Fertilizers and Pesticides

Efforts to reduce and manage the use of fertilizers are needed. Return flows from irrigation carrying nitrates from fertilizers is suspected in Jenin, Tulkarem, and Qalqilia areas.

7.2.10 Information Management

GIS is important to planning and decision-making, and is essential to aquifer protection activities as it integrates varied and multi-disciplinary data and information in a consistent format. A well-designed GIS also provides a viable and effective means data sharing and dissemination.

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APPENDICES

Appendix A: Hydrogeological Properties of Wells in the Western Basin Portion Located in the West Bank

Well Name	Governorate	Depth to Water (m)	Total Measured Rainfall over Direct Recharge Area (mm/year)	*Net Recharge* (mm/year)	Aquifer Media	Aquifer Pumped	Formation	Significant Area of Soil Cover (≥ 2 m) within Inferred Flowpath (Yes/ Partly/ No)	Topography Slope in Direct Recharge Area	Protective Aquitards in Subsurface (Yes/ Partly/ No)	Karst Feature Observed along Flowpath (Yes/ No)
'ABED AL FATTAH MAJD	QALQILIA	90	500-550	157-180	Massive Bedded Limestone	UC	Bet/Heb	Partly	Low/ Moderate	Partly	Yes
'AZZUN VILLAGE COUNCIL	QALQILIA	183	500-550	157-180	Massive Bedded Limestone	LC	UBK/LBK	Partly	Low/ Moderate	Partly	Yes
SUDQI SHBAITAH	QALQILIA	216	500-550	157-180	Massive Bedded Limestone	LC	UBK/LBK	Partly	Low/ Moderate	Partly	Yes
YUSEF ANEES AL SHILLAH	QALQILIA	110	500-550	157-180	Massive Bedded Limestone	UC	Bet/Heb	Partly	Low/ Moderate	Partly	Yes
MUHAMMAD ABU HIJLAH	QALQILIA	129	500-550	157-180	Massive Bedded Limestone	UC	Bet/Heb	Partly	Low/ Moderate	Partly	Yes
SHAREEF ABU HIJLAH 4	QALQILIA	123	500-550	157-180	Massive Bedded Limestone	UC	Bet/Heb	Partly	Low/ Moderate	Partly	Yes
MUHAMMAD TAHA SALAMAH	QALQILIA	130	500-550	157-180	Massive Bedded Limestone	UC	Bet/Heb	Partly	Low/ Moderate	Partly	Yes
MUHAMMAD AL HAJ YUSEF	QALQILIA	130	500-550	157-180	Massive Bedded Limestone	UC	Bet/Heb	Partly	Low/ Moderate	Partly	Yes
'ABED AL KAREEM 'ABDALLAH	QALQILIA	75	500-550	157-180	Massive Bedded Limestone	UC	Bet/Heb	Partly	Low/ Moderate	Partly	Yes
YUSEF MUHAMMAD 'OMAR	QALQILIA	69	500-550	157-180	Massive Bedded Limestone	UC	Bet/Heb	Partly	Low/ Moderate	Partly	Yes
SADEQ AL SALEM	QALQILIA	86	500-550	157-180	Massive Bedded Limestone	UC	Bet/Heb	Partly	Low/ Moderate	Partly	Yes
KAMEL AL SALEM	QALQILIA	96	500-550	157-180	Massive Bedded Limestone	UC	Bet/Heb	Partly	Low/ Moderate	No data	No data
MUHAMMAD AHMAD SALEH	QALQILIA	76	500-550	157-180	Massive Bedded Limestone	UC	Bet/Heb	Partly	Low/ Moderate	Partly	Yes
'ABED AL RAHMAN ABU SALEH	QALQILIA	84	500-550	157-180	Massive Bedded Limestone	UC	Bet/Heb	Partly	Low/ Moderate	Partly	Yes
FARUQ SALEEM AL SHAKER	QALQILIA	117	500-550	157-180	Massive Bedded Limestone	UC	Bet/Heb	Partly	Low/ Moderate	Partly	Yes
MUHAMMAD QADDURAH & PARTNERS	QALQILIA	71	500-550	157-180	Massive Bedded Limestone	UC	Bet/Heb	Partly	Low/ Moderate	Partly	Yes
MUHAMMAD QADDURAH & PARTNERS	QALQILIA	61	500-550	157-180	Massive Bedded Limestone	UC	Bet/Heb	Partly	Low/ Moderate	Partly	Yes
MUHAMMAD QADDURAH & PARTNERS	QALQILIA	56	500-550	157-180	Massive Bedded Limestone	UC	Bet/Heb	Partly	Low/ Moderate	Partly	Yes
SALEEM 'UDAH & PARTNERS	QALQILIA	94	500-550	157-180	Massive Bedded Limestone	UC	Bet/Heb	Partly	Low/ Moderate	Partly	Yes
AHMAD QASEM ABU KHARRUB	QALQILIA	36	500-550	157-180	Massive Bedded Limestone	UC	Bet/Heb	Partly	Low/ Moderate	Partly	Yes

Well Name	Governorate	Depth to Water (m)	Total Measured Rainfall over Direct Recharge Area (mm/year)	*Net Recharge* (mm/year)	Aquifer Media	Aquifer Pumped	Formation	Significant Area of Soil Cover (≥ 2 m) within Inferred Flowpath (Yes/ Partly/ No)	Topography Slope in Direct Recharge Area	Protective Aquitards in Subsurface (Yes/ Partly/ No)	Karst Feature Observed along Flowpath (Yes/ No)
'ABED AL RAHEEM AS'AD JADA'	QALQILIA	51	500-550	157-180	Massive Bedded Limestone	UC	Bet/Heb	Partly	Low/ Moderate	Partly	Yes
AHMAD QASEM ABU KHARRUB	QALQILIA	54	500-550	157-180	Massive Bedded Limestone	UC	Bet/Heb	Partly	Low/ Moderate	Partly	Yes
AHMAD SHANTI	QALQILIA	34	500-550	157-180	Massive Bedded Limestone	UC	Bet/Heb	Partly	Low/ Moderate	Partly	Yes
GHAZI JAMAL AL QASEM	QALQILIA	31	500-550	157-180	Massive Bedded Limestone	UC	Bet/Heb	Partly	Low/ Moderate	Partly	Yes
GHAZI JAMAL AL QASEM	QALQILIA	35	500-550	157-180	Massive Bedded Limestone	UC	Bet/Heb	Partly	Low/ Moderate	Partly	Yes
'ABED AL RAHEEM AS'AD JADA'	QALQILIA	51	500-550	157-180	Massive Bedded Limestone	UC	Bet/Heb	Partly	Low/ Moderate	Partly	Yes
HABLAH VILLAGE COUNCIL	QALQILIA	51	500-550	157-180	Massive Bedded Limestone	UC	Bet/Heb	Partly	Low/ Moderate	Partly	Yes
IBRAHEEM ABU AL RUZZ	QALQILIA	100	500-550	157-180	Massive Bedded Limestone	UC	Bet/Heb	Partly	Low/ Moderate	Partly	Yes
JAMEEL AL WALWEEL	QALQILIA	106	500-550	157-180	Massive Bedded Limestone	UC	Bet/Heb	Partly	Low/ Moderate	Partly	Yes
'ALI HASAN ABU SALMAN	QALQILIA	50	500-550	157-180	Massive Bedded Limestone	UC	Bet/Heb	Partly	Low/ Moderate	Partly	Yes
SAMI 'ABDALLAH YUSEF	QALQILIA	78	500-550	157-180	Massive Bedded Limestone	UC	Bet/Heb	Partly	Low/ Moderate	Partly	Yes
MUHAMMAD 'OMAR KHALEEL	QALQILIA	71	500-550	157-180	Massive Bedded Limestone	UC	Bet/Heb	Partly	Low/ Moderate	Partly	Yes
LUTFI 'OMAR	QALQILIA	71	500-550	157-180	Massive Bedded Limestone	UC	Bet/Heb	Partly	Low/ Moderate	Partly	Yes
KARNI SHAMRUN	QALQILIA	285	550-600	180-203	Massive Bedded Limestone	LC	UBK/LBK	Partly	Low/ Moderate	Partly	Yes
'ABED AL 'AZEEZ ABU SAFIEH & PARTNERS	QALQILIA	73	500-550	157-180	Massive Bedded Limestone	UC	Bet/Heb	Partly	Low/ Moderate	Partly	Yes
RASHEED SHANTI	QALQILIA	28	500-550	157-180	Massive Bedded Limestone	UC	Bet/Heb	Partly	Low/ Moderate	No	No data
'ALI IDREES SHANTI	QALQILIA	30	500-550	157-180	Massive Bedded Limestone	UC	Bet/Heb	Partly	Low/ Moderate	No	No data
MUHAMMAD HADDAD	QALQILIA	34	500-550	157-180	Massive Bedded Limestone	UC	Bet/Heb	Partly	Low/ Moderate	No	No data
AHMAD ABU KHADEEJAH	QALQILIA	46	500-550	157-180	Massive Bedded Limestone	UC	Bet/Heb	Partly	Low/ Moderate	No	No data

Well Name	Governorate	Depth to Water (m)	Total Measured Rainfall over Direct Recharge Area (mm/year)	Net Recharge (mm/year)	Aquifer Media	Aquifer Pumped	Formation	Significant Area of Soil Cover (≥ 2 m) within Inferred Flowpath (Yes/ Partly/ No)	Topography Slope in Direct Recharge Area	Protective Aquitards in Subsurface (Yes/ Partly/ No)	Karst Feature Observed along Flowpath (Yes/ No)
'ALI ABU KHADER	QALQILIA	56	500-550	157-180	Massive Bedded Limestone	UC	Bet/Heb	Partly	Low/ Moderate	No	No data
AHMAD MUHAMMAD 'ABED AL RAHMAN	QALQILIA	26	500-550	157-180	Massive Bedded Limestone	UC	Bet/Heb	Partly	Low/ Moderate	No	No data
FAHMI 'ABED AL SALAM QADDURAH	QALQILIA	16	500-550	157-180	Massive Bedded Limestone	UC	Bet/Heb	Partly	Low/ Moderate	No	No data
'ABED AL KAREEM QUB'AH	QALQILIA	26	500-550	157-180	Massive Bedded Limestone	UC	Bet/Heb	Partly	Low/ Moderate	No	No data
'ABED AL KAREEM QUB'AH	QALQILIA	26	500-550	157-180	Massive Bedded Limestone	UC	Bet/Heb	Partly	Low/ Moderate	No	No data
MUSTAFA ABU AL 'ADAL	QALQILIA	28	500-550	157-180	Massive Bedded Limestone	UC	Bet/Heb	Partly	Low/ Moderate	No	No data
MUSTAFA ABU AL 'ADAL	QALQILIA	28	500-550	157-180	Massive Bedded Limestone	UC	Bet/Heb	Partly	Low/ Moderate	No	No data
SALEH ABU AL DHURAH	QALQILIA	28	500-550	157-180	Massive Bedded Limestone	UC	Bet/Heb	Partly	Low/ Moderate	No	No data
MUSTAFA NAZZAL & PARTNERS	QALQILIA	34	500-550	157-180	Massive Bedded Limestone	UC	Bet/Heb	Partly	Low/ Moderate	No	No data
RAFEEQ 'ABAED AL RAZEQ	QALQILIA	31	500-550	157-180	Massive Bedded Limestone	UC	Bet/Heb	Partly	Low/ Moderate	No	No data
'ALI ABU 'ULBAH & PARTNERS	QALQILIA	101	500-550	157-180	Massive Bedded Limestone	UC	Bet/Heb	Partly	Low/ Moderate	No	No data
'ABDALLAH MUHAMMAD 'ABED AL RAHMAN	QALQILIA	34	500-550	157-180	Massive Bedded Limestone	UC	Bet/Heb	Partly	Low/ Moderate	No	No data
SHAKER AL BARHAM	QALQILIA	38	500-550	157-180	Massive Bedded Limestone	UC	Bet/Heb	Partly	Low/ Moderate	No	No data
MUHAMMAD SA'EED BARHAM	QALQILIA	46	500-550	157-180	Massive Bedded Limestone	UC	Bet/Heb	Partly	Low/ Moderate	No	No data
'ABED AL RAHEEM AL 'ABED	QALQILIA	31	500-550	157-180	Massive Bedded Limestone	UC	Bet/Heb	Partly	Low/ Moderate	No	No data
QALQILYA MUNICIPALITY	QALQILIA	38	500-550	157-180	Massive Bedded Limestone	UC	Bet/Heb	Partly	Low/ Moderate	No	No data
MAHMUD YUSEF TAHA	QALQILIA	34	500-550	157-180	Massive Bedded Limestone	UC	Bet/Heb	Partly	Low/ Moderate	No	No data
MUSTAFA NAZZAL	QALQILIA	52	500-550	157-180	Massive Bedded Limestone	UC	Bet/Heb	Partly	Low/ Moderate	No	No data
'ABED AL RAHEEM HASAN	QALQILIA	86	500-550	157-180	Massive Bedded Limestone	UC	Bet/Heb	Partly	Low/ Moderate	No	No data
YUSEF HASANAIN KHATER	QALQILIA	42	500-550	157-180	Massive Bedded Limestone	UC	Bet/Heb	Partly	Low/ Moderate	No	No data

Well Name	Governorate	Depth to Water (m)	Total Measured Rainfall over Direct Recharge Area (mm/year)	Net Recharge (mm/year)	Aquifer Media	Aquifer Pumped	Formation	Significant Area of Soil Cover (≥ 2 m) within Inferred Flowpath (Yes/ Partly/ No)	Topography Slope in Direct Recharge Area	Protective Aquitards in Subsurface (Yes/ Partly/ No)	Karst Feature Observed along Flowpath (Yes/ No)
REDA ABU KHADER	QALQILIA	46	500-550	157-180	Massive Bedded Limestone	UC	Bet/Heb	Partly	Low/ Moderate	No	No data
'UTHMAN AL TABEEB	QALQILIA	26	500-550	157-180	Massive Bedded Limestone	UC	Bet/Heb	Partly	Low/ Moderate	No	No data
IBRAHEEM ABU SAMRAH	QALQILIA	54	500-550	157-180	Massive Bedded Limestone	UC	Bet/Heb	Partly	Low/ Moderate	No	No data
'ABDALLAH GHNAIM	QALQILIA	61	500-550	157-180	Massive Bedded Limestone	UC	Bet/Heb	Partly	Low/ Moderate	No	No data
AHMAD ABU AL NASER	QALQILIA	21	500-550	157-180	Massive Bedded Limestone	UC	Bet/Heb	Partly	Low/ Moderate	No	No data
'ABDALLAH 'ABED AL RAHMAN	QALQILIA	48	500-550	157-180	Massive Bedded Limestone	UC	Bet/Heb	Partly	Low/ Moderate	No	No data
MUHAMMAD SA'EED YUNES	QALQILIA	40	500-550	157-180	Massive Bedded Limestone	UC	Bet/Heb	Partly	Low/ Moderate	No	No data
QALQILYA MUNICIPALITY	QALQILIA	96	500-550	157-180	Massive Bedded Limestone	UC	Bet/Heb	Partly	Low/ Moderate	No	No data
'ALI NAJEEB 'ASHUR	QALQILIA	76	500-550	157-180	Massive Bedded Limestone	UC	Bet/Heb	Partly	Low/ Moderate	No	No data
HASAN AL HAJ HASAN	QALQILIA	51	500-550	157-180	Massive Bedded Limestone	UC	Bet/Heb	Partly	Low/ Moderate	No	No data
OTHMAN ABU MARYAM	QALQILIA	106	500-550	157-180	Massive Bedded Limestone	UC	Bet/Heb	Partly	Low/ Moderate	No	No data
FADEL KITTANAH & PARTNERS	TULKARM	44	550-600	180-203	Massive Bedded Limestone	UC	Bet/Heb	Yes	Low/ Moderate	Partly	Yes
'AREF 'ABED AL QADER	TULKARM	191	500-550	157-180	Massive Bedded Limestone	UC	Bet/Heb	Yes	Low/ Moderate	Partly	Yes
MUHAMMAD MEKKAWI	TULKARM	41	550-600	180-203	Massive Bedded Limestone	UC	Bet/Heb	Yes	Low/ Moderate	Partly	Yes
RASHEED SAMARAH & TAHSEEN SHADEED	TULKARM	46	550-600	180-203	Massive Bedded Limestone	UC	Bet/Heb	Yes	Low/ Moderate	Partly	Yes
MUHAMMAD 'ABED AL RAZEQ & PARTNERS	TULKARM	72	550-600	180-203	Massive Bedded Limestone	UC	Bet/Heb	Yes	Low/ Moderate	Partly	Yes
NAJEEB 'ALI MUSA	TULKARM	119	550-600	180-203	Massive Bedded Limestone	UC	Bet/Heb	Yes	Low/ Moderate	Partly	Yes

Well Name	Governorate	Depth to Water (m)	Total Measured Rainfall over Direct Recharge Area (mm/year)	Net Recharge (mm/year)	Aquifer Media	Aquifer Pumped	Formation	Significant Area of Soil Cover (≥ 2 m) within Inferred Flowpath (Yes/ Partly/ No)	Topography Slope in Direct Recharge Area	Protective Aquitards in Subsurface (Yes/ Partly/ No)	Karst Feature Observed along Flowpath (Yes/ No)
'ANABTA MUNICIPALITY	TULKARM	78	550-600	180-203	Massive Bedded Limestone	UC	Bet/Heb	Yes	Low/ Moderate	Partly	Yes
'ANABTA MUNICIPALITY	TULKARM	75	550-600	180-203	Massive Bedded Limestone	UC	Bet/Heb	Yes	Low/ Moderate	Partly	Yes
JAMEEL 'AWARTANI	TULKARM	106	550-600	180-203	Massive Bedded Limestone	UC	Bet/Heb	Yes	Low/ Moderate	Partly	Yes
HASEEB I'MUS	TULKARM	54	550-600	180-203	Massive Bedded Limestone	UC	Bet/Heb	Yes	Low/ Moderate	Partly	Yes
SALEH YASEEN HAMDAN	TULKARM	65	550-600	180-203	Massive Bedded Limestone	UC	Bet/Heb	Yes	Low/ Moderate	Partly	Yes
AS'AD RABEE' & PARTNERS	TULKARM	60	550-600	180-203	Massive Bedded Limestone	UC	Bet/Heb	Yes	Low/ Moderate	Partly	Yes
'ATTEEL COOPERATIVE SOCIETY	TULKARM	51	550-600	180-203	Massive Bedded Limestone	UC	Bet/Heb	Yes	Low/ Moderate	Partly	Yes
MUHAMMAD NEMER BARAKAT	TULKARM	56	550-600	180-203	Massive Bedded Limestone	UC	Bet/Heb	Yes	Low/ Moderate	Partly	Yes
BAL'A VILLAGE COUNCIL	TULKARM	182	550-600	180-203	Massive Bedded Limestone	UC	Bet/Heb	Yes	Low/ Moderate	Partly	Yes
MUHAMMAD KHALAF	TULKARM	48	550-600	180-203	Massive Bedded Limestone	UC	Bet/Heb	Yes	Low/ Moderate	Partly	Yes
MUHAMMAD ABU SHAMS	TULKARM	44	550-600	180-203	Massive Bedded Limestone	UC	Bet/Heb	Yes	Low/ Moderate	Partly	Yes
MUHAMMAD ABU SHAMS	TULKARM	41	550-600	180-203	Massive Bedded Limestone	UC	Bet/Heb	Yes	Low/ Moderate	Partly	Yes
'AZEEZ MAS'UD	TULKARM	75	550-600	180-203	Massive Bedded Limestone	UC	Bet/Heb	Yes	Low/ Moderate	Partly	Yes
SAQER AL SA'ED	TULKARM	48	550-600	180-203	Massive Bedded Limestone	UC	Bet/Heb	Yes	Low/ Moderate	Partly	Yes
'ABED AL MAJEED QASEM	TULKARM	65	550-600	180-203	Massive Bedded Limestone	UC	Bet/Heb	Yes	Low/ Moderate	No	Yes
DAIR AL GHSUN VILLAGE COUNCIL	TULKARM	169	550-600	180-203	Massive Bedded Limestone	UC	Bet/Heb	Yes	Low/ Moderate	No	Yes
ZUBAYDAH AL SA'EED	TULKARM	109	550-600	180-203	Massive Bedded Limestone	UC	Bet/Heb	Yes	Low/ Moderate	Partly	Yes
SADEEQ JAMUS	TULKARM	90	500-550	157-180	Massive Bedded Limestone	UC	Bet/Heb	Yes	Low/ Moderate	Partly	Yes
AS'AD TAFFAL & AHMAD KHRAISHAH	TULKARM	91	500-550	157-180	Massive Bedded Limestone	UC	Bet/Heb	Yes	Low/ Moderate	Partly	Yes

Well Name	Governorate	Depth to Water (m)	Total Measured Rainfall over Direct Recharge Area (mm/year)	Net Recharge (mm/year)	Aquifer Media	Aquifer Pumped	Formation	Significant Area of Soil Cover (≥ 2 m) within Inferred Flowpath (Yes/ Partly/ No)	Topography Slope in Direct Recharge Area	Protective Aquitards in Subsurface (Yes/ Partly/ No)	Karst Feature Observed along Flowpath (Yes/ No)
MUHAMMAD 'OMAR SAFAREENI	TULKARM	100	500-550	157-180	Massive Bedded Limestone	UC	Bet/Heb	Yes	Low/ Moderate	Partly	Yes
MUHAMMAD 'ABED AL HALEEM	TULKARM	121	500-550	157-180	Massive Bedded Limestone	UC	Bet/Heb	Yes	Low/ Moderate	Partly	Yes
MUHAMMAD YUSEF 'OMAR	TULKARM	36	500-550	157-180	Massive Bedded Limestone	UC	Bet/Heb	Yes	Low/ Moderate	Partly	Yes
ISMA'EEL I'TAIR	TULKARM	43	500-550	157-180	Massive Bedded Limestone	UC	Bet/Heb	Yes	Low/ Moderate	Partly	Yes
WASFI 'ABED AL KAREEM	TULKARM	65	500-550	157-180	Massive Bedded Limestone	UC	Bet/Heb	Yes	Low/ Moderate	Partly	Yes
RAFEEQ HAMDALLAH	TULKARM	55	500-550	157-180	Massive Bedded Limestone	UC	Bet/Heb	Yes	Low/ Moderate	Partly	Yes
AHMAD ABU SHANAB & PARTNERS	TULKARM	51	500-550	157-180	Massive Bedded Limestone	UC	Bet/Heb	Yes	Low/ Moderate	Partly	Yes
HASAN 'ISA & PARTNERS	TULKARM	28	500-550	157-180	Massive Bedded Limestone	UC	Bet/Heb	Yes	Low/ Moderate	Partly	Yes
MUHAMMAD AHMAD ABU SHANAB	TULKARM	38	500-550	157-180	Massive Bedded Limestone	UC	Bet/Heb	Yes	Low/ Moderate	Partly	Yes
SAL'EET	TULKARM	138	500-550	157-180	Massive Bedded Limestone	UC	Bet/Heb	Yes	Low/ Moderate	Partly	Yes
HASAN MAHMUD KHALEEL	TULKARM	113	550-600	180-203	Massive Bedded Limestone	UC	Bet/Heb	Yes	Low/ Moderate	Partly	Yes
MUHAMMAD KHADER 'ABDALLAH	TULKARM	154	500-550	157-180	Massive Bedded Limestone	UC	Bet/Heb	Yes	Low/ Moderate	Partly	Yes
KAMEL AL SALEM & PARTNERS	TULKARM	242	550-600	180-203	Massive Bedded Limestone	LC	UBK/LBK	Yes	Low/ Moderate	Partly	Yes
MUHAMMAD AL TAHER & PARTNERS	TULKARM	44	550-600	180-203	Massive Bedded Limestone	UC	Bet/Heb	Yes	Low/ Moderate	Partly	Yes
RA'FAT AL QUBBAJ	TULKARM	69	550-600	180-203	Massive Bedded Limestone	UC	Bet/Heb	Yes	Low/ Moderate	Partly	Yes
QAFFEEN VILLAGE COUNCIL	TULKARM	102	550-600	180-203	Massive Bedded Limestone	UC-T	Jer/Bet/Heb	Yes	Low/ Moderate	No	Yes
SHUFA WATER COOPERATIVE COMMITTEE	TULKARM	74	500-550	157-180	Massive Bedded Limestone	UC	Bet/Heb	Yes	Low/ Moderate	Partly	Yes
I'QAB FRAIJ & PARTNERS	TULKARM	54	500-550	157-180	Massive Bedded Limestone	UC	Bet/Heb	Yes	Low/ Moderate	Partly	Yes
'ALI ABU SALEH	TULKARM	56	500-550	157-180	Massive Bedded Limestone	UC	Bet/Heb	Yes	Low/ Moderate	Partly	Yes
'ABED ALRAHMAN ABU SALEH	TULKARM	45	500-550	157-180	Massive Bedded Limestone	UC	Bet/Heb	Yes	Low/ Moderate	Partly	Yes

Well Name	Governorate	Depth to Water (m)	Total Measured Rainfall over Direct Recharge Area (mm/year)	Net Recharge (mm/year)	Aquifer Media	Aquifer Pumped	Formation	Significant Area of Soil Cover (≥ 2 m) within Inferred Flowpath (Yes/ Partly/ No)	Topography Slope in Direct Recharge Area	Protective Aquitards in Subsurface (Yes/ Partly/ No)	Karst Feature Observed along Flowpath (Yes/ No)
'ABED AL RAHEEM MER'IB	TULKARM	86	500-550	157-180	Massive Bedded Limestone	UC	Bet/Heb	Yes	Low/ Moderate	Partly	Yes
SA'EED JABER	TULKARM	76	500-550	157-180	Massive Bedded Limestone	UC	Bet/Heb	Yes	Low/ Moderate	Partly	Yes
SHAKER SAMARAH	TULKARM	47	500-550	157-180	Massive Bedded Limestone	UC	Bet/Heb	Yes	Low/ Moderate	Partly	Yes
'ABDALLAH SHRAIM & PARTNERS	TULKARM	38	500-550	157-180	Massive Bedded Limestone	UC	Bet/Heb	Yes	Low/ Moderate	Partly	Yes
'ABED ALKAREEM QASEM	TULKARM	48	500-550	157-180	Massive Bedded Limestone	UC	Bet/Heb	Yes	Low/ Moderate	Partly	Yes
RASHEED HANNUN & PARTNERS	TULKARM	45	500-550	157-180	Massive Bedded Limestone	UC	Bet/Heb	Yes	Low/ Moderate	Partly	Yes
MUHAMMAD SA'EED KAMAL	TULKARM	44	500-550	157-180	Massive Bedded Limestone	UC	Bet/Heb	Yes	Low/ Moderate	Partly	Yes
KHALED SALEEM HANNUN	TULKARM	76	500-550	157-180	Massive Bedded Limestone	UC	Bet/Heb	Yes	Low/ Moderate	Partly	Yes
HAFEDH ALHAMDALLAH	TULKARM	56	500-550	157-180	Massive Bedded Limestone	UC	Bet/Heb	Yes	Low/ Moderate	Partly	Yes
RASHEED DHYAB	TULKARM	48	500-550	157-180	Massive Bedded Limestone	UC	Bet/Heb	Yes	Low/ Moderate	Partly	Yes
'ABED AL RAHEEM ABU BAKER	TULKARM	48	500-550	157-180	Massive Bedded Limestone	UC	Bet/Heb	Yes	Low/ Moderate	Partly	Yes
'OMAR AL KARMI	TULKARM	34	500-550	157-180	Massive Bedded Limestone	UC	Bet/Heb	Yes	Low/ Moderate	Partly	Yes
TULKARM MUNICIPALITY	TULKARM	51	500-550	157-180	Massive Bedded Limestone	UC	Bet/Heb	Yes	Low/ Moderate	Partly	Yes
TULKARM MUNICIPALITY	TULKARM	41	500-550	157-180	Massive Bedded Limestone	UC	Bet/Heb	Yes	Low/ Moderate	Partly	Yes
MUSTAFA AL SA'EED	TULKARM	34	500-550	157-180	Massive Bedded Limestone	UC	Bet/Heb	Yes	Low/ Moderate	Partly	Yes
'ABED AL QADER QUZMAR	TULKARM	44	500-550	157-180	Massive Bedded Limestone	UC	Bet/Heb	Yes	Low/ Moderate	Partly	Yes
AL KHADURI AGRICULTURAL SCHOOL	TULKARM	31	500-550	157-180	Massive Bedded Limestone	UC	Bet/Heb	Yes	Low/ Moderate	Partly	Yes
OBSERVATION WELL	TULKARM	46	500-550	157-180	Massive Bedded Limestone	UC	Bet/Heb	Yes	Low/ Moderate	Partly	Yes
TULKARM MUNICIPALITY	TULKARM	46	500-550	157-180	Massive Bedded Limestone	UC	Bet/Heb	Yes	Low/ Moderate	Partly	Yes

Well Name	Governorate	Depth to Water (m)	Total Measured Rainfall over Direct Recharge Area (mm/year)	Net Recharge (mm/year)	Aquifer Media	Aquifer Pumped	Formation	Significant Area of Soil Cover (≥ 2 m) within Inferred Flowpath (Yes/ Partly/ No)	Topography Slope in Direct Recharge Area	Protective Aquitards in Subsurface (Yes/ Partly/ No)	Karst Feature Observed along Flowpath (Yes/ No)
ZAITA VILLAGE COUNCIL	TULKARM	76	550-600	180-203	Massive Bedded Limestone	UC	Bet/Heb	Yes	Low/ Moderate	No	No data
'ABED AL JABBAR SAMARAH	TULKARM	36	550-600	180-203	Massive Bedded Limestone	UC	Bet/Heb	Yes	Low/ Moderate	No	No data
FARIS & RUSHDEE ABU SABHAH	TULKARM	46	550-600	180-203	Massive Bedded Limestone	UC	Bet/Heb	Yes	Low/ Moderate	No	No data
'AWNI 'ABD AL HADI	JENIN	114	550-600	180-203	Massive Bedded Limestone	UC-T	Jer/Bet/Heb	Partly	Low/ Moderate	No	Yes
ADEEB KITTANAH	JENIN	105	550-600	180-203	Massive Bedded Limestone	UC	Bet/Heb	Partly	Low/ Moderate	Partly	Yes
YA'BAD MUNICIPALITY	JENIN	240	550-600	180-203	Massive Bedded Limestone	UC-T	Jer/Bet/Heb	Yes	Low/ Moderate	Partly	Yes
DAIR SHARAF NO. 1(looks in Dair Sharaf)	NABLUS	200	550-600	180-203	Massive Bedded Limestone	UC	Bet/Heb	Partly	Low/ Moderate	Partly	Yes
DAIR SHARAF NO. 3	NABLUS	181	550-600	180-203	Massive Bedded Limestone	UC	Bet/Heb	Partly	Low/ Moderate	Partly	Yes
DAIR SHARAF NO. 2	NABLUS	207	550-600	180-203	Massive Bedded Limestone	UC	Bet/Heb	Partly	Low/ Moderate	Partly	Yes
DAIR SHARAF NO. 2A	NABLUS	207	550-600	180-203	Massive Bedded Limestone	LC	UBK/LBK	Partly	Low/ Moderate	Partly	Yes
AL ZAWYAH WELL	SALFIT	171	500-550	157-180	Massive Bedded Limestone	UC	Bet/Heb	Yes	Low/ Moderate	Yes	No data
HARIS EXPLORATION WELL	SALFIT	315	600-700	203-249	Massive Bedded Limestone	LC	UBK/LBK	Partly	Low/ Moderate	Partly	Yes
MARDA WELL	SALFIT	170	600-700	203-249	Massive Bedded Limestone	UC	Bet/Heb	Partly	Low/ Moderate	Partly	Yes
ARE'AIL	SALFIT	270	600-700	203-249	Massive Bedded Limestone	LC	UBK/LBK	Partly	Low/ Moderate	Partly	Yes
DHEEB REDA 'UDAH	SALFIT	255	500-550	157-180	Massive Bedded Limestone	LC	UBK/LBK	Partly	Low/ Moderate	Partly	Yes
SHEBTEEN NO. 1	RAMALLAH	279	550-600	180-203	Massive Bedded Limestone	LC	UBK/LBK	No	Moderate	Partly	No Data
SHEBTEEN NO. 2	RAMALLAH	209	550-600	180-203	Massive Bedded Limestone	LC	UBK/LBK	No	Moderate	Partly	No Data
SHEBTEEN NO. 4	RAMALLAH	220	550-600	180-203	Massive Bedded Limestone	LC	UBK/LBK	No	Moderate	Partly	No Data
SHEBTEEN No.5	RAMALLAH	142	500-550	157-180	Massive Bedded Limestone	LC	UBK/LBK	No	Moderate	Partly	No Data
HEBRON NO.4	HEBRON	270	400-450	111-134	Massive Bedded Limestone	UC	Bet/Heb	Partly	Low/ Moderate	Partly	Yes

Well Name	Governorate	Depth to Water (m)	Total Measured Rainfall over Direct Recharge Area (mm/year)	Net Recharge (mm/year)	Aquifer Media	Aquifer Pumped	Formation	Significant Area of Soil Cover (≥ 2 m) within Inferred Flowpath (Yes/ Partly/ No)	Topography Slope in Direct Recharge Area	Protective Aquitards in Subsurface (Yes/ Partly/ No)	Karst Feature Observed along Flowpath (Yes/ No)
HEBRON 4	HEBRON	270	400-450	111-134	Massive Bedded Limestone	UC	Bet/Heb	Partly	Low/ Moderate	No	Yes
AL FAWWAR - HEBRON MUNICIPALITY NO.1C(2)	HEBRON	270	400-450	111-134	Massive Bedded Limestone	UC	Bet/Heb	Partly	Low/ Moderate	No	Yes
AL FAWWAR - HEBRON MUNICIPALITY NO. 3	HEBRON	270	400-450	111-134	Massive Bedded Limestone	UC	Bet/Heb	Partly	Low/ Moderate	No	Yes
AL REEHIYYAH	HEBRON	140	350-400	88-111	Massive Bedded Limestone	T	Jer	Partly	Low/ Moderate	Partly	Yes

Appendix B: Hydrogeological Properties of Springs in the Western Basin Portion Located in the West Bank

Spring Name	Governorate	Depth to Water (m)	Total Measured Rainfall over Direct Recharge Area (mm/year)	Net Recharge (mm/year)	Aquifer Media	Aquifer Pumped	Formation	Significant Area of Soil Cover (≥ 2 m) within Inferred Flowpath (Yes/ Partly/ No)	Topography Slope in Direct Recharge Area	Protective Aquitards in Subsurface (Yes/ Partly/ No)	Karst Feature Observed along Flowpath (Yes/ No)
AL SAMU' NO.1	HEBRON	190	300-350	65-88	Massive Bedded Limestone	T	Jer	Partly	Low/ Moderate	Partly	Yes
KAFFET 'UDAH	NABLUS	0	550-600	180-203	Massive Bedded Limestone	UC	Bet/Heb	Partly	Low/ Moderate	Partly	Yes
AL FAWWAR	NABLUS	0	550-600	180-203	Massive Bedded Limestone	UC	Bet/Heb	Partly	Low/ Moderate	Partly	Yes
AL JUZAH	NABLUS	0	550-600	180-203	Massive Bedded Limestone	UC	Bet/Heb	Partly	Low/ Moderate	Partly	Yes
AL BASSAH	NABLUS	0	550-600	180-203	Massive Bedded Limestone	UC	Bet/Heb	Partly	Low/ Moderate	Partly	Yes
AL MAQYUDAH	NABLUS	0	550-600	180-203	Massive Bedded Limestone	UC	Bet/Heb	Partly	Low/ Moderate	Partly	Yes
AL MATWI	SALFIT	0	600-700	203-249	Massive Bedded Limestone	UC	Bet/Heb	Partly	Low/ Moderate	Partly	Yes
SHAMIYYAH	SALFIT	0	600-700	203-249	Massive Bedded Limestone	UC	Bet/Heb	Partly	Low/ Moderate	Partly	Yes
AL SHALLAL	SALFIT	0	600-700	203-249	Massive Bedded Limestone	UC	Bet/Heb	Partly	Low/ Moderate	Partly	Yes
'ADAS	SALFIT	0	600-700	203-249	Massive Bedded Limestone	UC	Bet/Heb	Partly	Low/ Moderate	Partly	Yes
AL FAWWARA	SALFIT	0	550-600	180-203	Massive Bedded Limestone	UC	Bet/Heb	Partly	Low/ Moderate	Partly	Yes
El Balad/Ibwein	RAMALLAH	0	600-700	203-249	Massive Bedded Limestone	UC	Bet/Heb	No	Moderate	Partly	Yes
AL SUFLA	RAMALLAH	0	600-700	203-249	Massive Bedded Limestone	UC	Bet/Heb	No	Moderate	Partly	Yes
El Balad/Arura	RAMALLAH	0	600-700	203-249	Massive Bedded Limestone	UC	Bet/Heb	No	Moderate	Partly	Yes
DAQLAH	RAMALLAH	0	550-600	180-203	Massive Bedded Limestone	UC	Bet/Heb	No	Moderate	Partly	Yes
ABU FAYYAD	RAMALLAH	0	550-600	180-203	Massive Bedded Limestone	UC	Bet/Heb	No	Moderate	Partly	Yes
AL DAIR	RAMALLAH	0	550-600	180-203	Massive Bedded Limestone	UC	Bet/Heb	No	Moderate	Partly	Yes
KAFER	RAMALLAH	0	550-600	180-203	Massive Bedded Limestone	UC	Bet/Heb	No	Moderate	Partly	Yes

Well Name	Governorate	Depth to Water (m)	Total Measured Rainfall over Direct Recharge Area (mm/year)	Net Recharge (mm/year)	Aquifer Media	Aquifer Pumped	Formation	Significant Area of Soil Cover (≥ 2 m) within Inferred Flowpath (Yes/ Partly/ No)	Topography Slope in Direct Recharge Area	Protective Aquitards in Subsurface (Yes/ Partly/ No)	Karst Feature Observed along Flowpath (Yes/ No)
QARAWAH	RAMALLAH	0	600-700	203-249	Massive Bedded Limestone	UC	Bet/Heb	No	Moderate	Partly	Yes
RAYYA	RAMALLAH	0	550-600	180-203	Massive Bedded Limestone	UC	Bet/Heb	No	Moderate	Partly	Yes
RAYYA AL FUQA	RAMALLAH	0	550-600	180-203	Massive Bedded Limestone	UC	Bet/Heb	No	Moderate	Partly	Yes
DELBAH & LAQTAN	RAMALLAH	0	500-550	157-180	Massive Bedded Limestone	UC	Bet/Heb	No	Moderate	Partly	Yes
Ligtan *	RAMALLAH	0	500-550	157-180	Massive Bedded Limestone	UC	Bet/Heb	No	Moderate	Partly	Yes
Dilba *	RAMALLAH	0	500-550	157-180	Massive Bedded Limestone	UC	Bet/Heb	No	Moderate	Partly	Yes
ZARQA	RAMALLAH	0	500=550	157-180	Massive Bedded Limestone	UC	Bet/Heb	No	Moderate	Partly	Yes
AL MGHARAH	RAMALLAH	0	500-550	157-180	Massive Bedded Limestone	UC	Bet/Heb	No	Moderate	Partly	Yes
AL 'ALAM	RAMALLAH	0	500-550	157-180	Massive Bedded Limestone	UC	Bet/Heb	No	Moderate	Partly	Yes
AL QUS (Qaus)	RAMALLAH	0	550-600	180-203	Massive Bedded Limestone	UC	Bet/Heb	No	Moderate	Partly	Yes
KUBAR	RAMALLAH	0	550-600	180-203	Massive Bedded Limestone	UC	Bet/Heb	No	Moderate	Partly	Yes
AL ZARQAH	RAMALLAH	0	500-550	157-180	Massive Bedded Limestone	UC	Bet/Heb	No	Moderate	Partly	Yes
AL ZARQAH AL TEHTA	RAMALLAH	0	550-600	180-203	Massive Bedded Limestone	UC	Bet/Heb	No	Moderate	Partly	Yes
AL QWAIQBAH	RAMALLAH	0	550-600	180-203	Massive Bedded Limestone	UC	Bet/Heb	No	Moderate	Partly	Yes
'AKARI	RAMALLAH	0	550-600	180-203	Massive Bedded Limestone	UC	Bet/Heb	No	Moderate	Partly	Yes
AL BALAD	RAMALLAH	0	500-550	157-180	Massive Bedded Limestone	UC	Bet/Heb	No	Moderate	Partly	Yes
AL QUS	RAMALLAH	0	550-600	180-203	Massive Bedded Limestone	UC	Bet/Heb	No	Moderate	Partly	Yes
SHAKARYA	RAMALLAH	0	550-600	180-203	Massive Bedded Limestone	UC	Bet/Heb	No	Moderate	Partly	Yes
DAIR 'AMMAR	RAMALLAH	0	550-600	180-203	Massive Bedded Limestone	UC	Bet/Heb	No	Moderate	Partly	Yes
AL BALAD	RAMALLAH	0	500-550	157-180	Massive Bedded Limestone	UC	Bet/Heb	No	Moderate	Partly	Yes

Spring Name	Governorate	Depth to Water (m)	Total Measured Rainfall over Direct Recharge Area (mm/year)	Net Recharge (mm/year)	Aquifer Media	Aquifer Pumped	Formation	Significant Area of Soil Cover (≥ 2 m) within Inferred Flowpath (Yes/ Partly/ No)	Topography Slope in Direct Recharge Area	Protective Aquitards in Subsurface (Yes/ Partly/ No)	Karst Feature Observed along Flowpath (Yes/ No)
'AREEK AL FUQA	RAMALLAH	0	500-550	157-180	Massive Bedded Limestone	UC	Bet/Heb	No	Moderate	Partly	Yes
'AREEK AL TEHTA	RAMALLAH	0	500-550	157-180	Massive Bedded Limestone	UC	Bet/Heb	No	Moderate	Partly	Yes
AL JARYUT	RAMALLAH	0	500-550	157-180	Massive Bedded Limestone	UC	Bet/Heb	No	Moderate	Partly	Yes
BAIT SUREEK	RAMALLAH	0	500-550	157-180	Massive Bedded Limestone	UC	Bet/Heb	No	Moderate	Partly	Yes
AL THARWANI	RAMALLAH	0	550-600	180-203	Massive Bedded Limestone	UC	Bet/Heb	Partly	Low/ Moderate	Partly	Yes
BAIT DUQQU	JERUSALEM	0	550-600	180-203	Massive Bedded Limestone	UC	Bet/Heb	Partly	Low/ Moderate	Partly	Yes
JANAN	JERUSALEM	0	550-600	180-203	Massive Bedded Limestone	UC	Bet/Heb	Partly	Low/ Moderate	Partly	Yes
AL BALAD	JERUSALEM	0	550-600	180-203	Massive Bedded Limestone	UC	Bet/Heb	Partly	Low/ Moderate	Partly	Yes
BATTEER	BETHLEHEM	0	550-600	180-203	Massive Bedded Limestone	UC	Bet/Heb	Partly	Low/ Moderate	Partly	Yes
AL JAME'	BETHLEHEM	0	550-600	180-203	Massive Bedded Limestone	UC	Bet/Heb	Partly	Low/ Moderate	Partly	Yes
AL 'AMUD	BETHLEHEM	0	550-600	180-203	Massive Bedded Limestone	UC	Bet/Heb	Partly	Low/ Moderate	Partly	Yes
AL SKHUNAH	BETHLEHEM	0	550-600	180-203	Massive Bedded Limestone	UC	Bet/Heb	Partly	Low/ Moderate	Partly	Yes
'UDAH	BETHLEHEM	0	550-600	180-203	Massive Bedded Limestone	UC	Bet/Heb	Partly	Low/ Moderate	Partly	Yes
BERKAT URF	BETHLEHEM	0	550-600	180-203	Massive Bedded Limestone	UC	Bet/Heb	Partly	Low/ Moderate	Partly	Yes
AL KAREESAH	BETHLEHEM	0	550-600	180-203	Massive Bedded Limestone	UC	Bet/Heb	Partly	Low/ Moderate	Partly	Yes
AL NAMUS	BETHLEHEM	0	550-600	180-203	Massive Bedded Limestone	UC	Bet/Heb	Partly	Low/ Moderate	Partly	Yes
El Balad/ Nahalin	BETHLEHEM	0	550-600	180-203	Massive Bedded Limestone	UC	Bet/Heb	Partly	Low/ Moderate	Partly	Yes
FARES	BETHLEHEM	0	500-550	157-180	Massive Bedded Limestone	UC	Bet/Heb	Partly	Low/ Moderate	Partly	Yes
El Balad/ Wadi Fukin	BETHLEHEM	0	500-550	157-180	Massive Bedded Limestone	UC	Bet/Heb	Partly	Low/ Moderate	Partly	Yes

Spring Name	Governorate	Depth to Water (m)	Total Measured Rainfall over Direct Recharge Area (mm/year)	Net Recharge (mm/year)	Aquifer Media	Aquifer Pumped	Formation	Significant Area of Soil Cover (≥ 2 m) within Inferred Flowpath (Yes/ Partly/ No)	Topography Slope in Direct Recharge Area	Protective Aquitards in Subsurface (Yes/ Partly/ No)	Karst Feature Observed along Flowpath (Yes/ No)
AL MAGHARAH	BETHLEHEM	0	500-550	157-180	Massive Bedded Limestone	UC	Bet/Heb	Partly	Low/ Moderate	Partly	Yes
AL JURAH	BETHLEHEM	0	500-550	157-180	Massive Bedded Limestone	UC	Bet/Heb	Partly	Low/ Moderate	Partly	Yes
SUBA	BETHLEHEM	0	550-600	180-203	Massive Bedded Limestone	UC	Bet/Heb	Partly	Low/ Moderate	Partly	Yes
SADEEQ	BETHLEHEM	0	500-550	157-180	Massive Bedded Limestone	UC	Bet/Heb	Partly	Low/ Moderate	Partly	Yes
AL TEEN	BETHLEHEM	0	550-600	180-203	Massive Bedded Limestone	UC	Bet/Heb	Partly	Low/ Moderate	Partly	Yes
AL FAWWAR	BETHLEHEM	0	500-550	157-180	Massive Bedded Limestone	UC	Bet/Heb	Partly	Low/ Moderate	Partly	Yes
UM AL DEEK	BETHLEHEM	0	550-600	180-203	Massive Bedded Limestone	UC	Bet/Heb	Partly	Low/ Moderate	Partly	Yes
BAQQAR	HEBRON	0	450-500	134-157	Massive Bedded Limestone	UC	Bet/Heb	Partly	Low/ Moderate	Partly	Yes
BAIT KAHEL	HEBRON	0	450-500	134-157	Massive Bedded Limestone	UC	Bet/Heb	Partly	Low/ Moderate	Partly	Yes
QUF EL SHARQIA	HEBRON	0	450-500	134-157	Massive Bedded Limestone	UC	Bet/Heb	Partly	Low/ Moderate	Partly	Yes
BUSTAN	HEBRON	0	450-500	134-157	Massive Bedded Limestone	UC	Bet/Heb	Partly	Low/ Moderate	Partly	Yes
AL NUQQAR	HEBRON	0	450-500	134-157	Massive Bedded Limestone	UC	Bet/Heb	Partly	Low/ Moderate	Partly	Yes
TAYYUR	HEBRON	0	450-500	134-157	Massive Bedded Limestone	UC	Bet/Heb	Partly	Low/ Moderate	Partly	Yes
AL SA'BIYYAH	HEBRON	0	450-500	134-157	Massive Bedded Limestone	UC	Bet/Heb	Partly	Low/ Moderate	Partly	Yes
AL MA'MUDIYYAH	HEBRON	0	450-500	134-157	Massive Bedded Limestone	UC	Bet/Heb	Partly	Low/ Moderate	Partly	Yes
FAR'AH	HEBRON	0	400-450	111-134	Massive Bedded Limestone	UC	Bet/Heb	Partly	Low/ Moderate	Partly	Yes
KANAR AL GHARBIYYAH	HEBRON	0	400-450	111-134	Massive Bedded Limestone	UC	Bet/Heb	Partly	Low/ Moderate	Partly	Yes
KANAR AL SHARQIYYAH	HEBRON	0	400-450	111-134	Massive Bedded Limestone	UC	Bet/Heb	Partly	Low/ Moderate	Partly	Yes
KANAR WUSTA	HEBRON	0	400-450	111-134	Massive Bedded Limestone	UC	Bet/Heb	Partly	Low/ Moderate	Partly	Yes

Spring Name	Governorate	Depth to Water (m)	Total Measured Rainfall over Direct Recharge Area (mm/year)	Net Recharge (mm/year)	Aquifer Media	Aquifer Pumped	Formation	Significant Area of Soil Cover (≥ 2 m) within Inferred Flowpath (Yes/ Partly/ No)	Topography Slope in Direct Recharge Area	Protective Aquitards in Subsurface (Yes/ Partly/ No)	Karst Feature Observed along Flowpath (Yes/ No)
SHA'BAN AL GHARBIYYA	HEBRON	0	400-450	111-134	Massive Bedded Limestone	UC	Bet/Heb	Partly	Low/ Moderate	Partly	Yes
SET AL RUM	HEBRON	0	400-450	111-134	Massive Bedded Limestone	UC	Bet/Heb	Partly	Low/ Moderate	Partly	Yes
KALLAT DYAB	HEBRON	0	400-450	111-134	Massive Bedded Limestone	UC	Bet/Heb	Partly	Low/ Moderate	Partly	Yes
AL FRAIDEES	HEBRON	0	450-500	134-157	Massive Bedded Limestone	UC	Bet/Heb	Partly	Low/ Moderate	Partly	Yes
JUNAYNAH	HEBRON	0	450-500	134-157	Massive Bedded Limestone	UC	Bet/Heb	Partly	Low/ Moderate	Partly	Yes
'IMRAN NO. 2	HEBRON	0	400-450	111-134	Massive Bedded Limestone	UC	Bet/Heb	Partly	Low/ Moderate	Partly	Yes
'IMRAN NO. 1	HEBRON	0	400-450	111-134	Massive Bedded Limestone	UC	Bet/Heb	Partly	Low/ Moderate	Partly	Yes
ABU KHAIT	HEBRON	0	400-450	111-134	Massive Bedded Limestone	UC	Bet/Heb	Partly	Low/ Moderate	Partly	Yes
AL HEJRAH	HEBRON	0	400-450	111-134	Massive Bedded Limestone	UC	Bet/Heb	Partly	Low/ Moderate	Partly	Yes
DELBAH	HEBRON	0	400-450	111-134	Massive Bedded Limestone	UC	Bet/Heb	Partly	Low/ Moderate	Partly	Yes
AL MAJNUNAH	HEBRON	0	400-450	111-134	Massive Bedded Limestone	UC	Bet/Heb	Partly	Low/ Moderate	Partly	Yes
AL KARMEL	HEBRON	0	350-400	88-111	Massive Bedded Limestone	UC	Bet/Heb	Partly	Low/ Moderate	Partly	Yes

Appendix C: Vulnerability Index Calculations of Wells in the Western Basin Portion Located in the West Bank

Well Name	Governorate	Rating for Parameter D	Weight for Parameter D	Rating for Parameter R	Weight for Parameter R	Rating for Parameter A	Weight for Parameter A	Rating for Parameter S	Weight for Parameter S	Rating for Parameter T	Weight for Parameter T	Rating for Parameter I	Weight for Parameter I	Rating for Parameter K	Weight for Parameter K	V. I.	Category
ABED AL FATTAH MAJD	QALQILIA	3	5	10	4	6	3	6	2	7	1	6	5	10	3	152	H
AZZUN VILLAGE OUNCIL	QALQILIA	1	5	10	4	3	3	6	2	7	1	6	5	10	3	133	M
UDQI SHBAITAH	QALQILIA	1	5	10	4	3	3	6	2	7	1	6	5	10	3	133	M
USEF ANEES AL HILLAH	QALQILIA	3	5	10	4	6	3	6	2	7	1	6	5	10	3	152	H
MUHAMMAD ABU IJLAH	QALQILIA	3	5	10	4	6	3	6	2	7	1	6	5	10	3	152	H
HAREEF ABU HIJLAH 4	QALQILIA	3	5	10	4	6	3	6	2	7	1	6	5	10	3	152	H
MUHAMMAD TAHA ALAMAH	QALQILIA	3	5	10	4	6	3	6	2	7	1	6	5	10	3	152	H
MUHAMMAD AL HAJ USEF	QALQILIA	3	5	10	4	6	3	6	2	7	1	6	5	10	3	152	H
ABED AL KAREEM ABDALLAH	QALQILIA	3	5	10	4	6	3	6	2	7	1	6	5	10	3	152	H
USEF MUHAMMAD OMAR	QALQILIA	3	5	10	4	6	3	6	2	7	1	6	5	10	3	152	H
ADEQ AL SALEM	QALQILIA	3	5	10	4	6	3	6	2	7	1	6	5	10	3	152	H
AMEL AL SALEM	QALQILIA	3	5	10	4	6	3	6	2	7	1	6	5	6	3	140	M
MUHAMMAD AHMAD ALEH	QALQILIA	3	5	10	4	6	3	6	2	7	1	6	5	10	3	152	H
ABED AL RAHMAN ABU ALEH	QALQILIA	3	5	10	4	6	3	6	2	7	1	6	5	10	3	152	H
ARUQ SALEEM AL HAKER	QALQILIA	3	5	10	4	6	3	6	2	7	1	6	5	10	3	152	H
MUHAMMAD QADDURAH & ARTNERS	QALQILIA	3	5	10	4	6	3	6	2	7	1	6	5	10	3	152	H
MUHAMMAD QADDURAH & ARTNERS	QALQILIA	3	5	10	4	6	3	6	2	7	1	6	5	10	3	152	H
MUHAMMAD QADDURAH & ARTNERS	QALQILIA	3	5	10	4	6	3	6	2	7	1	6	5	10	3	152	H
ALEEM 'UDAH & ARTNERS	QALQILIA	3	5	10	4	6	3	6	2	7	1	6	5	10	3	152	H
WASEL AL QASEM	QALQILIA	3	5	10	4	6	3	6	2	7	1	6	5	10	3	152	H
AHMAD QASEM ABU KHARRUB	QALQILIA	3	5	10	4	6	3	6	2	7	1	6	5	10	3	152	H
ABED AL RAHEEM AS'AD JADA'	QALQILIA	3	5	10	4	6	3	6	2	7	1	6	5	10	3	152	H
AHMAD QASEM ABU KHARRUB	QALQILIA	3	5	10	4	6	3	6	2	7	1	6	5	10	3	152	H
AHMAD SHANTI	QALQILIA	3	5	10	4	6	3	6	2	7	1	6	5	10	3	152	H
GHAZI JAMAL AL QASEM	QALQILIA	3	5	10	4	6	3	6	2	7	1	6	5	10	3	152	H
GHAZI JAMAL AL QASEM	QALQILIA	3	5	10	4	6	3	6	2	7	1	6	5	10	3	152	H
ABED AL RAHEEM AS'AD JADA'	QALQILIA	3	5	10	4	6	3	6	2	7	1	6	5	10	3	152	H

Well Name	Governorate	Rating for Parameter D	Weight for Parameter D	Rating for Parameter R	Weight for Parameter R	Rating for Parameter A	Weight for Parameter A	Rating for Parameter S	Weight for Parameter S	Rating for Parameter T	Weight for Parameter T	Rating for Parameter I	Weight for Parameter I	Rating for Parameter K	Weight for Parameter K	V. I.	Category
ABLAH VILLAGE OUNCIL	QALQILIA	3	5	10	4	6	3	6	2	7	1	6	5	10	3	152	H
BRAHEEM ABU AL UZZ	QALQILIA	3	5	10	4	6	3	6	2	7	1	6	5	10	3	152	H
AMEEL AL WALWEEL	QALQILIA	3	5	10	4	6	3	6	2	7	1	6	5	10	3	152	H
LI HASAN ABU ALMAN	QALQILIA	3	5	10	4	6	3	6	2	7	1	6	5	10	3	152	H
AMI 'ABDALLAH USEF	QALQILIA	3	5	10	4	6	3	6	2	7	1	6	5	10	3	152	H
UHAMMAD 'OMAR HALEEL	QALQILIA	3	5	10	4	6	3	6	2	7	1	6	5	10	3	152	H
UTFI 'OMAR	QALQILIA	3	5	10	4	6	3	6	2	7	1	6	5	10	3	152	H
ARNI SHAMRUN	QALQILIA	1	5	10	4	3	3	6	2	7	1	6	5	10	3	133	M
BED AL 'AZEEZ ABU AFIEH & PARTNERS	QALQILIA	3	5	10	4	6	3	6	2	7	1	6	5	10	3	152	H
ASHEED SHANTI	QALQILIA	3	5	10	4	6	3	6	2	7	1	10	5	6	3	160	H
LI IDREES SHANTI	QALQILIA	3	5	10	4	6	3	6	2	7	1	10	5	6	3	160	H
UHAMMAD HADDAD	QALQILIA	3	5	10	4	6	3	6	2	7	1	10	5	6	3	160	H
HMAD ABU HADEEJAH	QALQILIA	3	5	10	4	6	3	6	2	7	1	10	5	6	3	160	H
LI ABU KHADER	QALQILIA	3	5	10	4	6	3	6	2	7	1	10	5	6	3	160	H
HMAD MUHAMMAD BED AL RAHMAN	QALQILIA	3	5	10	4	6	3	6	2	7	1	10	5	6	3	160	H
AHMI 'ABED AL ALAM QADDURAH	QALQILIA	3	5	10	4	6	3	6	2	7	1	10	5	6	3	160	H
BED AL KAREEM UB'AH	QALQILIA	3	5	10	4	6	3	6	2	7	1	10	5	6	3	160	H
BED AL KAREEM UB'AH	QALQILIA	3	5	10	4	6	3	6	2	7	1	10	5	6	3	160	H
USTAFA ABU AL DAL	QALQILIA	3	5	10	4	6	3	6	2	7	1	10	5	6	3	160	H
USTAFA ABU AL DAL	QALQILIA	3	5	10	4	6	3	6	2	7	1	10	5	6	3	160	H
ALEH ABU AL DHURAH	QALQILIA	3	5	10	4	6	3	6	2	7	1	10	5	6	3	160	H
USTAFA NAZZAL & ARTNERS	QALQILIA	3	5	10	4	6	3	6	2	7	1	10	5	6	3	160	H
AFEEQ 'ABAED AL AZEQ	QALQILIA	3	5	10	4	6	3	6	2	7	1	10	5	6	3	160	H
LI ABU 'ULBAH & ARTNERS	QALQILIA	3	5	10	4	6	3	6	2	7	1	10	5	6	3	160	H
BDALLAH UHAMMAD 'ABED AL AHMAN	QALQILIA	3	5	10	4	6	3	6	2	7	1	10	5	6	3	160	H
HAKER AL BARHAM	QALQILIA	3	5	10	4	6	3	6	2	7	1	10	5	6	3	160	H
UHAMMAD SA'EED ARHAM	QALQILIA	3	5	10	4	6	3	6	2	7	1	10	5	6	3	160	H
BED AL RAHEEM AL BED	QALQILIA	3	5	10	4	6	3	6	2	7	1	10	5	6	3	160	H
ALQILYA UNICIPALITY	QALQILIA	3	5	10	4	6	3	6	2	7	1	10	5	6	3	160	H
AHMUD YUSEF TAHA	QALQILIA	3	5	10	4	6	3	6	2	7	1	10	5	6	3	160	H

Well Name	Governorate	Rating for Parameter D	Weight for Parameter D	Rating for Parameter R	Weight for Parameter R	Rating for Parameter A	Weight for Parameter A	Rating for Parameter S	Weight for Parameter S	Rating for Parameter T	Weight for Parameter T	Rating for Parameter I	Weight for Parameter I	Rating for Parameter K	Weight for Parameter K	V. I.	Category
IUSTAFA NAZZAL	QALQILIA	3	5	10	4	6	3	6	2	7	1	10	5	6	3	160	H
BED AL RAHEEM ASAN	QALQILIA	3	5	10	4	6	3	6	2	7	1	10	5	6	3	160	H
USEF HASANAIN HATER	QALQILIA	3	5	10	4	6	3	6	2	7	1	10	5	6	3	160	H
BED AL RAHEEM HALAF	QALQILIA	3	5	10	4	6	3	6	2	7	1	10	5	6	3	160	H
EDA ABU KHADER	QALQILIA	3	5	10	4	6	3	6	2	7	1	10	5	6	3	160	H
UTHMAN AL TABEEB	QALQILIA	3	5	10	4	6	3	6	2	7	1	10	5	6	3	160	H
BRAHEEM ABU AMRAH	QALQILIA	3	5	10	4	6	3	6	2	7	1	10	5	6	3	160	H
BDALLAH GHNAIM	QALQILIA	3	5	10	4	6	3	6	2	7	1	10	5	6	3	160	H
HMAD ABU AL NASER	QALQILIA	3	5	10	4	6	3	6	2	7	1	10	5	6	3	160	H
BDALLAH 'ABED AL AHMAN	QALQILIA	3	5	10	4	6	3	6	2	7	1	10	5	6	3	160	H
IUHAMMAD SA'EED UNES	QALQILIA	3	5	10	4	6	3	6	2	7	1	10	5	6	3	160	H
ALQILYA IUNICIPALITY	QALQILIA	3	5	10	4	6	3	6	2	7	1	10	5	6	3	160	H
LI NAJEEB 'ASHUR	QALQILIA	3	5	10	4	6	3	6	2	7	1	10	5	6	3	160	H
ASAN AL HAJ HASAN	QALQILIA	3	5	10	4	6	3	6	2	7	1	10	5	6	3	160	H
THMAN ABU MARYAM	QALQILIA	3	5	10	4	6	3	6	2	7	1	10	5	6	3	160	H
ADEL KITTANAH & ARTNERS	TULKARM	3	5	10	4	6	3	3	2	7	1	6	5	10	3	146	M
REF 'ABED AL QADER	TULKARM	1	5	10	4	6	3	3	2	7	1	6	5	10	3	136	M
IUHAMMAD MEKKAWI	TULKARM	3	5	10	4	6	3	3	2	7	1	6	5	10	3	146	M
ASHEED SAMARAH & AHSEEN SHADEED	TULKARM	3	5	10	4	6	3	3	2	7	1	6	5	10	3	146	M
IUHAMMAD 'ABED AL AZEQ & PARTNERS	TULKARM	3	5	10	4	6	3	3	2	7	1	6	5	10	3	146	M
AJEEB 'ALI MUSA	TULKARM	3	5	10	4	6	3	3	2	7	1	6	5	10	3	146	M
NABTA IUNICIPALITY	TULKARM	3	5	10	4	6	3	3	2	7	1	6	5	10	3	146	M
NABTA IUNICIPALITY	TULKARM	3	5	10	4	6	3	3	2	7	1	6	5	10	3	146	M
AMEEL 'AWARTANI	TULKARM	3	5	10	4	6	3	3	2	7	1	6	5	10	3	146	M
ASEEB I'MUS	TULKARM	3	5	10	4	6	3	3	2	7	1	6	5	10	3	146	M
ALEH YASEEN AMDAN	TULKARM	3	5	10	4	6	3	3	2	7	1	6	5	10	3	146	M
S'AD RABEE' & ARTNERS	TULKARM	3	5	10	4	6	3	3	2	7	1	6	5	10	3	146	M
TTEEL COOPERATIVE OCIETY	TULKARM	3	5	10	4	6	3	3	2	7	1	6	5	10	3	146	M
IUHAMMAD NEMER ARAKAT	TULKARM	3	5	10	4	6	3	3	2	7	1	6	5	10	3	146	M
AL'A VILLAGE OUNCIL	TULKARM	1	5	10	4	6	3	3	2	7	1	6	5	10	3	136	M
IUHAMMAD KHALAF	TULKARM	3	5	10	4	6	3	3	2	7	1	6	5	10	3	146	M
IUHAMMAD ABU HAMS	TULKARM	3	5	10	4	6	3	3	2	7	1	6	5	10	3	146	M
IUHAMMAD ABU HAMS	TULKARM	3	5	10	4	6	3	3	2	7	1	6	5	10	3	146	M

Well Name	Governorate	Rating for Parameter D	Weight for Parameter D	Rating for Parameter R	Weight for Parameter R	Rating for Parameter A	Weight for Parameter A	Rating for Parameter S	Weight for Parameter S	Rating for Parameter T	Weight for Parameter T	Rating for Parameter I	Weight for Parameter I	Rating for Parameter K	Weight for Parameter K	V. I.	Category
ZEEZ MAS'UD	TULKARM	3	5	10	4	6	3	3	2	7	1	6	5	10	3	146	M
AQER AL SA'ED	TULKARM	3	5	10	4	6	3	3	2	7	1	6	5	10	3	146	M
BED AL MAJEED ASEM	TULKARM	3	5	10	4	6	3	3	2	7	1	10	5	10	3	166	H
AIR AL GHSUN ILLAGE COUNCIL	TULKARM	1	5	10	4	6	3	3	2	7	1	10	5	10	3	156	H
UBAYDAH AL SA'EED	TULKARM	3	5	10	4	6	3	3	2	7	1	6	5	10	3	146	M
ADEEQ JAMUS	TULKARM	3	5	10	4	6	3	3	2	7	1	6	5	10	3	146	M
S'AD TAFFAL & HMAD KHRAISHAH	TULKARM	3	5	10	4	6	3	3	2	7	1	6	5	10	3	146	M
UHAMMAD 'OMAR AFAREENI	TULKARM	3	5	10	4	6	3	3	2	7	1	6	5	10	3	146	M
UHAMMAD 'ABED AL ALEEM	TULKARM	3	5	10	4	6	3	3	2	7	1	6	5	10	3	146	M
UHAMMAD YUSEF MAR	TULKARM	3	5	10	4	6	3	3	2	7	1	6	5	10	3	146	M
SMA'EEL I'TAIR	TULKARM	3	5	10	4	6	3	3	2	7	1	6	5	10	3	146	M
ASFI 'ABED AL AREEM	TULKARM	3	5	10	4	6	3	3	2	7	1	6	5	10	3	146	M
AFEEQ HAMDALLAH	TULKARM	3	5	10	4	6	3	3	2	7	1	6	5	10	3	146	M
HMAD ABU SHANAB & ARTNERS	TULKARM	3	5	10	4	6	3	3	2	7	1	6	5	10	3	146	M
ASAN 'ISA & ARTNERS	TULKARM	3	5	10	4	6	3	3	2	7	1	6	5	10	3	146	M
UHAMMAD AHMAD BU SHANAB	TULKARM	3	5	10	4	6	3	3	2	7	1	6	5	10	3	146	M
AL'EET	TULKARM	3	5	10	4	6	3	3	2	7	1	6	5	10	3	146	M
ASAN MAHMUD HALEEL	TULKARM	3	5	10	4	6	3	3	2	7	1	6	5	10	3	146	M
UHAMMAD KHADER BDALLAH	TULKARM	1	5	10	4	6	3	3	2	7	1	6	5	10	3	136	M
AMEL AL SALEM & ARTNERS	TULKARM	1	5	10	4	3	3	3	2	7	1	6	5	10	3	127	M
UHAMMAD AL TAHER PARTNERS	TULKARM	3	5	10	4	6	3	3	2	7	1	6	5	10	3	146	M
A'FAT AL QUBBAJ	TULKARM	3	5	10	4	6	3	3	2	7	1	6	5	10	3	146	M
AFFEEN VILLAGE OUNCIL	TULKARM	3	5	10	4	8	3	3	2	7	1	10	5	10	3	172	H
HUFA WATER OOPERATIVE OMMITTEE	TULKARM	3	5	10	4	6	3	3	2	7	1	6	5	10	3	146	M
QAB FRAIJ & ARTNERS	TULKARM	3	5	10	4	6	3	3	2	7	1	6	5	10	3	146	M
LI ABU SALEH	TULKARM	3	5	10	4	6	3	3	2	7	1	6	5	10	3	146	M
BED ALRAHMAN ABU ALEH	TULKARM	3	5	10	4	6	3	3	2	7	1	6	5	10	3	146	M
BED AL RAHEEM IER'IB	TULKARM	3	5	10	4	6	3	3	2	7	1	6	5	10	3	146	M
A'EED JABER	TULKARM	3	5	10	4	6	3	3	2	7	1	6	5	10	3	146	M
HAKER SAMARAH	TULKARM	3	5	10	4	6	3	3	2	7	1	6	5	10	3	146	M
BDALLAH SHRAIM & ARTNERS	TULKARM	3	5	10	4	6	3	3	2	7	1	6	5	10	3	146	M

Well Name	Governorate	Rating for Parameter D	Weight for Parameter D	Rating for Parameter R	Weight for Parameter R	Rating for Parameter A	Weight for Parameter A	Rating for Parameter S	Weight for Parameter S	Rating for Parameter T	Weight for Parameter T	Rating for Parameter I	Weight for Parameter I	Rating for Parameter K	Weight for Parameter K	V. I.	Category
ABED ALKAREEM QASEM	TULKARM	3	5	10	4	6	3	3	2	7	1	6	5	10	3	146	M
ASHEED HANNUN & ARTNERS	TULKARM	3	5	10	4	6	3	3	2	7	1	6	5	10	3	146	M
MUHAMMAD SA'EED AMAL	TULKARM	3	5	10	4	6	3	3	2	7	1	6	5	10	3	146	M
HALED SALEEM ANNUN	TULKARM	3	5	10	4	6	3	3	2	7	1	6	5	10	3	146	M
AFEDH LHAMDALLAH	TULKARM	3	5	10	4	6	3	3	2	7	1	6	5	10	3	146	M
ASHEED DHYAB	TULKARM	3	5	10	4	6	3	3	2	7	1	6	5	10	3	146	M
ABED AL RAHEEM ABU AKER	TULKARM	3	5	10	4	6	3	3	2	7	1	6	5	10	3	146	M
OMAR AL KARMI	TULKARM	3	5	10	4	6	3	3	2	7	1	6	5	10	3	146	M
ULKARM MUNICIPALITY	TULKARM	3	5	10	4	6	3	3	2	7	1	6	5	10	3	146	M
ULKARM MUNICIPALITY	TULKARM	3	5	10	4	6	3	3	2	7	1	6	5	10	3	146	M
MUSTAFA AL SA'EED	TULKARM	3	5	10	4	6	3	3	2	7	1	6	5	10	3	146	M
ABED AL QADER QUZMAR	TULKARM	3	5	10	4	6	3	3	2	7	1	6	5	10	3	146	M
L KHADURI GRICULTURAL CHOOL	TULKARM	3	5	10	4	6	3	3	2	7	1	6	5	10	3	146	M
OBSERVATION WELL	TULKARM	3	5	10	4	6	3	3	2	7	1	6	5	10	3	146	M
ULKARM MUNICIPALITY	TULKARM	3	5	10	4	6	3	3	2	7	1	6	5	10	3	146	M
AITA VILLAGE OUNCIL	TULKARM	3	5	10	4	6	3	3	2	7	1	10	5	6	3	154	H
ABED AL JABBAR AMARAH	TULKARM	3	5	10	4	6	3	3	2	7	1	10	5	6	3	154	H
ARIS & RUSHDEE ABU ABHAH	TULKARM	3	5	10	4	6	3	3	2	7	1	10	5	6	3	154	H
AWNI 'ABD AL HADI	JENIN	3	5	10	4	8	3	6	2	7	1	10	5	10	3	178	E
DEEB KITTANAH	JENIN	3	5	10	4	6	3	6	2	7	1	6	5	10	3	152	H
A'BAD MUNICIPALITY	JENIN	1	5	10	4	8	3	3	2	7	1	6	5	10	3	142	M
DAIR SHARAF NO. (looks in Dair Sharaf)	NABLUS	1	5	10	4	6	3	6	2	7	1	6	5	10	3	142	M
DAIR SHARAF NO. 3	NABLUS	1	5	10	4	6	3	6	2	7	1	6	5	10	3	142	M
DAIR SHARAF NO. 2	NABLUS	1	5	10	4	6	3	6	2	7	1	6	5	10	3	142	M
DAIR SHARAF NO. 2A	NABLUS	1	5	10	4	3	3	6	2	7	1	6	5	10	3	133	M
L ZAWYAH WELL	SALFIT	1	5	10	4	6	3	3	2	7	1	6	5	6	3	124	L
ARIS EXPLORATION VELL	SALFIT	1	5	10	4	3	3	6	2	7	1	6	5	10	3	133	M
MARDA WELL	SALFIT	1	5	10	4	6	3	6	2	7	1	6	5	10	3	142	M
RE'AIL	SALFIT	1	5	10	4	3	3	6	2	7	1	6	5	10	3	133	M
DHEEB REDA 'UDAH	SALFIT	1	5	10	4	3	3	6	2	7	1	6	5	10	3	133	M
HEBTEEN NO. 1	RAMALLAH	1	5	10	4	3	3	10	2	5	1	6	5	6	3	127	M
HEBTEEN NO. 2	RAMALLAH	1	5	10	4	3	3	10	2	5	1	6	5	6	3	127	M
HEBTEEN NO. 4	RAMALLAH	1	5	10	4	3	3	10	2	5	1	6	5	6	3	127	M
HEBTEEN No.5	RAMALLAH	3	5	10	4	3	3	10	2	5	1	6	5	6	3	137	M
EBRON NO.4	HEBRON	1	5	5	4	6	3	6	2	7	1	6	5	10	3	122	L

Well Name	Governorate	Rating for Parameter D	Weight for Parameter D	Rating for Parameter R	Weight for Parameter R	Rating for Parameter A	Weight for Parameter A	Rating for Parameter S	Weight for Parameter S	Rating for Parameter T	Weight for Parameter T	Rating for Parameter I	Weight for Parameter I	Rating for Parameter K	Weight for Parameter K	V. I.	Category
EBRON 4	HEBRON	1	5	5	4	6	3	6	2	7	1	10	5	10	3	142	M
L FAWWAR - HEBRON IUNICIPALITY O.1C(2)	HEBRON	1	5	5	4	6	3	6	2	7	1	10	5	10	3	142	M
L FAWWAR - HEBRON IUNICIPALITY NO. 3	HEBRON	1	5	5	4	6	3	6	2	7	1	10	5	10	3	142	M
L REEHIYYAH	HEBRON	3	5	5	4	10	3	6	2	7	1	6	5	10	3	144	M
L SAMU' NO.1	HEBRON	1	5	5	4	10	3	6	2	7	1	6	5	10	3	134	M

Appendix D: Vulnerability Index Calculations of Springs in the Western Basin Portion Located in the West Bank

Spring Name	Governorate	Rating for Parameter D	Weight for Parameter D	Rating for Parameter R	Weight for Parameter R	Rating for Parameter A	Weight for Parameter A	Rating for Parameter S	Weight for Parameter S	Rating for Parameter T	Weight for Parameter T	Rating for Parameter I	Weight for Parameter I	Rating for Parameter K	Weight for Parameter K	V. I.	Category
AFFET 'UDAH	NABLUS	10	5	10	4	6	3	6	2	7	1	6	5	10	3	187	E
L FAWWAR	NABLUS	10	5	10	4	6	3	6	2	7	1	6	5	10	3	187	E
L JUZAH	NABLUS	10	5	10	4	6	3	6	2	7	1	6	5	10	3	187	E
L BASSAH	NABLUS	10	5	10	4	6	3	6	2	7	1	6	5	10	3	187	E
L MAQYUDAH	NABLUS	10	5	10	4	6	3	6	2	7	1	6	5	10	3	187	E
L MATWI	SALFIT	10	5	10	4	6	3	6	2	7	1	6	5	10	3	187	E
HAMIYYAH	SALFIT	10	5	10	4	6	3	6	2	7	1	6	5	10	3	187	E
L SHALLAL	SALFIT	10	5	10	4	6	3	6	2	7	1	6	5	10	3	187	E
ADAS	SALFIT	10	5	10	4	6	3	6	2	7	1	6	5	10	3	187	E
L FAWWARA	SALFIT	10	5	10	4	6	3	6	2	7	1	6	5	10	3	187	E
l Balad/Ibwein	RAMALLAH	10	5	10	4	6	3	10	2	5	1	6	5	10	3	193	E
L SUFLA	RAMALLAH	10	5	10	4	6	3	10	2	5	1	6	5	10	3	193	E
l Balad/Arura	RAMALLAH	10	5	10	4	6	3	10	2	5	1	6	5	10	3	193	E
AQLAH	RAMALLAH	10	5	10	4	6	3	10	2	5	1	6	5	10	3	193	E
BU FAYYAD	RAMALLAH	10	5	10	4	6	3	10	2	5	1	6	5	10	3	193	E
L DAIR	RAMALLAH	10	5	10	4	6	3	10	2	5	1	6	5	10	3	193	E
AFER	RAMALLAH	10	5	10	4	6	3	10	2	5	1	6	5	10	3	193	E
ARAWAH	RAMALLAH	10	5	10	4	6	3	10	2	5	1	6	5	10	3	193	E
AYYA	RAMALLAH	10	5	10	4	6	3	10	2	5	1	6	5	10	3	193	E
AYYA AL FUQA	RAMALLAH	10	5	10	4	6	3	10	2	5	1	6	5	10	3	193	E
ELBAH & LAQTAN	RAMALLAH	10	5	10	4	6	3	10	2	5	1	6	5	10	3	193	E
igtan *	RAMALLAH	10	5	10	4	6	3	10	2	5	1	6	5	10	3	193	E
ilba *	RAMALLAH	10	5	10	4	6	3	10	2	5	1	6	5	10	3	193	E
ARQA	RAMALLAH	10	5	10	4	6	3	10	2	5	1	6	5	10	3	193	E
L MGHARAH	RAMALLAH	10	5	10	4	6	3	10	2	5	1	6	5	10	3	193	E
L 'ALAM	RAMALLAH	10	5	10	4	6	3	10	2	5	1	6	5	10	3	193	E
L QUS (Qaus)	RAMALLAH	10	5	10	4	6	3	10	2	5	1	6	5	10	3	193	E
UBAR	RAMALLAH	10	5	10	4	6	3	10	2	5	1	6	5	10	3	193	E
L ZARQAH	RAMALLAH	10	5	10	4	6	3	10	2	5	1	6	5	10	3	193	E
L ZARQAH AL TEHTA	RAMALLAH	10	5	10	4	6	3	10	2	5	1	6	5	10	3	193	E
L QWAIQBAH	RAMALLAH	10	5	10	4	6	3	10	2	5	1	6	5	10	3	193	E
KARI	RAMALLAH	10	5	10	4	6	3	10	2	5	1	6	5	10	3	193	E
L BALAD	RAMALLAH	10	5	10	4	6	3	10	2	5	1	6	5	10	3	193	E
L QUS	RAMALLAH	10	5	10	4	6	3	10	2	5	1	6	5	10	3	193	E
HAKARYA	RAMALLAH	10	5	10	4	6	3	10	2	5	1	6	5	10	3	193	E
AIR 'AMMAR	RAMALLAH	10	5	10	4	6	3	10	2	5	1	6	5	10	3	193	E
L BALAD	RAMALLAH	10	5	10	4	6	3	10	2	5	1	6	5	10	3	193	E
AREEK AL FUQA	RAMALLAH	10	5	10	4	6	3	10	2	5	1	6	5	10	3	193	E
AREEK AL TEHTA	RAMALLAH	10	5	10	4	6	3	10	2	5	1	6	5	10	3	193	E
L JARYUT	RAMALLAH	10	5	10	4	6	3	10	2	5	1	6	5	10	3	193	E
AIT SUREEK	RAMALLAH	10	5	10	4	6	3	10	2	5	1	6	5	10	3	193	E
L THARWANI	RAMALLAH	10	5	10	4	6	3	6	2	7	1	6	5	10	3	187	E
AIT DUQQU	JERUSALEM	10	5	10	4	6	3	6	2	7	1	6	5	10	3	187	E
ANAN	JERUSALEM	10	5	10	4	6	3	6	2	7	1	6	5	10	3	187	E
L BALAD	JERUSALEM	10	5	10	4	6	3	6	2	7	1	6	5	10	3	187	E
ATTEER	BETHLEHEM	10	5	10	4	6	3	6	2	7	1	6	5	10	3	187	E
L JAME'	BETHLEHEM	10	5	10	4	6	3	6	2	7	1	6	5	10	3	187	E

Spring Name	Governorate	Rating for Parameter D	Weight for Parameter D	Rating for Parameter R	Weight for Parameter R	Rating for Parameter A	Weight for Parameter A	Rating for Parameter S	Weight for Parameter S	Rating for Parameter T	Weight for Parameter T	Rating for Parameter I	Weight for Parameter I	Rating for Parameter K	Weight for Parameter K	V. I.	Category
L 'AMUD	BETHLEHEM	10	5	10	4	6	3	6	2	7	1	6	5	10	3	187	E
L SKHUNAH	BETHLEHEM	10	5	10	4	6	3	6	2	7	1	6	5	10	3	187	E
JDAH	BETHLEHEM	10	5	10	4	6	3	6	2	7	1	6	5	10	3	187	E
ERKAT URF	BETHLEHEM	10	5	10	4	6	3	6	2	7	1	6	5	10	3	187	E
L KAREESAH	BETHLEHEM	10	5	10	4	6	3	6	2	7	1	6	5	10	3	187	E
L NAMUS	BETHLEHEM	10	5	10	4	6	3	6	2	7	1	6	5	10	3	187	E
l Balad/ Nahalin	BETHLEHEM	10	5	10	4	6	3	6	2	7	1	6	5	10	3	187	E
ARES	BETHLEHEM	10	5	10	4	6	3	6	2	7	1	6	5	10	3	187	E
l Balad/ Wadi Fukin	BETHLEHEM	10	5	10	4	6	3	6	2	7	1	6	5	10	3	187	E
L MAGHARAH	BETHLEHEM	10	5	10	4	6	3	6	2	7	1	6	5	10	3	187	E
L JURAH	BETHLEHEM	10	5	10	4	6	3	6	2	7	1	6	5	10	3	187	E
UBA	BETHLEHEM	10	5	10	4	6	3	6	2	7	1	6	5	10	3	187	E
ADEEQ	BETHLEHEM	10	5	10	4	6	3	6	2	7	1	6	5	10	3	187	E
L TEEN	BETHLEHEM	10	5	10	4	6	3	6	2	7	1	6	5	10	3	187	E
L FAWWAR	BETHLEHEM	10	5	10	4	6	3	6	2	7	1	6	5	10	3	187	E
M AL DEEK	BETHLEHEM	10	5	10	4	6	3	6	2	7	1	6	5	10	3	187	E
AQQAR	HEBRON	10	5	5	4	6	3	6	2	7	1	6	5	10	3	167	H
AIT KAHEL	HEBRON	10	5	5	4	6	3	6	2	7	1	6	5	10	3	167	H
UF EL SHARQIA	HEBRON	10	5	5	4	6	3	6	2	7	1	6	5	10	3	167	H
USTAN	HEBRON	10	5	5	4	6	3	6	2	7	1	6	5	10	3	167	H
L NUQQAR	HEBRON	10	5	5	4	6	3	6	2	7	1	6	5	10	3	167	H
AYYUR	HEBRON	10	5	5	4	6	3	6	2	7	1	6	5	10	3	167	H
L SA'BIYYAH	HEBRON	10	5	5	4	6	3	6	2	7	1	6	5	10	3	167	H
L MA'MUDIYYAH	HEBRON	10	5	5	4	6	3	6	2	7	1	6	5	10	3	167	H
AR'AH	HEBRON	10	5	5	4	6	3	6	2	7	1	6	5	10	3	167	H
ANAR AL HARBIYYAH	HEBRON	10	5	5	4	6	3	6	2	7	1	6	5	10	3	167	H
ANAR AL HARQIYYAH	HEBRON	10	5	5	4	6	3	6	2	7	1	6	5	10	3	167	H
ANAR WUSTA	HEBRON	10	5	5	4	6	3	6	2	7	1	6	5	10	3	167	H
HA'BAN AL HARBIYYA	HEBRON	10	5	5	4	6	3	6	2	7	1	6	5	10	3	167	H
ET AL RUM	HEBRON	10	5	5	4	6	3	6	2	7	1	6	5	10	3	167	H
ALLAT DYAB	HEBRON	10	5	5	4	6	3	6	2	7	1	6	5	10	3	167	H
L FRAIDEES	HEBRON	10	5	5	4	6	3	6	2	7	1	6	5	10	3	167	H
UNAYNAH	HEBRON	10	5	5	4	6	3	6	2	7	1	6	5	10	3	167	H
MRAN NO. 2	HEBRON	10	5	5	4	6	3	6	2	7	1	6	5	10	3	167	H
MRAN NO. 1	HEBRON	10	5	5	4	6	3	6	2	7	1	6	5	10	3	167	H
BU KHAIT	HEBRON	10	5	5	4	6	3	6	2	7	1	6	5	10	3	167	H
L HEJRAH	HEBRON	10	5	5	4	6	3	6	2	7	1	6	5	10	3	167	H
ELBAH	HEBRON	10	5	5	4	6	3	6	2	7	1	6	5	10	3	167	H
L MAJNUNAH	HEBRON	10	5	5	4	6	3	6	2	7	1	6	5	10	3	167	H

Appendix E: Wells (in the Research Area) discharging from Perched Water of the Upper Cenomanian-Turonian Aquifer

Well Name	Locality	Governorate	Formation	Aquifer
HEBRON NO.4	Abu Al'asja	Hebron	Bethlehem/Hebron	Upper Cenomanian
HEBRON 4	Al Fawwar	Hebron	Bethlehem/Hebron	Upper Cenomanian
AL THARWANI	Yatta	Hebron	Bethlehem/Hebron	Upper Cenomanian
ADEEB KITTANAH	Al Nazlah Al Sharqiyyah	Jenin	Bethlehem/Hebron	Upper Cenomanian
DAIR SHARAF NO. 3	Dair Sharaf	Nablus	Bethlehem/Hebron	Upper Cenomanian
DAIR SHARAF NO. 2	Dair Sharaf	Nablus	Bethlehem/Hebron	Upper Cenomanian
DAIR SHARAF NO. 1	Bait Iba	Nablus	Bethlehem/Hebron	Upper Cenomanian
MUHAMMAD QADDURAH & PARTNERS	Habla	Qalqilia	Bethlehem/Hebron	Upper Cenomanian
MUHAMMAD QADDURAH & PARTNERS	Habla	Qalqilia	Bethlehem/Hebron	Upper Cenomanian
MUHAMMAD QADDURAH & PARTNERS	Habla	Qalqilia	Bethlehem/Hebron	Upper Cenomanian
SALEEM 'UDAH & PARTNERS	Habla	Qalqilia	Bethlehem/Hebron	Upper Cenomanian
WASEL AL QASEM	Habla	Qalqilia	Bethlehem/Hebron	Upper Cenomanian
AHMAD QASEM ABU KHARRUB	Habla	Qalqilia	Bethlehem/Hebron	Upper Cenomanian
'ABED AL RAHEEM AS'AD JADA'	Habla	Qalqilia	Bethlehem/Hebron	Upper Cenomanian
AHMAD QASEM ABU KHARRUB	Habla	Qalqilia	Bethlehem/Hebron	Upper Cenomanian
AHMAD SHANTI	Habla	Qalqilia	Bethlehem/Hebron	Upper Cenomanian
RASHEED SHANTI	Qalqilia	Qalqilia	Bethlehem/Hebron	Upper Cenomanian
'ALI IDREES SHANTI	Qalqilia	Qalqilia	Bethlehem/Hebron	Upper Cenomanian
GHAZI JAMAL AL QASEM	Habla	Qalqilia	Bethlehem/Hebron	Upper Cenomanian
GHAZI JAMAL AL QASEM	Habla	Qalqilia	Bethlehem/Hebron	Upper Cenomanian
MUHAMMAD HADDAD	Qalqilia	Qalqilia	Bethlehem/Hebron	Upper Cenomanian
'ABED AL RAHEEM AS'AD JADA'	Habla	Qalqilia	Bethlehem/Hebron	Upper Cenomanian
AHMAD ABU KHADEEJAH	Qalqilia	Qalqilia	Bethlehem/Hebron	Upper Cenomanian
'ALI ABU KHADER	Qalqilia	Qalqilia	Bethlehem/Hebron	Upper Cenomanian
AHMAD MUHAMMAD 'ABED AL RAHMAN	Qalqilia	Qalqilia	Bethlehem/Hebron	Upper Cenomanian
FAHMI 'ABED AL SALAM QADDURAH	Qalqilia	Qalqilia	Bethlehem/Hebron	Upper Cenomanian
'ABED AL KAREEM QUB'AH	Qalqilia	Qalqilia	Bethlehem/Hebron	Upper Cenomanian
'ABED AL KAREEM QUB'AH	Qalqilia	Qalqilia	Bethlehem/Hebron	Upper Cenomanian
MUSTAFA ABU AL 'ADAL	Qalqilia	Qalqilia	Bethlehem/Hebron	Upper Cenomanian
MUSTAFA ABU AL 'ADAL	Qalqilia	Qalqilia	Bethlehem/Hebron	Upper Cenomanian
SALEH ABU AL DHURAH	Qalqilia	Qalqilia	Bethlehem/Hebron	Upper Cenomanian
MUSTAFA NAZZAL & PARTNERS	Qalqilia	Qalqilia	Bethlehem/Hebron	Upper Cenomanian
RAFEEQ 'ABAED AL RAZEQ	Qalqilia	Qalqilia	Bethlehem/Hebron	Upper Cenomanian
'ALI ABU 'ULBAH & PARTNERS	Qalqilia	Qalqilia	Bethlehem/Hebron	Upper Cenomanian
'ABDALLAH MUHAMMAD 'ABED AL RAHMAN	Qalqilia	Qalqilia	Bethlehem/Hebron	Upper Cenomanian
SHAKER AL BARHAM	Qalqilia	Qalqilia	Bethlehem/Hebron	Upper Cenomanian
MUHAMMAD SA'EED BARHAM	Qalqilia	Qalqilia	Bethlehem/Hebron	Upper Cenomanian
'ABED AL RAHEEM AL 'ABED	Qalqilia	Qalqilia	Bethlehem/Hebron	Upper Cenomanian
QALQILYA MUNICIPALITY	Qalqilia	Qalqilia	Bethlehem/Hebron	Upper Cenomanian
MAHMUD YUSEF TAHA	Qalqilia	Qalqilia	Bethlehem/Hebron	Upper Cenomanian
MUSTAFA NAZZAL	Qalqilia	Qalqilia	Bethlehem/Hebron	Upper Cenomanian
'ABED AL RAHEEM HASAN	Qalqilia	Qalqilia	Bethlehem/Hebron	Upper Cenomanian
YUSEF HASANAIN KHATER	Qalqilia	Qalqilia	Bethlehem/Hebron	Upper Cenomanian
'ABED AL RAHEEM KHALAF	Qalqilia	Qalqilia	Bethlehem/Hebron	Upper Cenomanian
REDA ABU KHADER	Qalqilia	Qalqilia	Bethlehem/Hebron	Upper Cenomanian
'UTHMAN AL TABEEB	Qalqilia	Qalqilia	Bethlehem/Hebron	Upper Cenomanian
IBRAHEEM ABU AL RUZZ	Izbat Abu Salman	Qalqilia	Bethlehem/Hebron	Upper Cenomanian
JAMEEL AL WALWEEL	Izbat Abu Salman	Qalqilia	Bethlehem/Hebron	Upper Cenomanian
IBRAHEEM ABU SAMRAH	Qalqilia	Qalqilia	Bethlehem/Hebron	Upper Cenomanian
'ABDALLAH GHNAIM	Qalqilia	Qalqilia	Bethlehem/Hebron	Upper Cenomanian

Well Name	Locality	Governorate	Formation	Aquifer
AHMAD ABU AL NASER	Qalqilia	Qalqilia	Bethlehem/Hebron	Upper Cenomanian
'ABDALLAH 'ABED AL RAHMAN	Qalqilia	Qalqilia	Bethlehem/Hebron	Upper Cenomanian
MUHAMMAD SA'EED YUNES	Qalqilia	Qalqilia	Bethlehem/Hebron	Upper Cenomanian
QALQILYA MUNICIPALITY	Qalqilia	Qalqilia	Bethlehem/Hebron	Upper Cenomanian
HABLAH VILLAGE COUNCIL	Habla	Qalqilia	Bethlehem/Hebron	Upper Cenomanian
YUSEF ANEES AL SHILLAH	Azzun Al 'Atmah	Qalqilia	Bethlehem/Hebron	Upper Cenomanian
MUHAMMAD ABU HIJLAH	Azzun Al 'Atmah	Qalqilia	Bethlehem/Hebron	Upper Cenomanian
SHAREEF ABU HIJLAH 4	Azzun Al 'Atmah	Qalqilia	Bethlehem/Hebron	Upper Cenomanian
'ABED AL FATTAH MAJD	An Nabielyas	Qalqilia	Bethlehem/Hebron	Upper Cenomanian
MUHAMMAD TAHA SALAMAH	Azzun Al 'Atmah	Qalqilia	Bethlehem/Hebron	Upper Cenomanian
'ALI NAJEEB 'ASHUR	Qalqilia	Qalqilia	Bethlehem/Hebron	Upper Cenomanian
HASAN AL HAJ HASAN	Qalqilia	Qalqilia	Bethlehem/Hebron	Upper Cenomanian
SAMI 'ABDALLAH YUSEF	Jauus	Qalqilia	Bethlehem/Hebron	Upper Cenomanian
MUHAMMAD 'OMAR KHALEEL	Jauus	Qalqilia	Bethlehem/Hebron	Upper Cenomanian
'ABED AL 'AZEEZ ABU SAFIEH & PARTNERS	Kh. Al Mudawwar	Qalqilia	Bethlehem/Hebron	Upper Cenomanian
'ABED AL KAREEM 'ABDALLAH	Beit Amin	Qalqilia	Bethlehem/Hebron	Upper Cenomanian
'ALI HASAN ABU SALMAN	Izbat Abu Salman	Qalqilia	Bethlehem/Hebron	Upper Cenomanian
'OTHMAN ABU MARYAM	Qalqilia	Qalqilia	Bethlehem/Hebron	Upper Cenomanian
MUHAMMAD AL HAJ YUSEF	Azzun Al 'Atmah	Qalqilia	Bethlehem/Hebron	Upper Cenomanian
YUSEF MUHAMMAD 'OMAR	Beit Amin	Qalqilia	Bethlehem/Hebron	Upper Cenomanian
SADEQ AL SALEM	Falamya	Qalqilia	Bethlehem/Hebron	Upper Cenomanian
LUTFI 'OMAR	Jauus	Qalqilia	Bethlehem/Hebron	Upper Cenomanian
KAMEL AL SALEM	Falamya	Qalqilia	Bethlehem/Hebron	Upper Cenomanian
MUHAMMAD AHMAD SALEH	Falamya	Qalqilia	Bethlehem/Hebron	Upper Cenomanian
'ABED AL RAHMAN ABU SALEH	Falamya	Qalqilia	Bethlehem/Hebron	Upper Cenomanian
FARUQ SALEEM AL SHAKER	Falamya	Qalqilia	Bethlehem/Hebron	Upper Cenomanian
AL ZAWYAH WELL	Al Zawyah	Salfit	Bethlehem/Hebron	Upper Cenomanian
MUHAMMAD 'ABED AL HALEEM	Far'un	Tulkarm	Bethlehem/Hebron	Upper Cenomanian
MUHAMMAD YUSEF 'OMAR	Far'un	Tulkarm	Bethlehem/Hebron	Upper Cenomanian
ISMA'EEL I'TAIR	Far'un	Tulkarm	Bethlehem/Hebron	Upper Cenomanian
AHMAD ABU SHANAB & PARTNERS	Irtah	Tulkarm	Bethlehem/Hebron	Upper Cenomanian
HASAN 'ISA & PARTNERS	Irtah	Tulkarm	Bethlehem/Hebron	Upper Cenomanian
MUHAMMAD KHADER 'ABDALLAH	Kufur Jammal	Tulkarm	Bethlehem/Hebron	Upper Cenomanian
'ABDALLAH SHRAIM & PARTNERS	Tulkarm	Tulkarm	Bethlehem/Hebron	Upper Cenomanian
'ABED ALKAREEM QASEM	Tulkarm	Tulkarm	Bethlehem/Hebron	Upper Cenomanian
RASHEED HANNUN & PARTNERS	Tulkarm	Tulkarm	Bethlehem/Hebron	Upper Cenomanian
WASFI 'ABED AL KAREEM	Far'un	Tulkarm	Bethlehem/Hebron	Upper Cenomanian
'AREF 'ABED AL QADER	Al Ras	Tulkarm	Bethlehem/Hebron	Upper Cenomanian
MUHAMMAD AHMAD ABU SHANAB	Irtah	Tulkarm	Bethlehem/Hebron	Upper Cenomanian
SAL'EET	Kufr Sour	Tulkarm	Bethlehem/Hebron	Upper Cenomanian
MUHAMMAD SA'EED KAMAL	Tulkarm	Tulkarm	Bethlehem/Hebron	Upper Cenomanian
KHALED SALEEM HANNUN	Tulkarm	Tulkarm	Bethlehem/Hebron	Upper Cenomanian
I'QAB FRAIJ & PARTNERS	Shwaikah	Tulkarm	Bethlehem/Hebron	Upper Cenomanian
RA'FAT AL QUBBAJ	Nur Shams	Tulkarm	Bethlehem/Hebron	Upper Cenomanian
NAJEEB 'ALI MUSA	Anabta	Tulkarm	Bethlehem/Hebron	Upper Cenomanian
ZUBAYDAH AL SA'EED	Dhinnabah	Tulkarm	Bethlehem/Hebron	Upper Cenomanian
HAFEDH ALHAMDALLAH	Tulkarm	Tulkarm	Bethlehem/Hebron	Upper Cenomanian
RASHEED DHYAB	Tulkarm	Tulkarm	Bethlehem/Hebron	Upper Cenomanian
'ABED AL RAHEEM ABU BAKER	Tulkarm	Tulkarm	Bethlehem/Hebron	Upper Cenomanian
'OMAR AL KARMI	Tulkarm	Tulkarm	Bethlehem/Hebron	Upper Cenomanian
MUSTAFA AL SA'EED	Tulkarm	Tulkarm	Bethlehem/Hebron	Upper Cenomanian
'ABED AL QADER QUZMAR	Tulkarm	Tulkarm	Bethlehem/Hebron	Upper Cenomanian

Well Name	Locality	Governorate	Formation	Aquifer
HASAN MAHMUD KHALEEL	Kufur Al Labad	Tulkarm	Bethlehem/Hebron	Upper Cenomanian
'ABED AL MAJEED QASEM	Dair Al Ghsun	Tulkarm	Bethlehem/Hebron	Upper Cenomanian
SADEEQ JAMUS	Dhinnabah	Tulkarm	Bethlehem/Hebron	Upper Cenomanian
'ATTEEL COOPERATIVE SOCIETY	Atteel	Tulkarm	Bethlehem/Hebron	Upper Cenomanian
AS'AD TAFFAL & AHMAD KHRAISHAH	Dhinnabah	Tulkarm	Bethlehem/Hebron	Upper Cenomanian
MUHAMMAD 'OMAR SAFAREENI	Dhinnabah	Tulkarm	Bethlehem/Hebron	Upper Cenomanian
RAFEEQ HAMDALLAH	Iktabah	Tulkarm	Bethlehem/Hebron	Upper Cenomanian
OBSERVATION WELL	Tulkarm	Tulkarm	Bethlehem/Hebron	Upper Cenomanian
DAIR AL GHSUN VILLAGE COUNCIL	Dair Al Ghsun	Tulkarm	Bethlehem/Hebron	Upper Cenomanian
MUHAMMAD AL TAHER & PARTNERS	Nazlet 'Isa	Tulkarm	Bethlehem/Hebron	Upper Cenomanian
JAMEEL 'AWARTANI	Anabta	Tulkarm	Bethlehem/Hebron	Upper Cenomanian
TULKARM MUNICIPALITY	Tulkarm	Tulkarm	Jer/Bet/Heb	Upper Cenomanian
AL REEHIYYAH	Al Reehiyyah	Hebron	Jerusalem	Turonian
'ALI ABU SALEH	Shwaikah	Tulkarm	Jerusalem	Upper Cenomanian
'ABED ALRAHMAN ABU SALEH	Shwaikah	Tulkarm	Jerusalem	Turonian
'ABED AL RAHEEM MER'IB	Shwaikah	Tulkarm	Jerusalem	Upper Cenomanian
AL KHADURI AGRICULTURAL SCHOOL	Shwaikah	Tulkarm	Jerusalem	Upper Cenomanian
AL FAWWAR - HEBRON MUNICIPALITY NO.1C(2)	Al Fawwar	Hebron	Jerusalem/Bethlehem/Hebron	Upper Cenomanian
AL FAWWAR - HEBRON MUNICIPALITY NO. 3	Al Fawwar	Hebron	Jerusalem/Bethlehem/Hebron	Upper Cenomanian
'AWNI 'ABD AL HADI	Qaffeen	Jenin	Jerusalem/Bethlehem/Hebron	Upper Cenomanian-Turonian
YA'BAD MUNICIPALITY	Ya'bad	Jenin	Jerusalem/Bethlehem/Hebron	Upper Cenomanian-Turonian
MARDA WELL	Marda	Salfit	Jerusalem/Bethlehem/Hebron	Upper Cenomanian
SHUFA WATER COOPERATIVE COMMITTEE	Shufah	Tulkarm	Jerusalem/Bethlehem/Hebron	Upper Cenomanian
ZAITA VILLAGE COUNCIL	Zaita	Tulkarm	Jerusalem/Bethlehem/Hebron	Upper Cenomanian
'ABED AL JABBAR SAMARAH	Zaita	Tulkarm	Jerusalem/Bethlehem/Hebron	Upper Cenomanian
TULKARM MUNICIPALITY	Tulkarm	Tulkarm	Jerusalem/Bethlehem/Hebron	Upper Cenomanian
TULKARM MUNICIPALITY	Tulkarm	Tulkarm	Jerusalem/Bethlehem/Hebron	Upper Cenomanian
HASEEB I'MUS	Atteel	Tulkarm	Jerusalem/Bethlehem/Hebron	Upper Cenomanian
MUHAMMAD MEKKAWI	Allar	Tulkarm	Jerusalem/Bethlehem/Hebron	Upper Cenomanian
RASHEED SAMARAH & TAHSEEN SHADEED	Allar	Tulkarm	Jerusalem/Bethlehem/Hebron	Upper Cenomanian
FARIS & RUSHDEE ABU SABHAH	Zaita	Tulkarm	Jerusalem/Bethlehem/Hebron	Upper Cenomanian
SALEH YASEEN HAMDAN	Atteel	Tulkarm	Jerusalem/Bethlehem/Hebron	Upper Cenomanian
SA'EED JABER	Shwaikah	Tulkarm	Jerusalem/Bethlehem/Hebron	Upper Cenomanian
AS'AD RABEE' & PARTNERS	Atteel	Tulkarm	Jerusalem/Bethlehem/Hebron	Upper Cenomanian
MUHAMMAD NEMER BARAKAT	Atteel	Tulkarm	Jerusalem/Bethlehem/Hebron	Upper Cenomanian
MUHAMMAD 'ABED AL RAZEQ & PARTNERS	Allar	Tulkarm	Jerusalem/Bethlehem/Hebron	Upper Cenomanian
SHAKER SAMARAH	Shwaikah	Tulkarm	Jerusalem/Bethlehem/Hebron	Upper Cenomanian
BAL'A VILLAGE COUNCIL	Bal'a	Tulkarm	Jerusalem/Bethlehem/Hebron	Upper Cenomanian
MUHAMMAD KHALAF	Baqah Al Sharqiyyah	Tulkarm	Jerusalem/Bethlehem/Hebron	Upper Cenomanian
MUHAMMAD ABU SHAMS	Baqah Al Sharqiyyah	Tulkarm	Jerusalem/Bethlehem/Hebron	Upper Cenomanian
MUHAMMAD ABU SHAMS	Baqah Al Sharqiyyah	Tulkarm	Jerusalem/Bethlehem/Hebron	Upper Cenomanian
FADEL KITTANAH & PARTNERS	Al Nazalh Al Gharbiyyah	Tulkarm	Jerusalem/Bethlehem/Hebron	Upper Cenomanian
'AZEEZ MAS'UD	Baqah Al Sharqiyyah	Tulkarm	Jerusalem/Bethlehem/Hebron	Upper Cenomanian
SAQER AL SA'ED	Baqah Al Sharqiyyah	Tulkarm	Jerusalem/Bethlehem/Hebron	Upper Cenomanian
QAFFEEN VILLAGE COUNCIL	Qaffeen	Tulkarm	Jerusalem/Bethlehem/Hebron	Upper Cenomanian-Turonian
'ANABTA MUNICIPALITY	Anabta	Tulkarm	Jerusalem/Bethlehem/Hebron	Upper Cenomanian
'ANABTA MUNICIPALITY	Anabta	Tulkarm	Jerusalem/Bethlehem/Hebron	Upper Cenomanian

Appendix F: Springs (in the Research Area) discharging from Perched Water of the Upper Cenomanian-Turonian Aquifer

Spring Name	Locality	Governorate	Formation	Aquifer
BATTEER	Batteer	Bethlehem	Bethlehem/Hebron	Upper Cenomanian
AL JAME'	Batteer	Bethlehem	Bethlehem/Hebron	Upper Cenomanian
AL 'AMUD	Husan	Bethlehem	Bethlehem/Hebron	Upper Cenomanian
AL SKHUNAH	Husan	Bethlehem	Bethlehem/Hebron	Upper Cenomanian
'UDAH	Husan	Bethlehem	Bethlehem/Hebron	Upper Cenomanian
BERKAT URF	Husan	Bethlehem	Bethlehem/Hebron	Upper Cenomanian
AL KAREESAH	Husan	Bethlehem	Bethlehem/Hebron	Upper Cenomanian
AL NAMUS	Husan	Bethlehem	Bethlehem/Hebron	Upper Cenomanian
El Balad/ Nahalin	Nahhaleen	Bethlehem	Bethlehem/Hebron	Upper Cenomanian
FARES	Nahhaleen	Bethlehem	Bethlehem/Hebron	Upper Cenomanian
El Balad/ Wadi Fukin	Wadi Fukeen	Bethlehem	Bethlehem/Hebron	Upper Cenomanian
AL MAGHARAH	Wadi Fukeen	Bethlehem	Bethlehem/Hebron	Upper Cenomanian
AL JURAH	Wadi Fukeen	Bethlehem	Bethlehem/Hebron	Upper Cenomanian
SUBA	Wadi Fukeen	Bethlehem	Bethlehem/Hebron	Upper Cenomanian
SADEEQ	Wadi Fukeen	Bethlehem	Bethlehem/Hebron	Upper Cenomanian
AL TEEN	Wadi Fukeen	Bethlehem	Bethlehem/Hebron	Upper Cenomanian
AL FAWWAR	Wadi Fukeen	Bethlehem	Bethlehem/Hebron	Upper Cenomanian
UM AL DEEK	Wadi Fukeen	Bethlehem	Bethlehem/Hebron	Upper Cenomanian
BAQQAR	Halhul	Hebron	Bethlehem/Hebron	Upper Cenomanian
BAIT KAHEL	Beit Kahil	Hebron	Bethlehem/Hebron	Upper Cenomanian
QUF EL SHARQIA	Beit Kahil	Hebron	Bethlehem/Hebron	Upper Cenomanian
BUSTAN	Taffuh	Hebron	Bethlehem/Hebron	Upper Cenomanian
AL NUQQAR	Dura	Hebron	Bethlehem/Hebron	Upper Cenomanian
TAYYUR	Dura	Hebron	Bethlehem/Hebron	Upper Cenomanian
AL SA'BIYYAH	Dura	Hebron	Bethlehem/Hebron	Upper Cenomanian
AL MA'MUDIYYAH	Dura	Hebron	Bethlehem/Hebron	Upper Cenomanian
FAR'AH	Dura	Hebron	Bethlehem/Hebron	Upper Cenomanian
KANAR AL GHARBIYYAH	Dura	Hebron	Bethlehem/Hebron	Upper Cenomanian
KANAR AL SHARQIYYAH	Dura	Hebron	Bethlehem/Hebron	Upper Cenomanian
KANAR WUSTA	Dura	Hebron	Bethlehem/Hebron	Upper Cenomanian
SHA'BAN AL GHARBIYYA	Dura	Hebron	Bethlehem/Hebron	Upper Cenomanian
SET AL RUM	Dura	Hebron	Bethlehem/Hebron	Upper Cenomanian
KALLAT DYAB	Dura	Hebron	Bethlehem/Hebron	Upper Cenomanian
AL FRAIDEES	Dura	Hebron	Bethlehem/Hebron	Upper Cenomanian
JUNAYNAH	Dura	Hebron	Bethlehem/Hebron	Upper Cenomanian
'IMRAN NO. 2	Dura	Hebron	Bethlehem/Hebron	Upper Cenomanian
'IMRAN NO. 1	Dura	Hebron	Bethlehem/Hebron	Upper Cenomanian
ABU KHAIT	Dura	Hebron	Bethlehem/Hebron	Upper Cenomanian
AL HEJRAH	Dura	Hebron	Bethlehem/Hebron	Upper Cenomanian
DELBAH	Dura	Hebron	Bethlehem/Hebron	Upper Cenomanian
AL MAJNUNAH	Dura	Hebron	Bethlehem/Hebron	Upper Cenomanian
AL KARMEL	Yatta	Hebron	Bethlehem/Hebron	Upper Cenomanian
BAIT DUQQU	Beit Duqqu	Jerusalem	Bethlehem/Hebron	Upper Cenomanian
JANAN	Qatanna	Jerusalem	Bethlehem/Hebron	Upper Cenomanian
AL BALAD	Qatanna	Jerusalem	Bethlehem/Hebron	Upper Cenomanian
KAFFET 'UDAH	Deir Eistiya	Nablus	Bethlehem/Hebron	Upper Cenomanian
AL FAWWAR	Deir Eistiya	Nablus	Bethlehem/Hebron	Upper Cenomanian
AL JUZAH	Deir Eistiya	Nablus	Bethlehem/Hebron	Upper Cenomanian
AL BASSAH	Deir Eistiya	Nablus	Bethlehem/Hebron	Upper Cenomanian
AL MAQYUDAH	Deir Eistiya	Nablus	Bethlehem/Hebron	Upper Cenomanian
Spring Name	**Locality**	**Governorate**	**Formation**	**Aquifer**

El Balad/Ibwein	Ibwein	Ramallah	Bethlehem/Hebron	Upper Cenomanian
AL SUFLA	Ibwein	Ramallah	Bethlehem/Hebron	Upper Cenomanian
El Balad/Arura	Arura	Ramallah	Bethlehem/Hebron	Upper Cenomanian
DAQLAH	Umm Safa	Ramallah	Bethlehem/Hebron	Upper Cenomanian
ABU FAYYAD	Beit Rima	Ramallah	Bethlehem/Hebron	Upper Cenomanian
AL DAIR	Dair Ghassanah	Ramallah	Bethlehem/Hebron	Upper Cenomanian
KAFER	Kafr 'Ein	Ramallah	Bethlehem/Hebron	Upper Cenomanian
QARAWAH	Qarawat Bani Zeid	Ramallah	Bethlehem/Hebron	Upper Cenomanian
RAYYA	Deir Nidham	Ramallah	Bethlehem/Hebron	Upper Cenomanian
RAYYA AL FUQA	Deir Nidham	Ramallah	Bethlehem/Hebron	Upper Cenomanian
DELBAH & LAQTAN	Abud	Ramallah	Bethlehem/Hebron	Upper Cenomanian
Ligtan *	Abud	Ramallah	Bethlehem/Hebron	Upper Cenomanian
Dilba *	Abud	Ramallah	Bethlehem/Hebron	Upper Cenomanian
ZARQA	Dair Ghassanah	Ramallah	Bethlehem/Hebron	Upper Cenomanian
AL MGHARAH	Abud	Ramallah	Bethlehem/Hebron	Upper Cenomanian
AL 'ALAM	Abud	Ramallah	Bethlehem/Hebron	Upper Cenomanian
AL QUS (Qaus)	Bir Zeit	Ramallah	Bethlehem/Hebron	Upper Cenomanian
KUBAR	Kobar	Ramallah	Bethlehem/Hebron	Upper Cenomanian
AL ZARQAH	Beitllu	Ramallah	Bethlehem/Hebron	Upper Cenomanian
AL ZARQAH AL TEHTA	Beitllu	Ramallah	Bethlehem/Hebron	Upper Cenomanian
AL QWAIQBAH	Beitllu	Ramallah	Bethlehem/Hebron	Upper Cenomanian
'AKARI	Beitllu	Ramallah	Bethlehem/Hebron	Upper Cenomanian
AL BALAD	Beitllu	Ramallah	Bethlehem/Hebron	Upper Cenomanian
AL QUS	Beitllu	Ramallah	Bethlehem/Hebron	Upper Cenomanian
SHAKARYA	Der Ammar	Ramallah	Bethlehem/Hebron	Upper Cenomanian
DAIR 'AMMAR	Der Ammar	Ramallah	Bethlehem/Hebron	Upper Cenomanian
AL BALAD	Jammala	Ramallah	Bethlehem/Hebron	Upper Cenomanian
'AREEK AL FUQA	Ein 'Arik	Ramallah	Bethlehem/Hebron	Upper Cenomanian
'AREEK AL TEHTA	Ein 'Arik	Ramallah	Bethlehem/Hebron	Upper Cenomanian
AL JARYUT	Beituniya	Ramallah	Bethlehem/Hebron	Upper Cenomanian
BAIT SUREEK	Beit Surik	Ramallah	Bethlehem/Hebron	Upper Cenomanian
AL MATWI	Salfit	Salfit	Bethlehem/Hebron	Upper Cenomanian
SHAMIYYAH	Salfit	Salfit	Bethlehem/Hebron	Upper Cenomanian
AL SHALLAL	Salfit	Salfit	Bethlehem/Hebron	Upper Cenomanian
'ADAS	Salfit	Salfit	Bethlehem/Hebron	Upper Cenomanian
AL FAWWARA	Kafr Ad Dik	Salfit	Bethlehem/Hebron	Upper Cenomanian
AL SAMU' NO.1	Kh.al seemya	Hebron	Jerusalem	Turonian