Groundwater Pollution Control to Bridge Supply / Demand Gap: Northern Districts as a Case Study

By

Nancy Salameh Rumman

Supervision Committee:

Dr. Ziad Mimi (Chairman)
Dr. Marwan Ghanem (Member)
Dr. Hani Qassem (Member)

A thesis submitted in partial fulfillment of the requirement for the Masters Degree in Water Engineering from the Faculty of Graduate Studies at Birzeit University

Groundwater Pollution Control to Bridge Supply / Demand Gap: Northern Districts as a Case Study

By

Nancy Salameh Rumman

This thesis was defended successfully on (   ) and was approved by all members of the Supervision Committee

Supervision Committee:

Dr. Ziad Mimi (Chairman)
Dr. Marwan Ghanem (Member)
Dr. Hani Qassem (Member)

	Signature
Dr. Ziad Mimi (Chairman)	---------------------------
Dr. Marwan Ghanem (Member)	---------------------------
Dr. Hani Qassem (Member)	---------------------------

Acknowledgements

There are several individuals whom I wish to recognize because of their assistance and encouragement, at various times and in various ways, while I was working on this thesis.

First of all, I would like to thank Dr. Ziad Mimi, my Advisor, who gave me a great deal of encouragement and support reviewing each chapter and giving me useful comments and helpful suggestions.

I am also indebted to Dr. Amjad Aliewi who showed a great reservoir of knowledge on water issues.

I would also like to thank the examiners Drs Marwan Ghanem and Hani Qassem who provided me with many useful comments and ideas.

Special thanks go to my colleagues at the SUSMAQ project, especially Eng. Jumana Abu Saada for assisting me in preparing the GIS maps.

I am especially grateful to my family for their endless love and patience, particularly my brother George to whom I remain deeply grateful.

Abstract

Pollution is a major challenge in controlling the gap between available water resources and demand. The northern districts of the West Bank and subsequently the Tulkarem district are identified in order to study the extent of pollution in a region that already suffers from a considerable gap between water supply and demand. Pollution in these areas will place the available water resources at a major risk and therefore will substantially increase the gap between supply and demand. Studying the extent of pollutants in the groundwater systems of the study area will help control the water supply/demand gap.

The study area reflects high recharge rates to the aquifers, mature karstic nature of these aquifers, and hence uncontrolled sewage disposal mean that water supply boreholes in this area are at high risk of contamination from pollution. This study presents a preliminary assessment of the effect of raw sewage on the aquifer system in the Wadi Zeimar area in the northern West Bank. This study identified pollution sources, develop a pollution model for sewage effluent of Wadi Zeimar and identify the most sensitive areas to groundwater pollution. Furthermore, this research provides additional emphasis on the supply/demand gap so that the negative impacts of pollution are better understood.

Modeling the movement of pollutants from sources in the study area showed that continuous disposal of raw sewage into Wadi Zeimar may significantly increase the levels of nitrates and chloride above WHO standards, which is a major pollution threat. The results of this study show that most of the study area is sensitive to pollution and therefore and on the long run no raw wastewater should be discharged into Wadi Zeimar. Therefore, it is recommended that wastewater treatment facilities should be applied to the raw sewage before it is dumped into the Wadi.

Table of Contents

List of Tables

List of Figures

Abbreviations

ARIJ Applied Research Institute - Jerusalem

BOD Biochemical Oxygen Demand, a measure of pollution in water

CDM Camp Dresser and Mckee

CH2MHILL Name for Private Corporation

CSO Combined Sewer Overflow

DAR Deutsche Abwasser Reinigungs - Gesellschaft

EPA Environmental Protection Agency

GIS Geographic Information System

GMS Groundwater Modeling System

GTZ German Technical Cooperation Agency

HU Hebrew University

MEnA Ministry of Environmental Affairs, PNA

M&I Municipal and Industrial

MOPIC Ministry of Planning and International Cooperation, PNA

NRU Northern Regional Utilities

PASSIA Palestinian Academic Society for the Study of International Affairs, Jerusalem

PCBS Palestinian Central Bureau of Statistics, PNA

PECDAR Palestinian Economic Council for Development and Reconstruction

PNA Palestinian National Authority

PWA Palestinian Water Authority, PNA

SUSMAQ Sustainable Management of the West Bank and Gaza Aquifers

UG Universal Group for Engineering & Consulting

UNESCO United Nations Educational, Scientific and Cultural Organization

WAB Western Aquifer Basin

WB West Bank

WHO World Health Organization

WSSPS Water Sector Strategic Planning Study

ملخص

يعتبر التلوث من أكبر التحديات التي تتحكم في الفجوة بين مصادر المياه المتاحة والطلب عليه، ولدراسة هذا الموضوع فقد أخذت مناطق شمال الضفة الغربية ومنها منطقة طولكرم مكان الدراسة من اجل دراسة مدى أثر انتشار التلوث في هذه المناطق التي تعاني أصلاً من فجوة لا يستهان بها بين التزود بالمياه والطلب عليها، إن التلوث في منطقة الدراسة يعرض مصادر مياهها المتاحة لخطر رئيسي يؤدي بالتالي إلى زيادة الفجوة، لذلك إن دراسة انتشار التلوث في مصادر المياه الجوفية في منطقة الدراسة سيساعد في عملية ضبط هذه الفجوة بين التزود بالمياه والطلب عليها، وهذا هو موضوع بحث دراسة الماجستير هذه.

تكمن أهمية منطقة الدراسة في أنها تعكس معدلات عالية لتغذية الأحواض الجوفية، وكذلك خصائص عالية للكارست (التشققات في الصخور المغذية للأحواض) وبالتالي فإن عملية إلقاء مياه المجاري غير المعالجة على هذه المناطق، سيؤدي إلى زيادة خطر تلوث آبار التزود بالمياه وفيها تقدم هذه الدراسة تقييماً أولياً لاثر القاء مياه المجاري غير المعالجة على نظام المياه الجوفي في منقطة وادي زيمار في شمال الضفة الغربية، ستبين هذه الدراسة مصادر التلوث وتطور نموذجاً رياضياً لاثر إلقاء مياه المجاري غير المعالجة على المياه الجوفية في منطقة الدراسة، وكذلك تبين المناطق الحساسة لتلوث المياه الجوفية، وكذلك تقدم هذه الدراسة تحليلاً إضافياً على الفجوة بين التزود بالمياه والطلب عليها بحيث يمكن وبصورة أفضل إدراك الآثار السلبية للتلوث على هذه الفجوة.

تبين نتائج النموذج الرياضي لهذه الدراسة أن استمرار إلقاء مياه المجاري غير المعالجة في وادي زيمار سيزيد معدلات الكلورايد والنيترات فوق معايير منظمة الصحة العالمية WHO وهذا بدوره يعتبر خطر تلوث أساسي، تبين النتائج أيضاً أن معظم منطقة الدراسة حساسة للتلوث وعليه فإنه وعلى المدى الطويل يجب أن لا تلقى مياه المجاري غير المعالجة في منطقة وادي زيمار، توصي هذه الدراسة بضرورة إنشاء محطة معالجة لمياه المجاري قبل إلقائها في منطقة وادي زيمار.

Chapter 1

Introduction

1.1 Background

Assessment of groundwater resources sensitivity to contamination (e.g., sewage contamination) is important because the motion of the contaminants will be affected by the slow movement of the groundwater and therefore, groundwater contamination will last for very long times, and contamination in groundwater systems will take long time before it will appear in aquifer abstractions. The sensitivity of aquifers to pollution needs to demonstrate the possibilities of penetration and spreading of pollutant depending on hydrogeological conditions.

There have been many years of neglect and lack of wastewater management in Palestinian Wadi Systems. Wadi Zeimar that runs from Nablus and passes through Tulkarem is a principle receiving Wadi for the discharge of wastewater in that region. Wadi Zeimar carries with its runoff the sewage effluent of the western part of Nablus City and all villages alongside the Wadi, the waste of limestone quarries and the industrial wastes of some manufacturers alongside the Wadi. This forms a great threat to the groundwater system in the vicinity of the Wadi as the aquifer is shallow and has a high degree of permeability with pronounced mature karst features above and below the water table, and nearly the whole course of Wadi Zeimar is running through areas sensitive to groundwater pollution. The samples from groundwater wells near Wadi Zeimar show raised levels of Chloride and Nitrates with time (DAR-UG, 1999).

Sources of pollution include industries alongside the Wadi (plastic, stone cutting, olive mills and leather tanning), and uncontrolled dumping of domestic wastes (Figures 1 & 2). The wastewater collection is very poor – only Tulkarem City, Tulkarem Camp, Nour Shams camp and Anabta have sewerage networks, the other villages using uncontrolled absorption holes that are discharged into the nearby Wadis. There is only one wastewater treatment plant in the area, which is located at Tulkarem.

Figure 1: Dumping of Wastes at Wadi Zeimar

All groundwater wells in the Tulkarem Region extract water from the upper aquifer which is mainly formed from the Hebron, Bethlehem and Jerusalem formations. Well depths are typically less than 400 m and the water levels are rarely more than 200 m below ground level. The Tulkarem region is part of the semi coastal zone receiving high rainfall; Wadi Zeimar is characterized by a typical perennial flow pattern like some other Wadis in the region. However in the dry season the water flow in the Wadi is mostly from raw wastewater discharged into the Wadi, mainly domestic and industrial wastewater from the Nablus district as well as from Anabta and Tulkarem.

The combination of high recharge rates, the karstic nature of the aquifer, and uncontrolled sewage disposal mean that water supply boreholes in this area are at high risk of contamination from pollution. This study presents a preliminary assessment of the effect of raw sewage on the aquifer system in the Wadi Zeimar area.

Figure 2: Dumping of Wastes at the Entrance of Shuweika – West of Shuweika Bridge

The long period of neglect of the West Bank environment and the lack of adequate environmental regulations and standards had resulted in the exposure of the aquifers in the Tulkarem-Qalqilya area to serious problems of pollution. This situation, if continued will result in damage to this major source of freshwater and thus the gap between supply and demand will increase. The major geophysical inputs to the problems of waste disposal and groundwater contamination deal with the chemistry and rates and directions of contaminant transport.

In general the aquifer system in the study area is at risk from:

- Untreated wastewater discharge leading to high nitrate levels
- Uncontrolled dumping of solid waste
- Agricultural fertilizer applications (high nitrate levels), and pesticides
- Discharges of hazardous waste
- Cesspits spread in the area

Because of the serious effect found in high levels of chlorides and nitrates in some groundwater wells in the study area, it is important to:

- Conduct aquifer management and modeling
- Identify the most sensitive areas for protection of water resources
- Identify all sources of pollution and assess groundwater pollution from hazardous wastes
- Establish a quality-monitoring network for water resources
- Control and monitor agrochemical fertilizers and pesticides
- Implement treatment of industrial effluent
- Conduct environmental impact assessment for new developments
- Address historical hazardous waste dumps
- Develop and implement a monitoring and management program for cisterns

This study will identify pollution sources, develop a pollution model for sewage effluent of Wadi Zeimar and identify the most sensitive areas to groundwater pollution. Furthermore, this research evaluates the water resources in the study area including the water supply/demand gap. This is because the negative impacts of pollution will be better understood.

1.2 The Study Area

In this research, Wadi Zeimar of the Tulkarem Area is the main study area. Because it is intended to model the extent of pollution in the aquifer system, the supply/ demand gap in the Northern Regional Utility area (NRU) (where Wadi Zeimar is located) is briefly analyzed so that the impacts of pollution on the availability of water resources will be realized. The PWA's National Strategy for water and sanitation is to establish four regional utilities in the West Bank and one in Gaza. These utilities will have a lean management set-up where water supply and adequate sewage disposal are regionally provided on a cost recovery an ecologically sound basis. The Northern Regional Utility (NRU) is one of the utilities in the West Bank. It includes: Nablus, Jenin, Tulkarem, Qalqilya, Villages, Councils and Refugee Camps (GTZ, 1997).

Wadi Zeimar was taken as a sub-area within NRU because of the following reasons:

1. It runs over two aquifer basins (Western and Northeastern) so that its pollution impacts will be greater.
2. Wadi Zeimar area has enough data to conduct such a pollution study.
3. For hydrogeological reasons, Wadi Zeimar area was extended to include part of Israel so all the Israeli wells in that area are included in the study.

1.3 Objectives

The objectives of this study are as follows:

(1) Conduct a pollution modeling study to determine the spread of sewage pollutant in the aquifer of the Wadi Zeimar area.

(2) Identify the sensitive areas to groundwater pollution within the model study area.

(3) Assess the water supply/demand gap for the Northern regional Utility (where Wadi Zeimar lies) so that the negative impacts of pollution on available water resources will better be realized.

1.4 Methodology and Approach

The methodology and approach of this study include mainly the following:

1. Desk analysis to the population and demand data in the Northern Regional Utility (NRU). Based on known annual growth of the Palestinian population, it was possible to forecast the population of the three governorates (Nablus, Tulkarem and Jenin) of NRU till the horizon 2020 based on two standards of living (underdeveloped and developed standards) it was also possible to derive water demands for domestic purposes. The industrial, commercial and public uses were taken as percentages and added up to arrive at municipal and industrial water demands (M&I). The leaked water from the M&I was estimated and added up. The agricultural water demand was calculated from estimating the irrigable lands. The water demands from M&I and irrigation were totaled.

The available water resources for Nablus, Tulkarem and Jenin governorates of the NRU were evaluated for the current situation and the gap was estimated on the assumption that the available water will remain the same till the horizon 2020.

2. Numerical modeling: A numerical groundwater pollution model was developed for the study area to study the effect of sewage on the aquifer system of the study area. The groundwater code used in this study is the GMS (Groundwater Modeling System, incorporating MODFLOW). This computer code was used for the purposes of this study because:

- It is suitable to achieve the objectives of this study
- It provides a powerful results extractor, water budgets, contour maps, interpolation facilities, particle tracking and transport modeling
- Easy to handle and run
- It is the most widely used groundwater flow model in the world
- It is the only system that supports TINs, solids, borehole data, 2D and 3D geo-statistics, and both finite-element and finite- difference models
- The GMS has many supported models and tools (BOSS International, 2000):
    - MODFLOW for flow simulation;
    - MODPATH for particle tracking analysis;
    - MT3D for contaminant transport simulation;
    - GIS tools to construct the conceptual model and boundary conditions directly on the top of the scanned map;
    - FEMWATER to simulate density driven, coupled flow and contaminant transport in both the saturated and unsaturated zones in addition to the representation of the complex stratigraphy;
    - SPEED2, which can be used to simulate flow in profile models;
    - GEOSTATISTICS can be used to generate 2D contour map or 3D iso-surface plot of the contaminant plume;
    - SITECHARACTERIZATION that enables the stratigraphy to be drawn using the borehole logs;

- STRATIGRAPHYMODEL, which can produce a stacked surface, models using boreholes, geophysics and scatter points.

3. Vulnerability Map: The available geological and hydrogeological maps were used to develop a vulnerability map within the model study area to determine the most sensitive areas to sewage pollution. The technique of GIS was mainly used to accommodate and integrate information together with hydrogeological assessment to arrive at a suitable vulnerability map to the study area.

1.5 Thesis Structure

The thesis is divided into six chapters:

Chapter one provides background about the area, objectives of this research and a description to the main elements of the methodology used in this thesis.

Chapter two discusses available water resources and the supply/demand gap in the NRU. It should be noted and as explained before this analysis was carried out to realize the negative impacts of pollution on available water resources.

Chapter three provides details about the model study area in terms of its climate, geology, hydrogeology and pollution sources.

Chapter four develops a groundwater pollution model to study the effect of dumping raw sewage in the Wadis on the groundwater systems. The sewage of Wadi Zeimar was taken as the case study.

Chapter five develops a vulnerability map within the model study area to identify most sensitive zones to pollution.

Chapter six provides summary of the work carried out in the thesis and recommended actions.

Chapter 2

Water Supply and Demand in NRU

2.1 Introduction

In order to realize the significance and the negative impacts of pollution on the availability of water resources in the study area, it is important to provide a clear picture about the gap between water supply and demand.

It is well known that the water resources in Palestine are scarce and the NRU as a whole suffers from shortages of water. Any pollution occurs to these limited water resources will increase the water supply/demand gap and the challenge to manage these scarce water resources will be stronger. Pollution is a major challenge in the management of available water resources. Other challenges comprise of system losses, tariff systems, institutional capabilities and ever increasing demands.

2.2 Population

Population increase is the fundamental parameter affecting future water needs. This determines not only municipal demand, but also agricultural demand and industrial demand. The assessment of future population Figures has been carried out using the PCBS census results as a base for the end of the year 1997, and then applying the following population growth rates as shown in Table 1.

Table 1: Population Growth Rates of the West Bank

Period	Population Growth Per Annum
1998-2000	3.5%
2001-2005	3.0%
2006-2010	2.5%
2010-2020	2%

As explained earlier the NRU includes three Districts: Nablus, Jenin and Tulkarem. The population of these districts till the year 2020 was estimated using the following geometrical growth model as show in Table 2:

$P_{t+n} = P_t (1+r)^n$

Where:

P_{t+n} : Population at time (t+n)

P_t : Population at present time

r : Rate of growth per unit time

n : length of time in years for which the projection is made

Table 2: Population of NRU

District	Population (1997)	Population (2005)	Population (2010)	Population (2020)
Nablus	294179	372657	405529	463891
Jenin	227498	288188	313609	358741
Tulkarem	195702	247909	269777	308602

It should be noted from Table 2 and Figure 3 that the Population of the year 1997 is based on the Palestinian Central Bureau of statistics (PCBS, 1999).

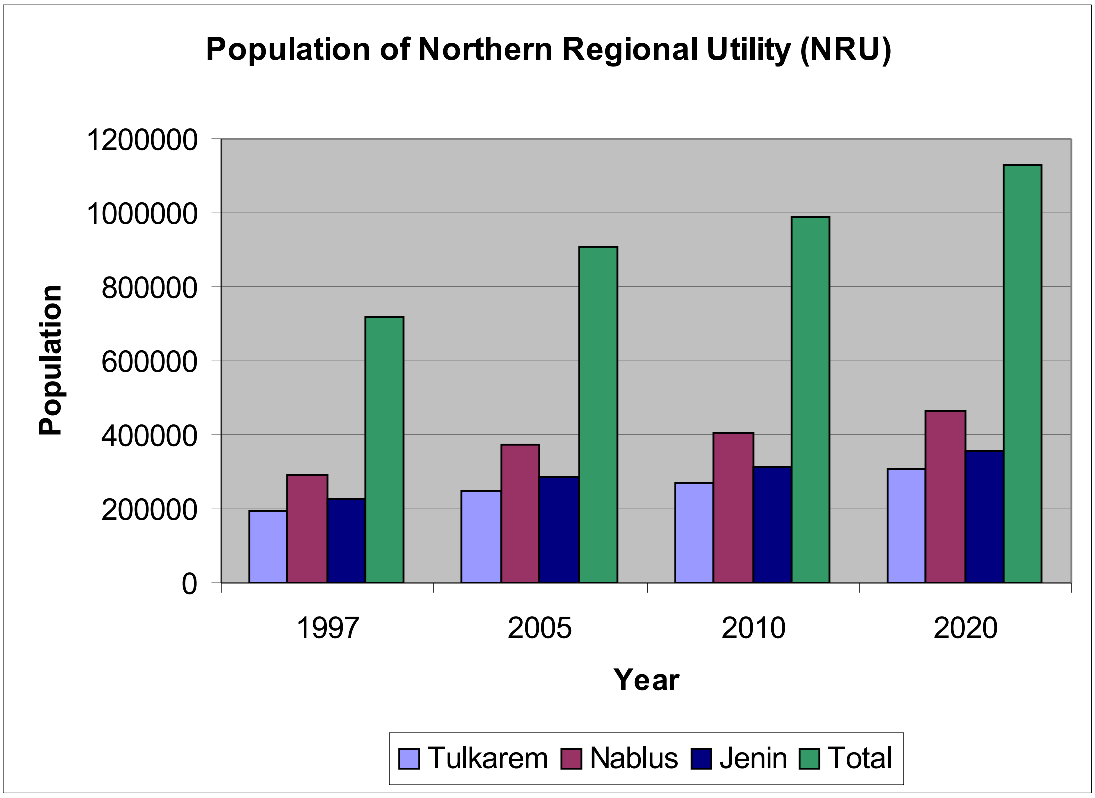

Figure 3: Population of Northern Regional Utility (NRU)

2.3 Water Supply in the NRU

The water supply for the NRU was taken from the Water Sector Strategic Planning Study (WSSPS), Volume I (PECDAR, 2001). The study was based on real data collected from different resources such as the database of the PWA. Table 3 is extracted from the WSSPS Study.

Table 3: Water Supply for NRU in the year 1997

Water Quantities in Mcm			
	Nablus	**Jenin**	**Tulkarem**
Resources			
M&I Wells	2.2	3.3	6.4
M&I Springs	2.6	0	0
M&I Mekorot	1.1	4.6	0.1
Total M&I	**5.9**	**7.9**	**6.5**
Agriculture			
Wells	8.8	5.7	15.3
Springs	1.3	0	2.1
Total	**16**	**13.6**	**23.9**

Studies conducted by CDM in 1999 showed that the difference between Bill quantities and the supplied water on part of the above districts led to the following losses as presented in the following Table 4.

Table 4: Losses estimation in conveyance systems of NRU (based on part of each district) compiled from CDM 1999

District	**Supplied Quantity (Mcm/yr)**	**Billed Quantity (Mcm/yr)**	**Losses (%)**
Nablus	12.24	6.73	45
Jenin	4.502	2.701	40
Tulkarem	7.77	4.275	45

2.4 Projected Domestic Demand

Because the year 1997 is the only year in which the PNA carried out real census it will be used in this study as a reference year for the calculations of all water demands and therefore will appear in all Tables of calculations.

The 1997 M&I consumption can be estimated as presented in the following Table 5.

Table 5: 1997 M&I Consumption for NRU

District	**Population**	**M&I supply with losses (Mcm/yr)**	**M&I supply without losses (Mcm/yr)**	**Per Capita l/d with losses**	**Per Capita l/d without losses**

Nablus	294179	12*	6.6	112	61
Jenin	227498	7.9	4.74	95	57
Tulkarem	195702	6.5	3.58	91	50

* This Figure was derived on the basis that a lot of agricultural wells contribute to the M&I consumption in the Nablus District (CDM 1997)

Based on 2% assumption of Water demand increase of municipal use, the following per capita consumption can be estimated as presented in the following Table 6.

Table 6: Projected M&I per capita water demand

District	1997	2005	2010	2020
Nablus	61	71	79	96
Jenin	57	67	74	90
Tulkarem	50	59	65	79

2.5 Water Demand of the Northern Regional Utility

The domestic water consumption for the year 1997 was calculated in the above section in addition to the projected per capita demand till the horizon 2020. The following assumptions are used in this study to estimate water demand for different purposes. The references of GTZ (1996), CDM (1997), MOPIC (1998), CH2MHILL (2002 & 2003), SUSMAQ & PWA (2001) and PECDAR (2001) were consulted but the WSSPS (PECDAR, 2001) study was the main reference used in this research due to the fact that it was a detailed study and based on surveyed data. The assumptions are as follows:

1. The target rates for future domestic water demands were estimated to vary from 50 to 96 l/c per d. These low rates represent the actual situation of limited water resources due to the constraints presented earlier in this chapter. This is considered as Scenario I. A second scenario is to assume that the living standards should improve to be around the WHO standards (100, 125, 150 and

200 l/c per d for the years 2001, 2005, 2010 and 2020 respectively) (Scenario II)

2. The supply in this study is taken from the WSSPS and presented in Table 3. In order to deal with the growing gap, the water supply Figures of 1997 were not increased as the suitable management options to ideal with the gap are explained later in this chapter.

3. The industrial and commercial needs are assumed to be a proportion of the domestic needs (7% for the year 1997, 9% for the year 2005 and 11% for the year 2010 and 16% for the year 2020). The low Figures for industrial and commercial needs are due to the constraints imposed on these sectors in Palestine during the 36 years of Israel's occupation to the West Bank, which limited the overall economic development in Palestine. The Palestinian industry includes only light and small industries and therefore do not represent the actual water needs of future stable industrial sector.

4. The leakage in the supply system for uses of both M&I is assumed to be as high as 40-45% at year 1997 and will reduce gradually to reach 15% in the year 2020. These Figures are reduced in the later horizons as it is hoped that the Palestinians will establish an efficient and proper supply system by then.

The following Tables: 7, 8, 9, 10, 11, and 12 represent the analysis carried out for the two scenarios mentioned in the above assumptions.

Scenario I: Very conservative demand based on actual situation in 1997.

Table 7: M&I and Irrigation Demands for Tulkarem Governorate – Scenario I

	Units	**Year 1997**	**Year 2005**	**Year 2010**	**Year 2020**

Population	Capita	195702	247909	269777	308602
Per capita domestic consumption	L/c per day	50	59	65	79
Total domestic consumption	Mcm/yr	3.57	5.34	5.42	8.90
Public demand	%	6	6	6	6
Public demand	Mcm/yr	0.21	0.32	0.33	0.53
Commercial and Industrial	%	7	9	11	16
Commercial and Industrial	Mcm/yr	0.25	0.48	0.60	1.42
Total M&I without leakage	Mcm/yr	4.03	6.14	6.35	10.85
Leakage	%	45	35	30	15
Leakage	Mcm/yr	1.8	2.15	1.9	1.63
Total M&I	**Mcm/yr**	**5.84**	**8.29**	**8.26**	**12.48**
Total Irrigation	**Mcm/yr**	**11.0**	**23.4**	**24.6**	**25.2**
Total Demand	**Mcm/yr**	**16.84**	**31.69**	**32.86**	**37.68**

Table 8: M&I and Irrigation Demands for Jenin Governorate - Scenario I

	Units	**Year 1997**	**Year 2005**	**Year 2010**	**Year 2020**
Population	Capita	227498	288188	313609	358741
Per capita domestic consumption	L/c per day	57	67	74	90
Total domestic consumption	Mcm/yr	4.733	7.05	8.47	11.79
Public demand	%	6	6	6	6
Public demand	Mcm/yr	0.284	0.423	0.51	0.71
Commercial and Industrial	%	7	9	11	16
Commercial and Industrial	Mcm/yr	0.331	0.64	0.93	1.886
Total M&I without leakage	Mcm/yr	5.348	8.11	9.91	14.39
Leakage	%	40	35	30	15
Leakage	Mcm/yr	2.139	2.84	2.97	2.16
Total M&I	**Mcm/yr**	**7.49**	**10.95**	**12.88**	**16.55**
Total Irrigation	**Mcm/yr**	**12.4**	**23.08**	**26.5**	**43.94**
Total Demand	**Mcm/yr**	**19.89**	**34.03**	**39.38**	**60.49**

Table 9: M&I and Irrigation Demands for Nablus Governorate - Scenario I

	Units	**Year 1997**	**Year 2005**	**Year 2010**	**Year 2020**
Population	Capita	294179	372657	405529	463891

Per capita domestic consumption	L/c per day	61	71	79	96
Total domestic consumption	Mcm/yr	6.55	9.66	11.69	16.25
Public demand	%	6	6	6	6
Public demand	Mcm/yr	0.40	0.58	0.70	0.9
Commercial and Industrial	%	7	9	11	16
Commercial and Industrial	Mcm/yr	0.46	0.87	1.29	2.6
Total M&I without leakage	Mcm/yr	7.41	11.11	13.68	19.75
Leakage	%	45	35	30	15
Leakage	Mcm/yr	3.33	3.89	4.10	2.96
Total M&I	**Mcm/yr**	**10.74**	**14.100**	**17.78**	**22.71**
Total Irrigation	**Mcm/yr**	**15.4**	**20.25**	**27.33**	**34.32**
Total Demand	**Mcm/yr**	**26.14**	**34.35**	**45.11**	**57.03**

Scenario II: Palestinian and WHO Standards

Table 10: M&I and Irrigation Demands for Tulkarem Governorate – Scenario II

	Units	Year 1997	Year 2005	Year 2010	Year 2020
Population	Capita	195702	247909	269777	308602
Per capita domestic consumption	L/c per day	100.00	125.00	150.00	200
Total domestic consumption	Mcm/yr	7.14	11.3	14.77	22.53
Public demand	%	6	6	6	6
Public demand	Mcm/yr	0.43	0.68	0.89	1.35
Commercial and Industrial	%	7	7	11	16
Commercial and Industrial	Mcm/yr	0.50	0.791	1.62	3.60
Total M&I without leakage	Mcm/yr	8.07	12.77	17.28	27.48
Leakage	%	45	35	30	15
Leakage	Mcm/yr	3.63	4.47	5.19	4.12
Total M&I	**Mcm/yr**	**11.70**	**17.24**	**22.47**	**31.60**
Total Irrigation	**Mcm/yr**	**11.0**	**23.4**	**24.6**	**25.2**
Total Demand	**Mcm/yr**	**22.7**	**40.64**	**47.07**	**56.80**

Table 11: M&I and Irrigation Demands for Jenin Governorate – Scenario II

	Units	Year 1997	Year 2005	Year 2010	Year 2020
Population	Capita	227498	288188	313609	358741

Per capita domestic consumption	L/c per day	100.00	125.00	150.00	200
Total domestic consumption	Mcm/yr	8.30	13.15	17.17	26.19
Public demand	%	6	6	6	6
Public demand	Mcm/yr	0.50	0.79	1.03	1.57
Commercial and Industrial	%	7	9	11	16
Commercial and Industrial	Mcm/yr	0.58	1.18	1.89	4.19
Total M&I without leakage	Mcm/yr	9.38	15.12	20.09	31.95
Leakage	%	40	35	30	15
Leakage	Mcm/yr	3.75	5.29	6.03	4.79
Total M&I	**Mcm/yr**	**13.13**	**20.41**	**26.12**	**36.74**
Total Irrigation	**Mcm/yr**	**12.4**	**23.08**	**26.5**	**43.94**
Total Demand	**Mcm/yr**	**25.53**	**43.49**	**52.62**	**80.68**

Table 12: M&I and Irrigation Demands for Nablus Governorate – Scenario II

	Units	**Year 1997**	**Year 2005**	**Year 2010**	**Year 2020**
Population	Capita	294179	372657	405529	463891
Per capita domestic consumption	L/c per day	100.00	125.00	150.00	200
Total domestic consumption	Mcm/yr	10.74	17.00	22.20	33.86
Public demand	%	6	6	6	6
Public demand	Mcm/yr	0.64	1.02	1.33	2.03
Commercial and Industrial	%	7	9	11	16
Commercial and Industrial	Mcm/yr	0.75	1.53	2.44	5.42
Total M&I without leakage	Mcm/yr	12.13	19.55	25.97	41.31
Leakage	%	45	35	30	15
Leakage	Mcm/yr	5.46	6.84	7.79	6.20
Total M&I	**Mcm/yr**	**17.59**	**26.39**	**33.76**	**47.51**
Total Irrigation	**Mcm/yr**	**15.4**	**20.25**	**27.33**	**34.32**
Total Demand	**Mcm/yr**	**32.99**	**46.64**	**61.09**	**81.83**

The above Tables show that the demand Figures for the NRU are 62.87, 100.07, 117.35 and 155.2 Mcm/yr for the years 1997, 2005, 2010 and 2020 respectively for Scenario I, and 81.22, 130.77, 160.78 and 219.31 Mcm/yr for the years 1997, 2005, 2010 and 2020 respectively for Scenario II.

2.6 Water Supply/Demand Gap

In Palestine, this gap is growing with time because water supply is artificially constrained by the stagnation of the peace process. This gap is having severe adverse effects on both current and future Palestinian socio-economic development.

Because the study area lies in the boundaries of the Northern Regional Utility (NRU) that the Palestinian Water Authority is planning to establish in order to supply water to the governorates of Nablus, Jenin and Tulkarem, the supply/demand Gap in the following Tables 13 and 14 is analyzed for the NRU as a whole.

Table 13: Supply/Demand Gap for the NRU Area: Scenario I

	Year 1997	**Year 2005**	**Year 2010**	**Year 2020**
Demand				
Tulkarem	**16.84**	**31.69**	**32.86**	**37.68**
Nablus	**26.14**	**34.35**	**45.11**	**57.03**
Jenin	**19.89**	**34.03**	**39.38**	**60.49**
Total Demand	62.87	100.07	117.35	155.2
Supply				
Tulkarem	23.9	23.9	23.9	23.9
Nablus	16	16	16	16
Jenin	13.6	13.6	13.6	13.6
Total Supply	53.5	53.5	53.5	53.5
Gap	**-9.37**	**-46.57**	**-63.85**	**-101.7**

Table 14: Supply/Demand Gap for the NRU: Scenario II

	Year 1997	**Year 2005**	**Year 2010**	**Year 2020**
Demand				
Tulkarem	**22.7**	**40.64**	**47.07**	**56.80**
Nablus	**32.99**	**46.64**	**61.09**	**81.83**
Jenin	**25.53**	**43.49**	**52.62**	**80.68**
Total Demand	81.22	130.77	160.78	219.31
Supply				
Tulkarem	23.9	23.9	23.9	23.9
Nablus	16	16	16	16

Jenin	13.6	13.6	13.6	13.6
Total Supply	53.5	53.5	53.5	53.5
Gap	**-27.72**	**-77.27**	**-107.28**	**-165.81**

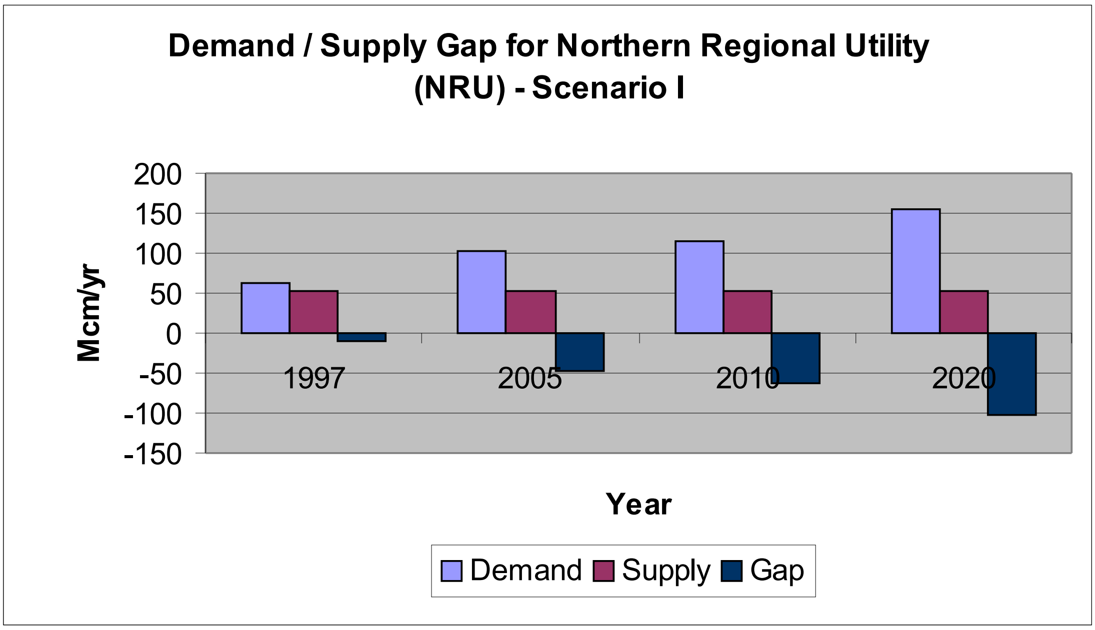

Figure 4: Demand / Supply Gap for Northern Regional Utility (NRU) – Scenario I

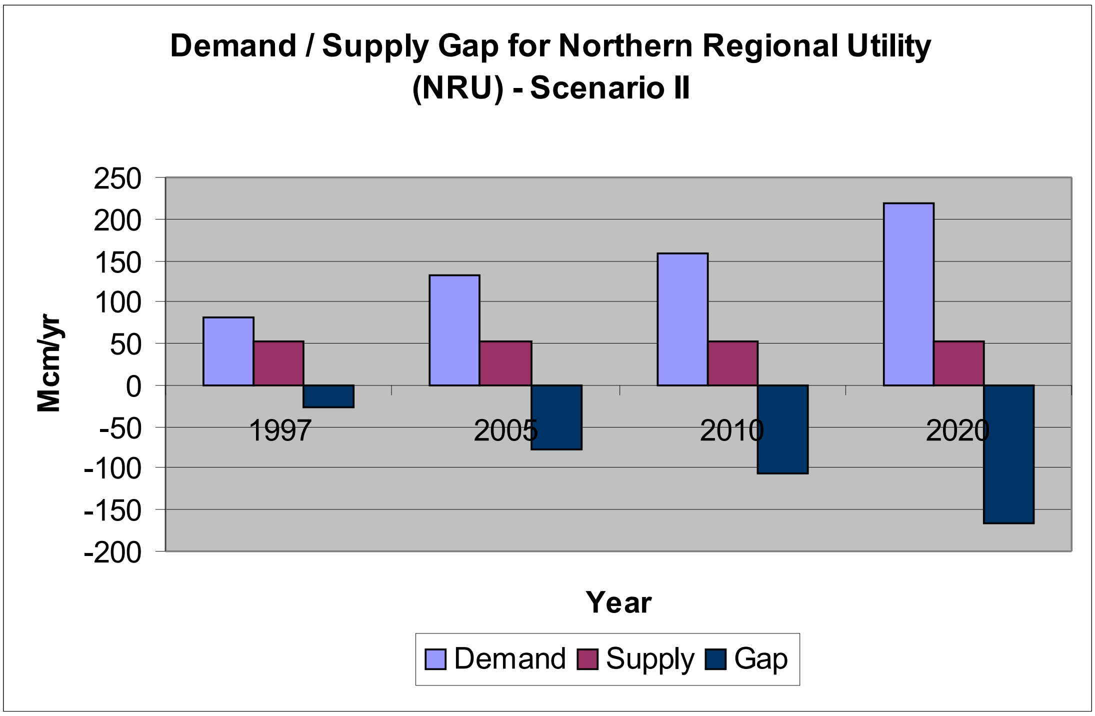

Figure 5: Demand / Supply Gap for Northern Regional Utility (NRU) – Scenario II

The above Tables (13 &14) and Figures (4 & 5) show that the water/supply demand gap for the NRU is –9.37, -46.57, -63.85 and –101.7 Mcm/yr for the years 1997, 2005, 2010 and 2020 respectively for Scenario I and –27.72, -77.27, -107.28 and –165.81 Mcm/yr for the years 1997, 2005, 2010 and 2020 respectively for Scenario II.

It should be realized that the gap means shortages of water and therefore any possible pollution cannot be afforded.

2.7 Groundwater Protection to Control the Water Supply/Demand Gap

It is important to bring an end to dumping raw wastewater and all sorts of wastes (industrial waste, solid waste etc) discharged to the natural environment through implementation and collection and treatment works in Palestine. The benefits of that are to protect the environment and the quality of water resources, which means that the water supply/demand gap will not go larger at least. This option will mean to construct cesspits and septic tanks in rural areas. There is evidence that some springs in the NRU are becoming polluted because of dumping raw sewage. Also, some wells in the Eastern Aquifer Basin especially in the Jordan valley are becoming saline. Protection measures should save these resources from pollution. This is an important management option to address the water supply/demand gap in Palestine.

In this study and considering the water supply/demand gap, conventional and non-conventional water resources will have to be mobilized and will account of water with lower quality as far as practical and economic for agricultural use. In addition to groundwater protection other suitable management options that can be developed in the NRU are: Groundwater development programmes (wells and springs), Rainwater harvesting, Demand management, Wastewater reuse and Changes to water policies.

Chapter 3

Assessment of Groundwater Resources and Pollution Issues

3.1 Introduction

This chapter describes the main features of the Groundwater resources and the key pollution issues in the Tulkarem Area which is the study area of the pollution model developed in this study. This includes a description of the Meteorology, Geology and Hydrogeology of the model study area, groundwater wells (Quantity and Quality), land use, and pollution sources and their impacts on the Groundwater resources.

The Tulkarem study area (Figure 6) is located at 32° N latitude in the north west of the West Bank, about 16 km to the east of the Mediterranean Sea and comprises part of the district of Tulkarem and a small part of Nablus district. Water resources are the most valuable natural resources of principal concern in the model of the study area, both due to the economic value and due to the sensitivity to pollution through the present wastewater disposal practices.

Tulkarem is a large city in the district and lies at one of the most accessible gateways from the Tulkarem plain to the Nablus hills located at the intersection of the north-south arteries of the Haifa-Lod railway and motorway both ruining along the western edge of the hills with the west-east highway leading from the coast to Nablus. Due to the fertility of the region, the population density is with about 580 persons/km2 higher as in other regions in Palestine.

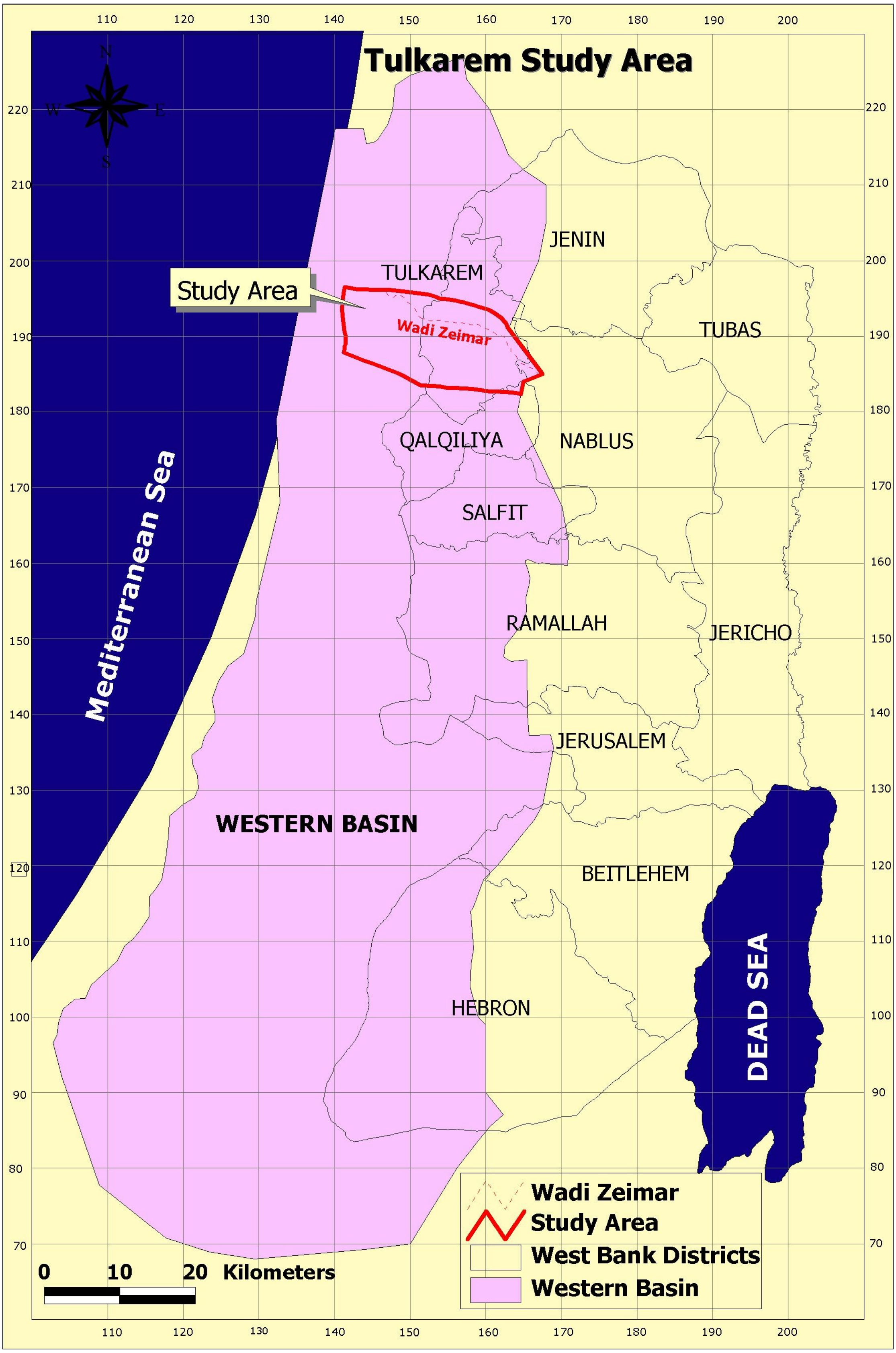

Figure 6: Tulkarem Study Area

3.2 Meteorology

The climate in the site is Mediterranean with two clearly defined climatic seasons, a wet winter relatively warm and a dry hot summer. The rainy seasons extends from middle of November to the end of April with the lowest temperatures occurring in January and February. The dry season begins at the end of springs and goes on until the beginning of the autumn. The average rainfall is around 600 mm per year.

Annual precipitation rate is in the range of 640mm in the Tulkarem district (Figure 7). Infiltration rates are approximately in the range 30-40% of the annual precipitation, while runoff is approximately 2-5% of annual precipitation (DAR-UG, 1999).

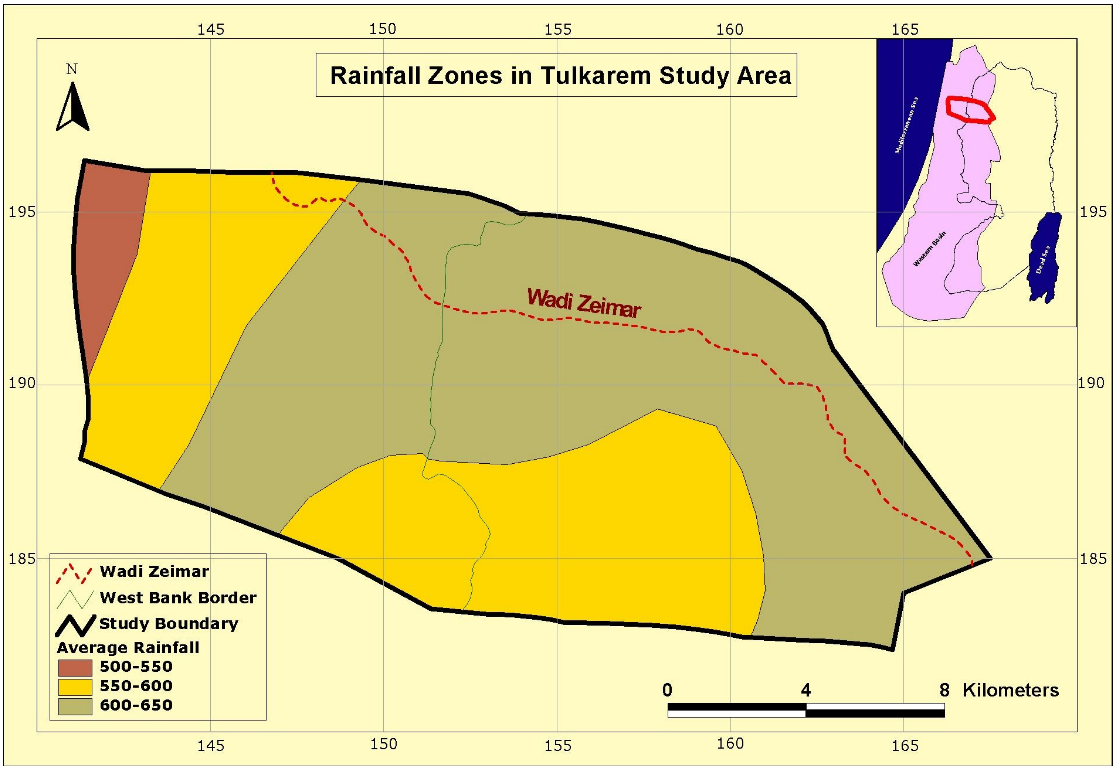

Figure 7: Rainfall Zones in Tulkarem Study Area

3.3 Geology and Hydrogeology

The exposed sequence of rocks in the Tulkarem area largely consists of limestone, dolomite, marl and chalk and it includes other sediments as chert, clay, evaporates and gravel with ages ranging from Lower Cenomanian to Recent (Figure 8). In areas of significant topographical relief the upper soil layer consists of three horizons of alluvial deposits that results from the weathering of sedimentary rocks. The thickness of the soil layer reaches 1-10 meters in the Tulkarem area.

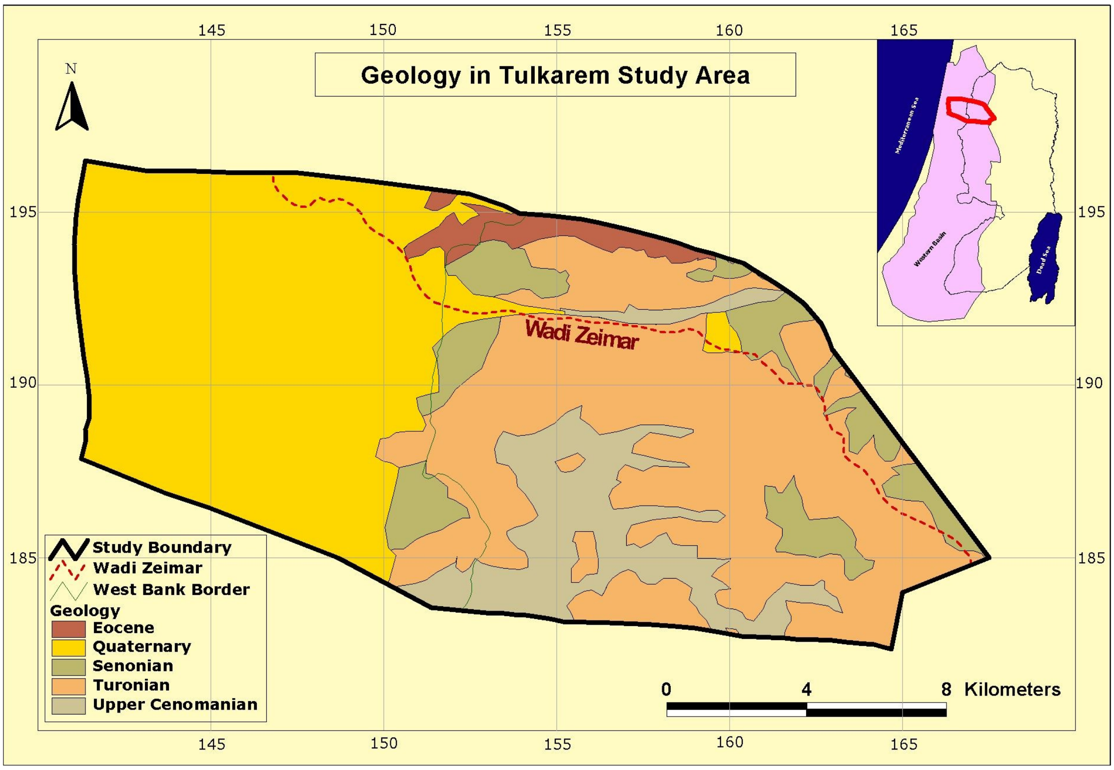

Figure 8: Geology in Tulkarem Study Area

The major regional aquifers in the model study area are the lower Cenomanian (Lower Aquifer), the Upper Cenomanian-Turonian (Upper Aquifer) and the Eocene complexes (Aliewi & Shaheen, 1996).

- Lower Aquifer:

The lower Beit Kahil Formation and to a lesser extent the Upper Beit Kahil Formation and sometimes the lower part of Yatta Formation form the lower aquifer. In the Tulkarem Area, the lower aquifer is not utilized yet since highly yielding wells are exploiting the shallower upper aquifer. The Lower Cenomanian Yatta Formation hydraulically separates the two regional aquifers across most of the West Bank. Although to the north, the presence of Yatta limestone gives rise to minor springs and seepages.

The Lower Aquifer has high water bearing capacity and productivity due to the great thickness of dolomite limestones and limestones (up to 400 m).

- Upper Aquifer:

The Hebron, Bethlehem and Jerusalem Formations mainly form the Upper Aquifer. In the southern and eastern part of the West Bank, the Bethlehem Formation is considered an aquitard, while to the north and west it has aquifer characteristics. Water levels (heads) in the Upper Aquifer are generally higher than in the Lower Aquifer. Yields from wells tapping the Upper Aquifer range from 40-400 m3/hr. Well depths are typically less than 400 m and water levels are rarely more than 200 m below ground level. All production wells in the Tulkarem area are from the Upper Aquifer. The high yields and productivity are explained by high transmissivities and high rates of natural recharge. Transmissivity values obtained from this aquifer wells range from 20 m2/day to several hundreds m2/day. The upper Aquifer is very susceptible to pollution sources infiltrating from the sub-soil.

- Eocene Aquifer

Jenin Subseries formation forms the shallow aquifer especially north and northwest of Tulkarem. The aquifer has limited storage and water transmissivity properties and is not a major water supply for domestic uses. Generally though, the ground water potential in Tertiary and Quaternary rocks is considered small compared to the Lower and Upper Aquifers. This Aquifer is separated from the underlying upper Aquifer by a 200-500 m thick sequence of chalks and marls which serves as a confining unit of the Upper Aquifer.

3.4 Groundwater wells

3.4.1 Groundwater Abstractions

All production wells (Figure 9) in the Tulkarem area are from the Upper Aquifer yielding some 24.4 Mcm/yr. The high yields and productivity are explained by high transmissivities and high rates of natural recharge (Figure 18). Transmissivity values obtained from this aquifer wells range from 20 m2/day to several hundred m2/day. Well depths are typically less than 400 m and the water levels rarely more than 200m below ground level (Table 15).

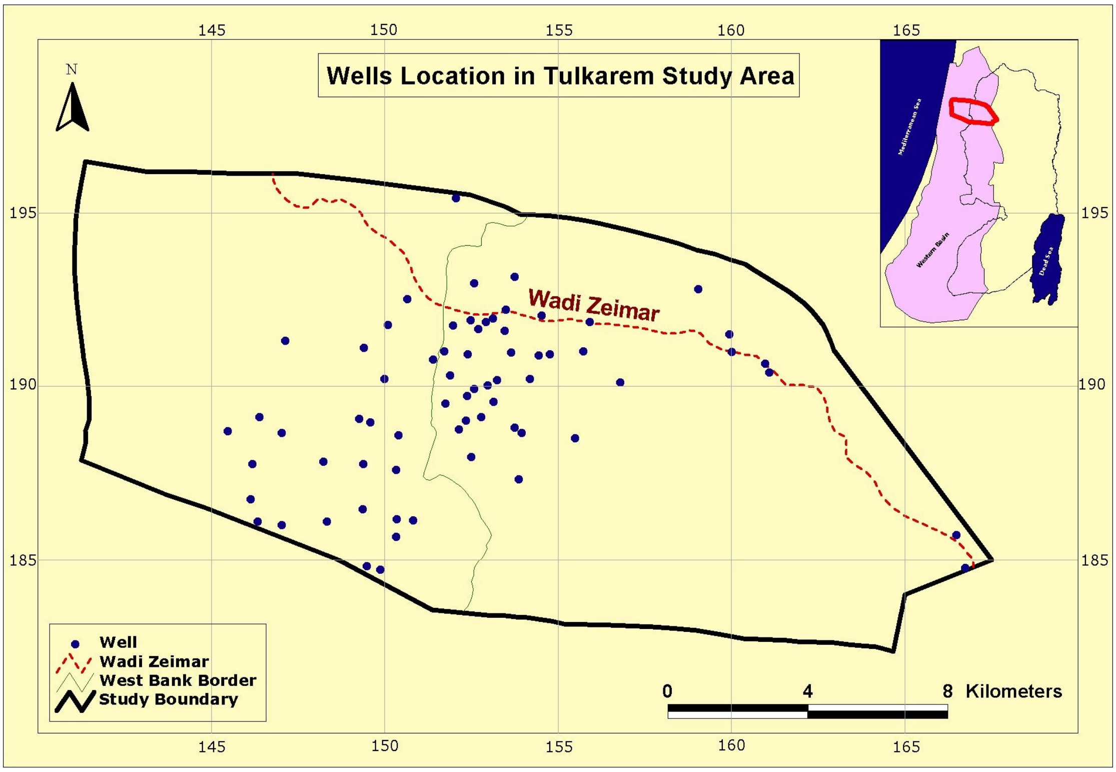

Figure 9: Wells Location in Study Area

Table 15: Wells in Model Study Area

Well ID	X	Y	Z	Locality	Well Depth	Formation
15-18/006	152500	187950	145	FAR'UN	165	Bet/Heb
15-18/007	152350	189000	60	FAR'UN	74	Bet/Heb
15-18/008	153750	188800	68	FAR'UN	100	Bet/Heb
15-18/009	152380	189720	75	IRTAH	89	Bet/Heb
15-18/010	152150	188750	52	IRTAH	66	Bet/Heb
15-18/017	153150	189550	62	TULKAREM	91	Bet/Heb
15-18/018	152580	189920	72	TULKAREM	92	Bet/Heb
15-18/019	153950	188650	70	TULKAREM	100	Bet/Heb
15-18/020	153870	187320	90	FAR'UN	110	Bet/Heb
15-18/021	155840	184720	218	AL RAS		Bet/Heb
15-18/022	151760	189500	62	IRTAH	71	Bet/Heb
15-18/024	155500	188500	100	SHUFAH	151	Jer/Bet/Heb
15-19/001	153130	191950	68	TULKAREM	125	Bet/Heb
15-19/002	153660	190960	100	TULKAREM	110	Bet/Heb
15-19/003	152580	192970	78	SHWAIKAH	106	Bet/Heb
15-19/004	152400	193040	80	SHWAIKAH	132	Jen
15-19/005	152600	192750	69	SHWAIKAH	106	Jen
15-19/006	155920	191840	95	NUR SHAMS	96	Bet/Heb
15-19/007	159950	191500	148	'ANABTA	200	Bet/Heb
15-19/012	155730	191000	135	DHINNABAH	154	Bet/Heb
15-19/013	153470	191600	80	TULKAREM	80	Bet/Heb
15-19/014	152970	190020	72	TULKAREM	86	Bet/Heb

15-19/015	153240	190180	72	TULKAREM	80	Bet/Heb
15-19/016	151900	190300	58	TULKAREM	80	Bet/Heb
15-19/017	152400	190920	75	TULKAREM	100	Jer/Bet/Heb
15-19/018	152480	191900	65	TULKAREM	118	Jer/Bet/Heb
15-19/019	151970	191750	58	TULKAREM	160	Bet/Heb
15-19/020	152700	191650	68	TULKAREM	135	Bet/Heb
15-19/025	153640	193640	110	SHWAIKAH	132	Jen
15-19/028	156800	190100	140	KUFUR AL LABAD	175	Bet/Heb
15-19/030	154770	190910	115	DHINNABAH	157	Bet/Heb
15-19/033	151720	191000	55	TULKAREM	60	Jen
15-19/034	153750	193150	100	SHWAIKAH	120	Jer/Bet/Heb
15-19/038	154440	190880	116	DHINNABAH	136	Bet/Heb
15-19/039	154200	190200	125	DHINNABAH	135	Bet/Heb
15-19/043	154540	192040	80	IKTABAH	90	Bet/Heb
15-19/044	153500	192210	70	SHWAIKAH	85	Jer/Bet/Heb
15-19/045	153120	190110	70	TULKAREM		Bet/Heb
15-19/046	152920	191840	70	TULKAREM	201	Jer/Bet/Heb
15-19/048	159050	192800	210	BAL'A	295	Jer/Bet/Heb
16-19/001	161100	190400	153	'ANABTA	150	Jer/Bet/Heb
16-19/002	160970	190650	150	'ANABTA	200	Jer/Bet/Heb
16-19/011	160020	190980	135	'ANABTA	160	Bet/Heb

3.4.2 Groundwater Quality Data

The groundwater wells located alongside Wadi Zeimar show water contamination from untreated sewage from the western part of Nablus flows in the Wadi. In addition, industrial wastewater generated from Tulkarem and Nablus industrial areas flows into the adjacent valleys without any treatment causing the high chloride and nitrate levels in some nearby wells that exceeds the WHO guidelines for drinking water. The following Table 16 shows some chloride and nitrate levels for selected wells in the model study area. The high nitrate concentrations in some wells may be caused by solid waste leachate at the dumping sites located close to these wells.

Table 16: Chloride and Nitrate levels for selected wells in the model study area

Well Name	**NO_3 (mg/1)**	**CL (mg/1)**
Anabta Municipality 2	72	85
Beit Iba	32	48
Najeeb El Musa	26	68
Hannoun	35	50
Qubbaj	68	110
Hafez Hamdallah	65	90
Iqab Freij	54	188
Mustafa Said	29	354
Tulkarem Municipality 3	74	152

Source: Aliewi & Younger (1999)

The levels of Nitrates and chlorides are high knowing that the normal values for unpolluted water resources in the Zeimar catchments are around 20 mg/l and 50 mg/l for nitrates and chlorides respectively. Knowing that the WHO guideline values are 50 and 250 mg/l for nitrates and chlorides respectively.

It should be noted that the combination of high recharge rates, the karstic nature of the aquifers in the model study area, and uncontrolled sewage disposal mean that water supply boreholes in this area are at high risk of contamination from pollution.

Generally the groundwater in the model study area is good but there is evidence that the quality is deteriorating (Figures 10 & 11). Pollution-indicating parameters like Nitrate found in the samples from the upper aquifer of Anabta and Tulkarem are exceeding the WHO guideline value of 50 mg/l for drinking water by far. Monitoring in Tulkarem shows a bacterial pollution in approximately 20% of the samples taken by the Health Department (DAR-UG, 1998).

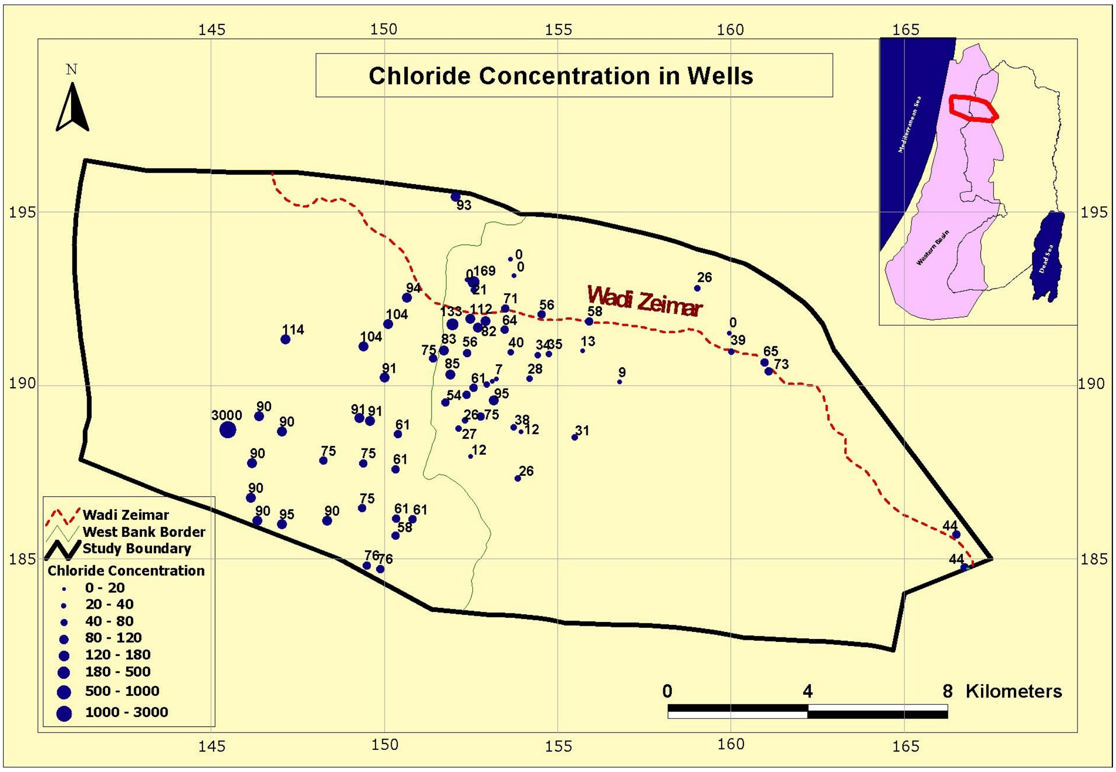

Figure 10: Chloride Concentrations in Tulkarem wells

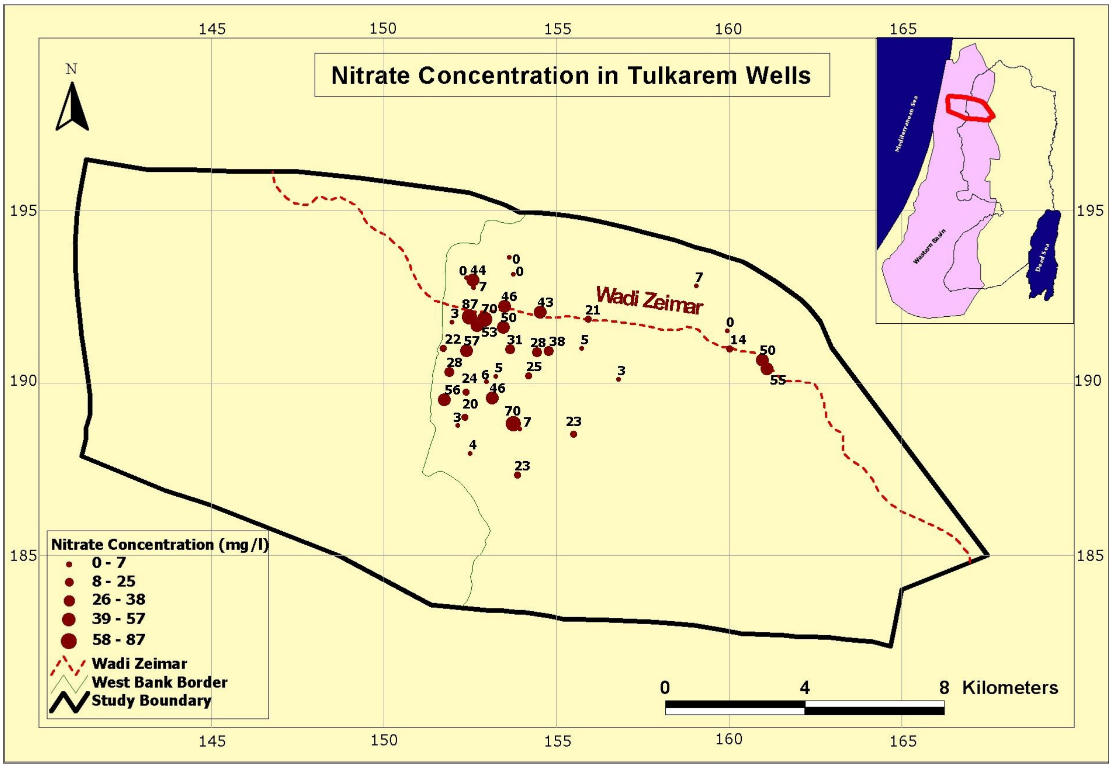

Figure 11: Nitrate Concentrations in Tulkarem wells

3.5 Land Use

The Tulkarem district covers approximately 33,453 hectares (Table 17), comprising 5.7% of the West Bank and 5.4% of Gaza Strip and West Bank. Currently, only 5.39% of the Tulkarem district contains Palestinian built-up areas, while approximately 2.73% is taken up by Israeli settlements, nature reserves, forests and military bases (Figure 12).

Table 17: Landuse Classification in the Tulkarem District

Landuse	Area (ha)	% of Land
Palestinian Builtup Areas	1,802.5	5.39
Israeli Settlements	317.0	0.95
Military Bases	7.5	0.02
Industrial Park	55.0	0.16
Nature Reserves	173.5	0.52
Forests	414.6	1.24
Cultivated Areas	12,810.5	38.30
Others*	17,872.4	53.42
Total	**33,453.0**	**100.00**
* Unused land or land used for grazing		

Source: (ARIJ 1996)

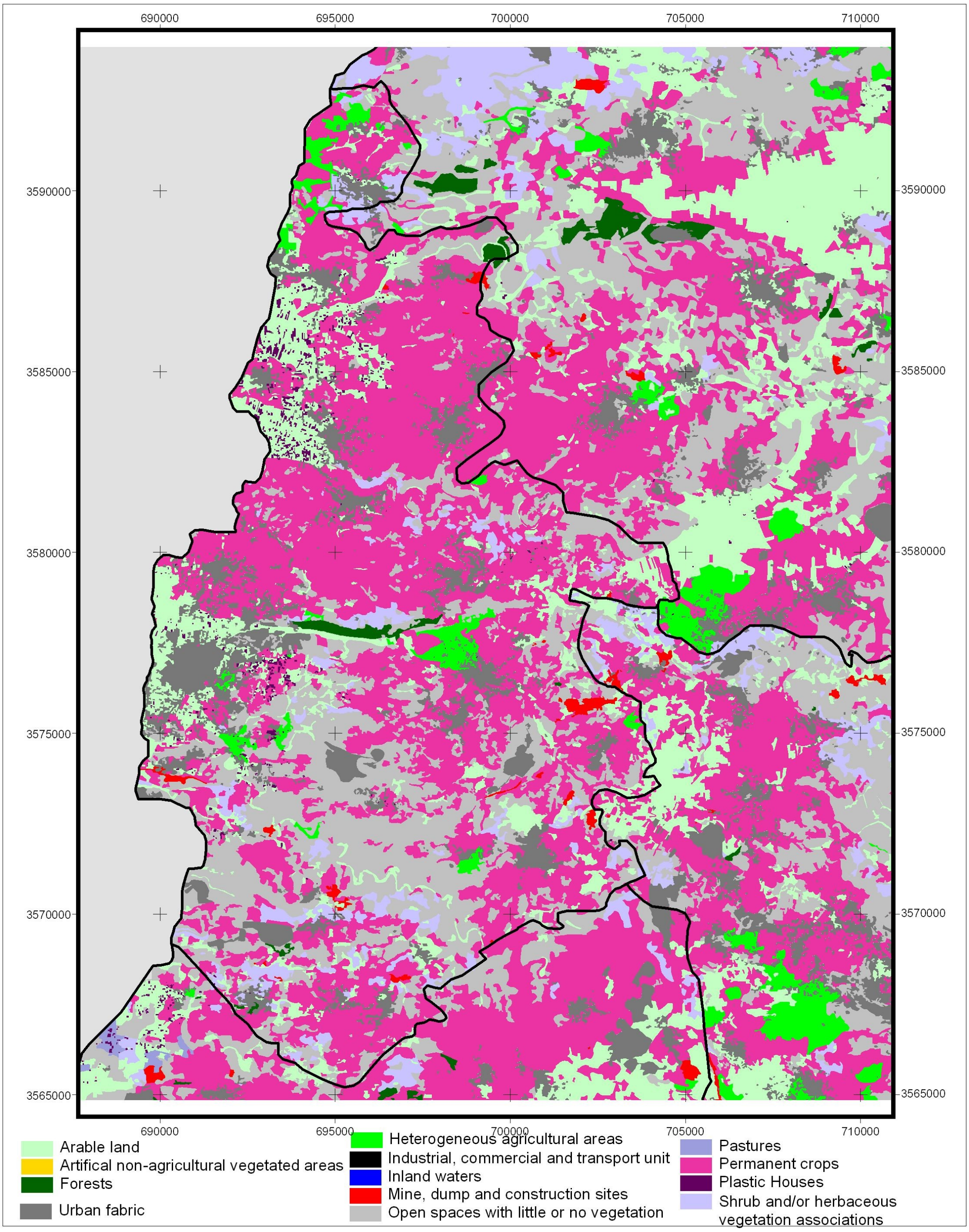

Figure 12: Landuse Map for Tulkarem Area
Source: (ARIJ, 1996)

3.6 Pollution Issues

3.6.1 Wastewater pollution

Wastewater is one of the major sources of pollution in the West Bank. Evidence for the domestic wastewater source of organic contamination in the model study area was collected by DAR-UG (1998) from measurements of anionic detergent concentrations for 26 water samples from wells tapping the area and four wastewater samples from Wadi Zeimar in the model study area. The anionic detergent concentrations in the sampled irrigation and domestic wells were in the range of 0.0-24.6 ppb and 0.0-6.1 ppb respectively which is below the EPA drinking water standard of 0.5 ppm. However any level of anionic detergent in a drinking water well definitely serves as an indication of contamination from human wastewater sources, since such detergents are non degradable and are derived only from household detergents found in domestic sewage. For the wastewater samples from Wadi Zeimar, the concentrations were in the range of 7.0-29.0 ppb. Levels of organic pollutants (in particular, NH4) were exceptionally high, and oxygen levels were extremely low. Measurements of BOD during and outside of the olive season showed approximately a three-fold difference, indicating the influence of olive pressing which forms by far the major non-residential land use in the Wadi Zeimar valley. Other smaller sources of pollution identified in the valley include leather tanning, tehina production, animal slaughter houses, quarrying and stone cutting, and other small-scale industries which lie mainly alongside the Wadi from Nablus to Tulkarem. Dumping of domestic waste and storm water overflow discharges from combined sewer overflow (CSO) systems may also affect pollution of water in the Wadi.

Raw sewage from the western pipeline of Nablus and Tulkarem sewage networks is discharged into Wadi Zeimar at a flow rate of 7,000 m3/day and 1,200 m3/day respectively (DAR-UG, 1998). The pressure from wastewater on the West Bank mountain aquifer is further intensified by the large amount of raw wastewater disposed by the Israeli settlements in the West Bank. The disposal of the wastewater from these settlements can be classified as follows:

- Wastewater collected and discharged to the nearby Wadis / valleys without treatment.
- Wastewater collected and disposed through the local Palestinian sewerage system.
- Wastewater collected and pumped to Israel over the green line.

The Israeli settlement program was not accompanied by adequate and proper environmental considerations. None of the settlements have developed sewage treatment plants. Sewage is often allowed to run into valleys even if a neighboring Palestinian village is threatened.

Appropriate management of wastewater has been neglected throughout the area of the West Bank: treatment and final disposal of wastewater is inadequate in both the Israeli and Palestinian communities in the area of the Western Aquifer. Both prior to and during the Israeli occupation, sewage collection networks in the West Bank are limited to major cities and to certain portions of these municipalities. Most of them are poorly designed and old. Leakage and flooding of the existing systems is therefore, common. In areas where sewage networks exist, wastewater is usually collected and discharged untreated into open areas in valleys.

The main pollution sources in model study area can be summarized as:

- Raw wastewater and industrial discharges drained into Wadi Zeimar, which infiltrates into the groundwater in the regions where the Wadi runs through sensitive areas.
- Wastewater infiltration into the groundwater from unsealed cesspits and absorption holes, including the disposal of untreated industrial wastewater through sewage networks and cesspits.
- Wastewater infiltration into the groundwater from Tulkarem wastewater ponds and sewer networks.
- Infiltration of irrigation water into the groundwater containing fertilizers and pesticides.

The quality of water in Wadi Zeimar is extremely poor and the Zeimar catchment area is considered one of the serious potential pollution sources over the highly permeable recharge area in the Western Basin. Sources of pollution include industries alongside the Wadi (plastic, stone cutting, olive mills and leather tanning), and uncontrolled dumping of domestic wastes (Figure 13). The wastewater collection is very poor – only Tulkarem City, Tulkarem Camp, Nour Shams camp and Anabta (Figure 14) have sewerage networks, the other villages using uncontrolled absorption holes that are discharged into the nearby Wadis. There is only one wastewater treatment plant in the model study area.

In the light of the above it is important to model the extent of sewage pollutants in the aquifer and to develop vulnerability map of the model study area.

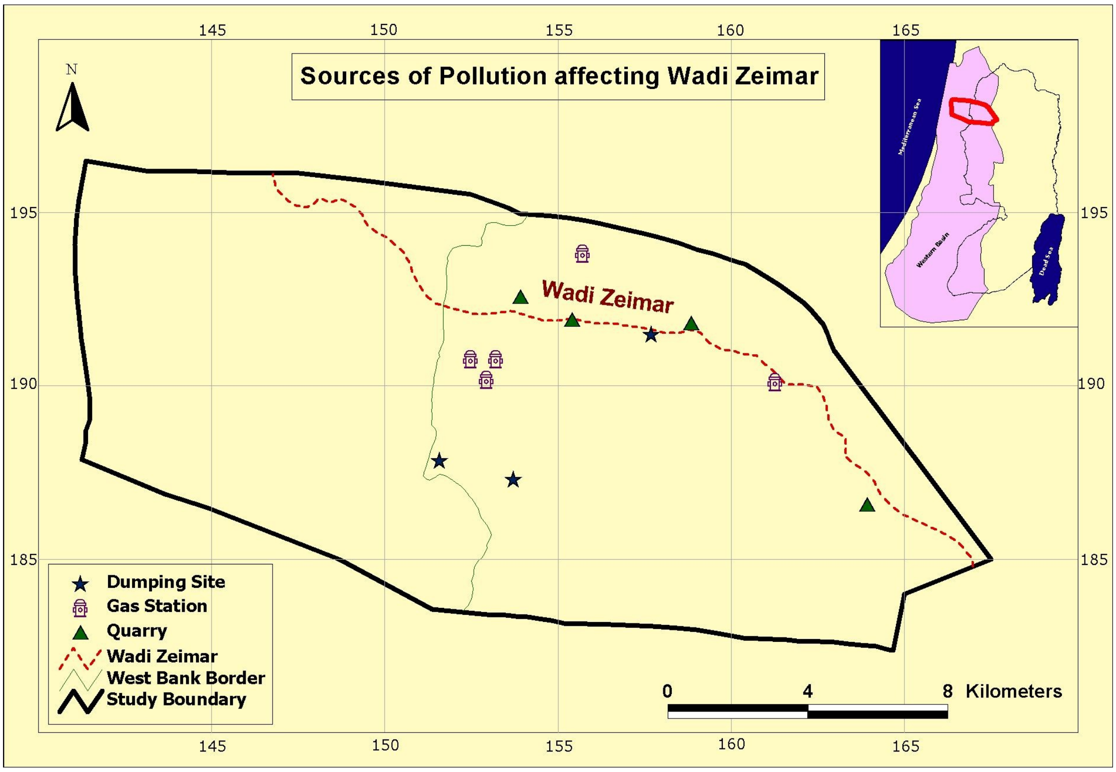

Figure 13: Sources of Pollution Affecting Wadi Zeimar

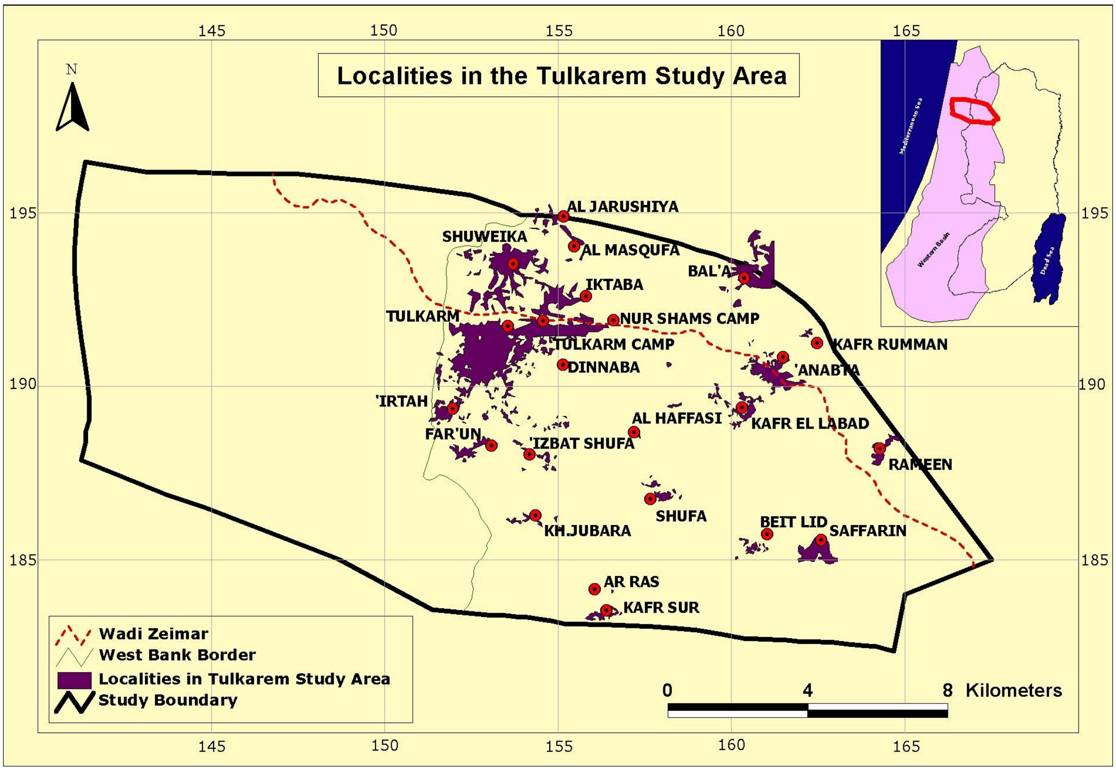

Figure 14: Localities in Tulkarem Area

Chapter 4

Groundwater Pollution Modeling in the Tulkarem Area

4.1 Modeling Approach

Many of the difficulties of modeling pollutant transport in karstic or fissured rocks can be attributed to uncertainties in determining the degree of contact between the contaminant and the rock matrix and the amount of delay or travel time, both of which affect attenuation processes. It can be difficult to determine the groundwater flow regime due to lack of information for identifying the distribution of fissures in the aquifer. Similarly, uncertainty about the geometry of fissures affects the movement of water between the fissures and the rock matrix, and the rock/water reactions that are dependent on the residence times of water in the aquifer. A further related difficulty is the determination of these same issues, in particular the residence times, in the unsaturated zone. Most previous modeling studies, especially at the regional scale (The Hebrew University (HU) & PCG, 1999) make simplifying assumptions related to the unsaturated zone travel times and mixing zones and mechanisms within the aquifer.

In this study, simplifying assumptions were made to allow a preliminary assessment of pollutant movement through the groundwater system. Only Darcian flow through the saturated zone of a single porosity, single permeability aquifer was modeled. Other modeling approach is dual-porosity modeling in which assumptions about karstic features will be part of the theory of the models. However, no to date models are comprehensively successful to modeling karst aquifers. Alternatively exasuration in hydraulic properties and dispersion properties are made to allow for modeling karst features in Darcian flow, as it has been shown that dispersivity and hydraulic properties are aquifer scale-dependant properties. Pollutant sources were taken effectively at the water Table, and transport through the unsaturated zone was not modeled. A conservative pollutant was modeled, nominally representing chloride as a tracer of the pollutant sources. Previous studies of the groundwater vulnerability in this area also used similar simplification (Aliewi &Younger, 1999). Although these assumptions are not strictly valid for this aquifer, the purpose of the modeling study was to obtain a preliminary assessment of the directions and timescales of pollutant movement within the flow system of a regional aquifer model that was developed within the SUSMAQ project.

4.2 Flow and Solute Transport Equations

4.2.1 The Flow Equation

A quantitative description of groundwater flow is a prerequisite to accurately representing solute transport in aquifers. A general form of the equation describing the transient flow of a compressible fluid in a non-homogeneous anisotropic aquifer may be derived by combining Darcy's law with the continuity equation (Anderson & Woessner, 1992). The general flow equation may be written in Cartesian tensor notation as:

$$\frac{\partial}{\partial x_i}\left[\frac{\rho K_{ij}}{\mu}\left(\frac{\partial p}{\partial x_j}+\rho g\frac{\partial z^*}{\partial x_j}\right)\right]=\rho\alpha\frac{\partial p}{\partial t}+\rho_o\varepsilon\beta\frac{\partial p}{\partial t}+\frac{\varepsilon}{V_o}\sum_{i=1}^{s}\frac{\partial m_i}{\partial t}+W^*\rho*\text{.......... ....}1$$

Where:

- Kij is the intrinsic permeability (a second-order tensor), L2;
- ρ is the fluid density, ML-3;
- μ is the dynamic viscosity, ML-1T-1;
- P is the fluid pressure, ML -1T-2
- g is the gravitational acceleration constant, LT-2
- Z* is the elevation of the references point above a standard datum, L;
- W* = W* (x,y,z,t) is the volume flux per unit volume(positive sign for outflow and negative for inflow), T-1;
- ρ* is the density of the source/sink fluid, ML-3
- α is the vertical compressibility coefficient of the medium, LM-1T2
- ρo is the fluid density at a reference pressure, temperature, and concentration, ML-3
- ε is the effective porosity (dimensionless);
- β is the compressibility coefficient of the fluid, LM-1T2;

- Vo is the reference volume of the fluid, L3;
- mi is the mass of species i in the reference volume Vo , M;
- s is the number of species, (dimensionless);
- Xi are the Cartesian coordinates, L; and
- t is time, T.

The Fluid density is a linear function of pressure and concentration, as indicated by the following relationship:

$$\rho = \rho_0 + \rho_0 \beta (P - P_o) + \frac{1}{V_o} \sum_{i-1}^{s} (m_i - m_{io}) \text{.......... .... .2}$$

Where P_o is the reference fluid pressure, $ML^{-1}T^{-2}$; and

M_{io} is the mass of species in the reference volume V_o at the reference pressure, M.

The density and viscosity of groundwater are both related to its temperature, pressure, and chemical content. Because isothermal conditions have been assumed, temperature changes need not be considered.

Equation 2 expresses the dependence of density on both the pressure and the mass concentrations of all species. Equation 2 may be rewritten in terms of concentration of a single chemical species of interest as:

$$\rho = \rho_0 + \rho_0 \beta (P - P_o) + \gamma (C - C_0) \text{......... ....}$$

Where: C is the mass concentration per unit volume of solution for the solute species of interest, ML^{-3}. C_0 is the concentration of the solute at the reference pressure and temperature, ML^{-3}. And γ is the constant of proportionality between concentration and fluid density (dimensionless).

If the relationship indicated by equation 3 is substituted for equation 2, then equation 1 may be rewritten as:

$$\frac{\partial}{\partial x_i}\left[\frac{\rho K_{ij}}{\mu}\left(\frac{\partial p}{\partial x_j} + \rho g \frac{\partial z^*}{\partial x_j}\right)\right] = \rho \alpha \frac{\partial p}{\partial t} + \rho_o \varepsilon \beta \frac{\partial p}{\partial t} + \varepsilon \gamma \frac{\partial C}{\partial t} + W^* \rho^* \text{.......... ....4}$$

Viscosity may be similarly expressed as a linear function of concentration by the following:

$$\mu = \mu_0 + \lambda (C - C_0) \text{......... ....}$$

Where: μ_0 is the dynamic viscosity of the fluid at the reference pressure, temperature, and concentration, $ML^{-1}T^{-1}$; and λ is the constant of proportionality between concentration and viscosity L^2T^{-1}.

Flow velocity is seepage velocity or average interstitial velocity, of groundwater flow and may be computed as:

$$V_i = \frac{q_i}{\varepsilon} \dots\dots\dots$$

Where V_i is the seepage velocity in the direction of x_i; LT^{-1}; and
q_i is the specific discharge, or specific flux; in the direction of x_i; LT^{-1}.

The specific discharge may be computed directly from Darcy's law, which is written as:

$$q_i = \frac{-k_{ij}}{\mu}\left(\frac{\partial P}{\partial x_j} + \rho g \frac{\partial z^*}{\partial x_j}\right) \dots\dots\dots$$

Groundwater flow can be expressed as:

$$\nabla \cdot (K\nabla h) = Ss\frac{dh}{dt} + Q(x, y, z, t) \dots\dots\dots$$

$$\nabla = \frac{\partial}{\partial x}\bar{i} + \frac{\partial}{\partial y}\bar{j} + \frac{\partial}{\partial z}\bar{k} \dots\dots\dots$$

$$K = \begin{bmatrix} K_{xx} & K_{xy} & K_{xz} \\ K_{yx} & K_{yy} & K_{yz} \\ K_{zx} & K_{zy} & K_{zz} \end{bmatrix} \dots\dots\dots \quad 10$$

$$\frac{\partial}{\partial x}\left(K_{xx}\frac{\partial h}{\partial x}\right) + \frac{\partial}{\partial x}\left(K_{xy}\frac{\partial h}{\partial y}\right) + \frac{\partial}{\partial x}\left(K_{xz}\frac{\partial h}{\partial z}\right) + \frac{\partial}{\partial y}\left(K_{yxx}\frac{\partial h}{\partial x}\right) + \frac{\partial}{\partial y}\left(K_{yy}\frac{\partial h}{\partial y}\right) + \frac{\partial}{\partial y}\left(K_{yz}\frac{\partial h}{\partial z}\right) +$$
$$\frac{\partial}{\partial z}\left(K_{zx}\frac{\partial h}{\partial x}\right) + \frac{\partial}{\partial z}\left(K_{zy}\frac{\partial h}{\partial y}\right) + \frac{\partial}{\partial z}\left(K_{zz}\frac{\partial h}{\partial z}\right) = Ss\frac{dh}{dt} + Q(x, y, z, t) \dots\dots\dots \quad 11$$

4.2.2 The Solute Transport Equation

It can be shown that the solute transport equation can be written as follows (Anderson & Woessner, 1992):

$$\varepsilon\frac{\partial C}{\partial t} = -\frac{\partial}{\partial x_i}\left(\varepsilon D_{ij}\frac{\partial C}{\partial x_j}\right) - \frac{\partial}{\partial x_i}(\varepsilon C V_i) - C' W^* + \varepsilon\sum_{k=1}^{S} R_k \dots\dots\dots \quad 12$$

Where:
C: The concentration of the solute (ML^{-3}),
ε: Porosity [1]
Dij: Dij is the coefficient of mechanical dispersion (a second-order tensor), L2T-1
And Dij is the coefficient of hydrodynamic dispersion (L2/T)

$$Dij = \alpha ijmn\frac{V_m V_n}{|V|} + D_m \dots\dots\dots$$

where: D_m is the coefficient of molecular diffusion (L^2/T)

α is the dispersivity tensor (L)

The dispersivity (α) of an isotropic porous medium can be defined by two constants:

α_L and α_T

For a two dimensional system:

$$D_{xx} = \alpha_L \frac{V_x^2}{|V|} + \alpha_T \frac{V_y^2}{|V|} \qquad \text{... 14}$$

$$D_{yy} = \alpha_T \frac{V_x^2}{|V|} + \alpha_L \frac{V_y^2}{|V|} \qquad \text{... 15}$$

$$D_{xy} = D_{yx} = (\alpha_L - \alpha_T) \frac{V_x V_y}{|V|} \qquad \text{... 16}$$

$$|V| = \sqrt{V_x^2 + V_y^2} \qquad \text{17}$$

Where

V is the groundwater velocity [L/T]

$$V_i = -\frac{K_{ij}}{\varepsilon} \frac{\partial h}{\partial x_j} \qquad \text{...}$$

C': is the concentration of the solute in the source or sink fluid, ML^{-3}.

W*: Other sources of solute influx [L3/T per unit volume] or [1/T]

$R_{k:}$ is the rate of production of the solute in reaction k of s different reactions (positive for addition of solute and negative for removal), $ML^{-3}\ T^{-1}$.

T: Time [T]

Xi, xj : Space [L]

4.3 Solution of Flow and Transport Equations in GMS

The GMS model solves the flow and solute transport models in a sequence. The flow equation is first solved and velocity values are obtained. These velocity values will be used to estimate initial values of dispersion coefficient. Then the solute transport equation is solved to produce new values of solute concentration, which will be used to update the density parameter in the flow equation, which will be solved again for the same time step. Then the loop will continue between flow and transport equation till equilibrium will be achieved. Then the model will repeat the same for the next time step in the same way as above till the simulation period is completed.

4.4 Model Description

The study area is part of the Western Aquifer Basin. A regional model for the Western Aquifer Basin was developed by the Palestinian Water Authority and the University of Newcastle upon Tyne (SUSMAQ, 2003). Figure 15 shows the water level results from the modeling studies of the Western Aquifer Basin. These modeling studies showed that some additional 100 Mcm/yr can be extracted on long term sustainable yield basis from the Palestinian zones of the Western Aquifer Basin.

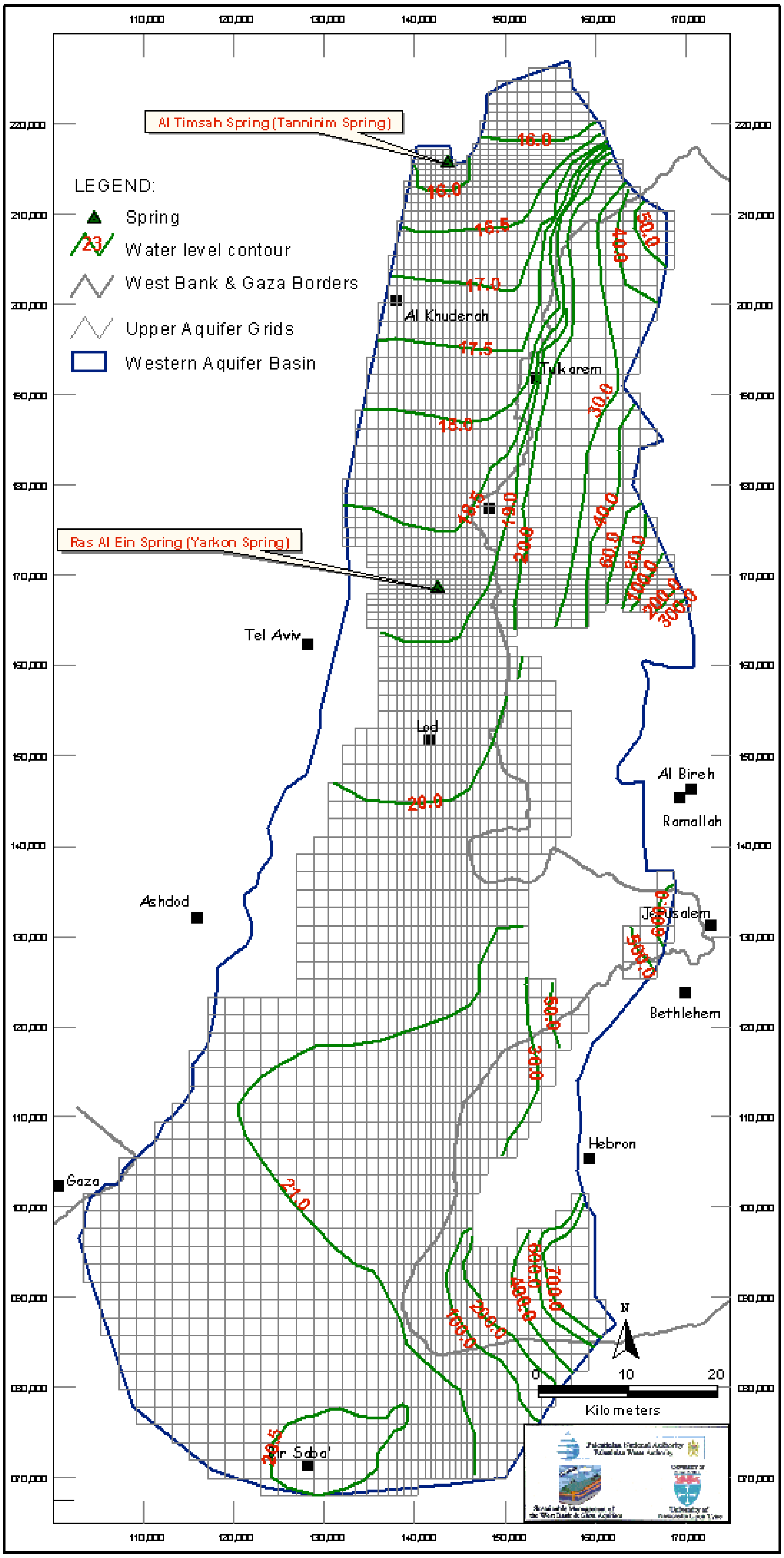

Figure 15: Simulated Water Levels for the Upper Aquifer for the Simulation Period, "1993-1998". (SUSMAQ, 2003)

In this research, a steady-state numerical model of the Tulkarem area was set up using the MODFLOW groundwater flow model (McDonald and Harbaugh, 1988), implemented within the GMS 3.1 (Groundwater Modeling System) graphical user interface. The model boundary comprises part of the district of Tulkarem, mainly a strip around Wadi Zeimar (Figure 16). The boundary was set to include the main sewage sources of pollution in the area. There are 67 Palestinian and Israeli wells in the model domain. The modeled area includes the city of Tulkarem and 22 surrounding villages, as well as towns and villages within Israel, and Israeli settlements within the West Bank. The model included the Upper and Lower Aquifers, as well as the Yatta formation as the aquitard. However, pollutant transport was modeled only for the Upper Aquifer because the lower aquifer is not utilized in the model area.

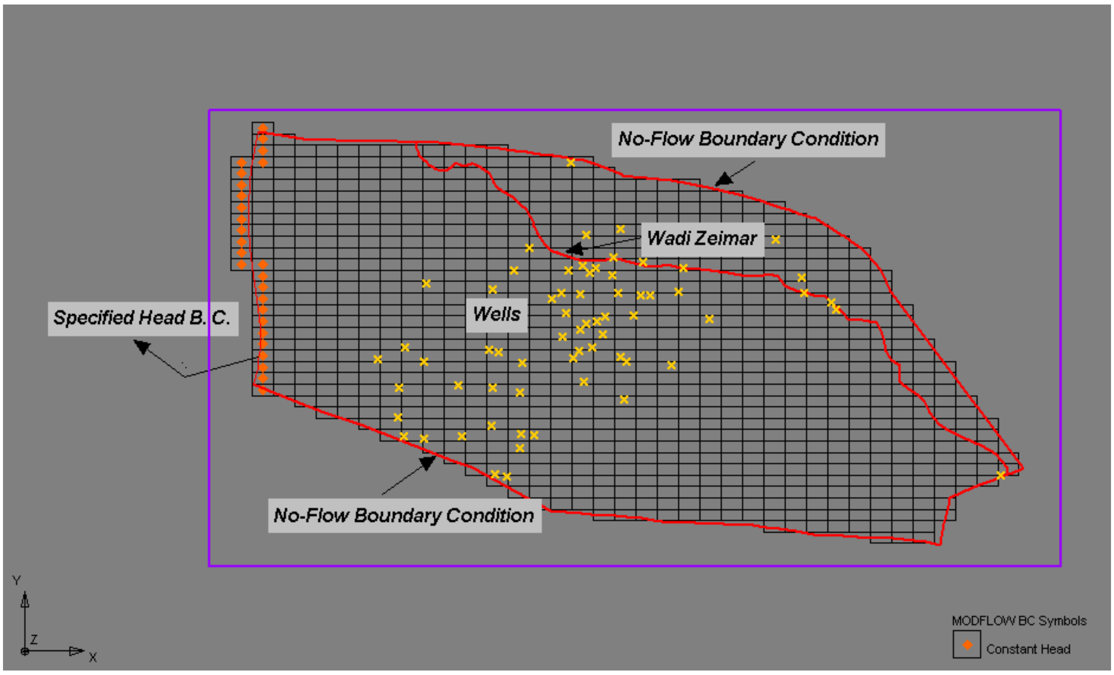

Figure 16: Finite-Difference Grid and Boundary Conditions for Tulkarem Area

The boundary conditions for the model were defined based on the groundwater levels from the regional flow model of the whole Western Aquifer Basin (the northern part of which is shown in Figure 15). The reason is that for many groundwater modeling studies, determining an appropriate set of boundary conditions can be difficult. It is often the case that classical boundaries such as rock outcroppings, rivers, and groundwater divides, may be located at a great distance from the site of interest. In such cases, it is often convenient to perform the modeling study in two phases.

In the first phase, a large, regional scale model is constructed and the model is extended to well-defined boundaries. During the second stage, a second, smaller, local scale model is constructed that occupies a small area within the regional model (Figure 20). The groundwater elevations computed from the regional model are applied as specified head boundary conditions to the local scale model. The layer data, including elevations and transmissivities, are also interpolated from the regional to the local model. A more detailed representation of the local flow conditions, including low capacity wells and barriers not included in the regional flow model can be constructed in the local scale model. Regional to local model conversion is often referred to as "telescopic grid refinement".

Groundwater flows from the high recharge areas in the West Bank converg regionally towards the major discharges at the Ras el Ein and Taninim springs, and locally towards major abstraction boreholes (Figure 17). No-flow boundary conditions were used for the eastern boundary at the limit of the outcrop of the upper Aquifer (note that the Wadi Zeimar flows from Nablus into the modeled area, since the surface water divide is further east than the model boundary), and for the northern and southern boundaries where the line of the boundary followed the regional groundwater flow direction. A fixed head boundary condition of 19.5 m above sea level was implemented at the western boundary, based on a piezometric level from the regional model.

Physical properties of the Upper Aquifer (upper and lower layer surfaces and transmissivities) were from the regional model onto the local model grid. In interpolated the local model region, lateral hydraulic conductivities ranged from 0.16 m/day in the higher eastern part of the model to 215 m/day in parts of the highly karstified and permeable aquifer along the coastal plain (Figure 18).

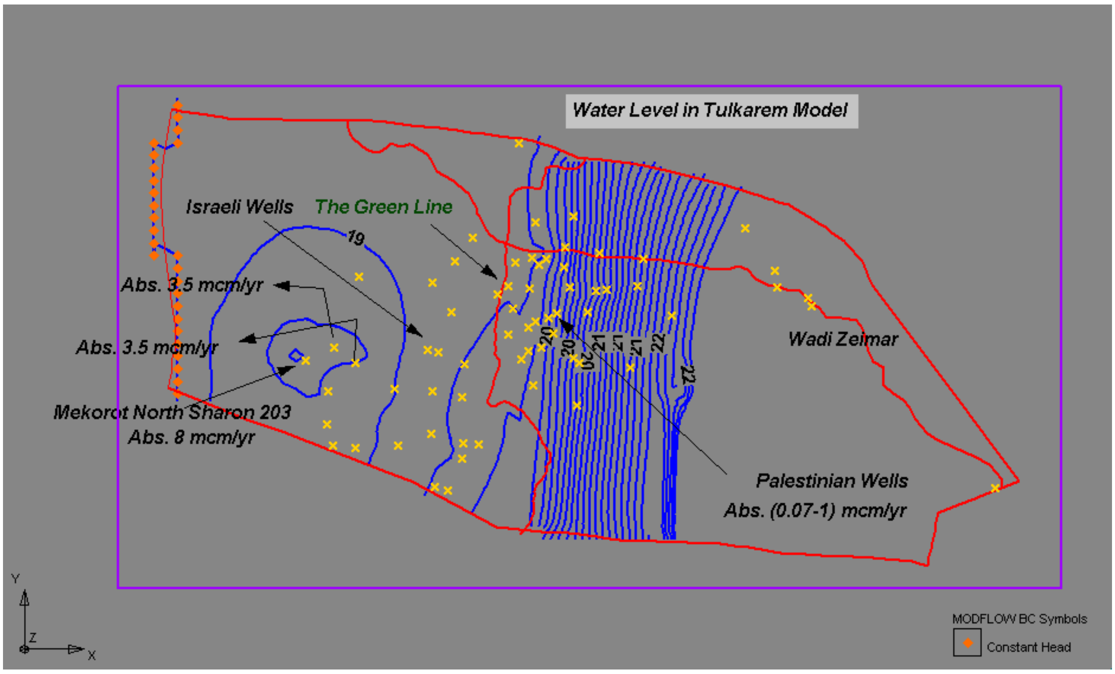

Figure 17: Groundwater Abstractions and Water Levels in Tulkarem Model

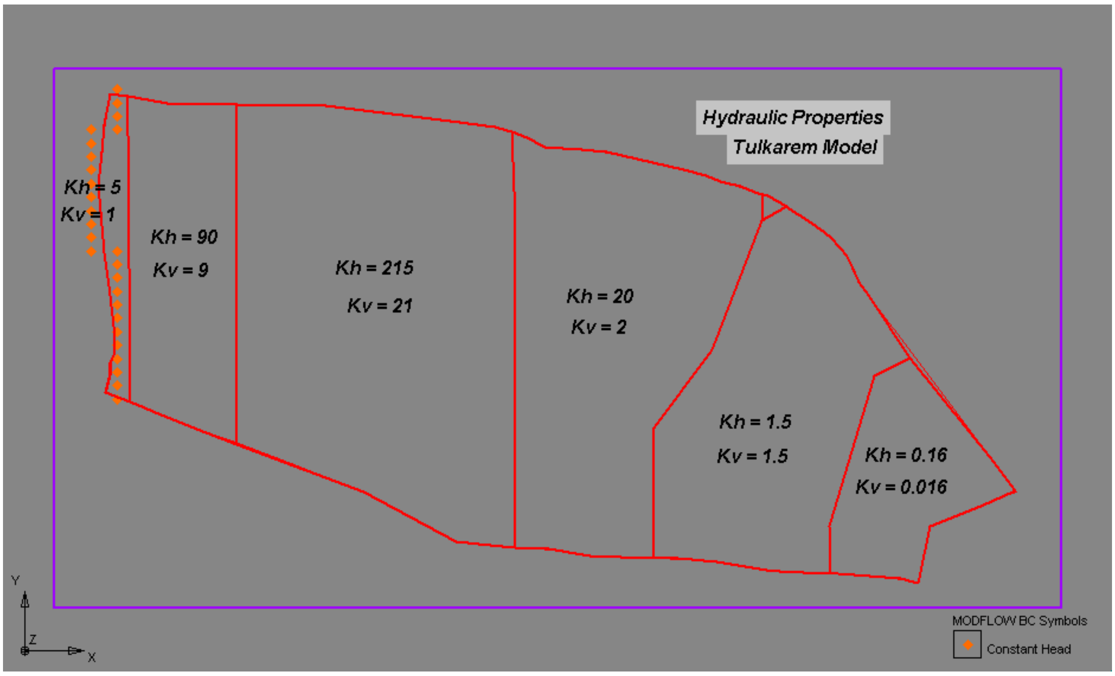

Figure 18: Hydraulic Properties for Tulkarem Model

The steady-state modeled groundwater levels (Figures 17 & 19) were consistent with those produced by the regional model (see Figures 15 & 20). Owing to the high permeabilities and greater aquifer thicknesses in the coastal plain region, the hydraulic gradients are very shallow in the western part of the model, whereas in the eastern part the hydraulic gradient is much steeper, reaching maximum groundwater levels of approximately 80 m above sea level (The water level contours above 22m are omitted in Figure 17 for clarity).

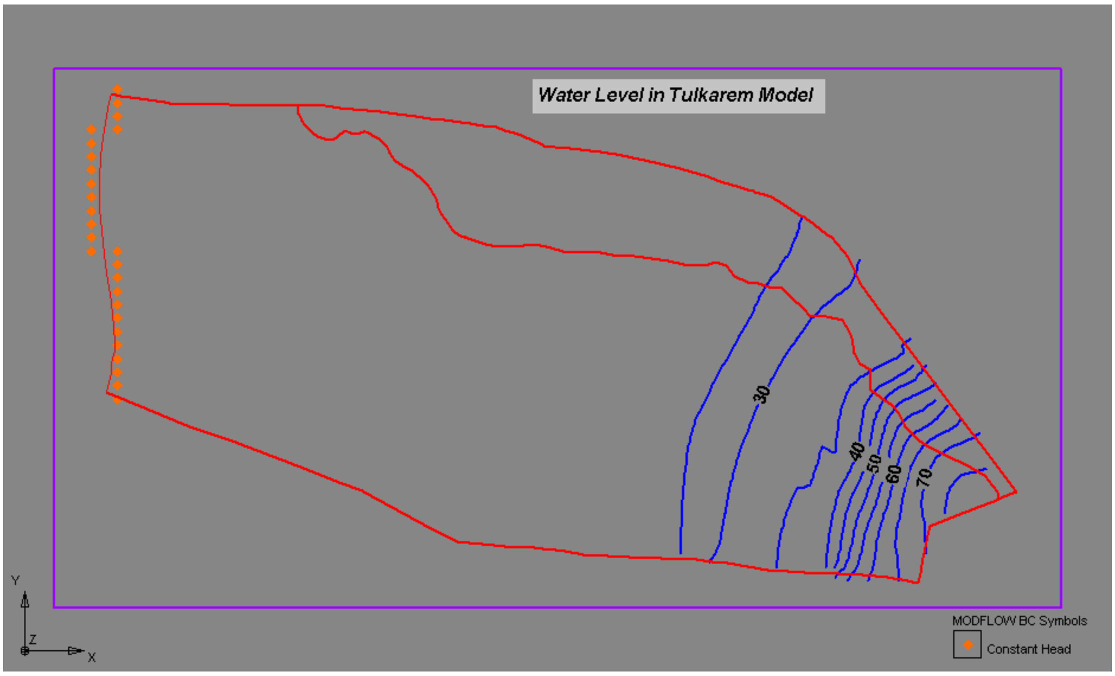

Figure 19: Ground Water levels for Tulkarem Area

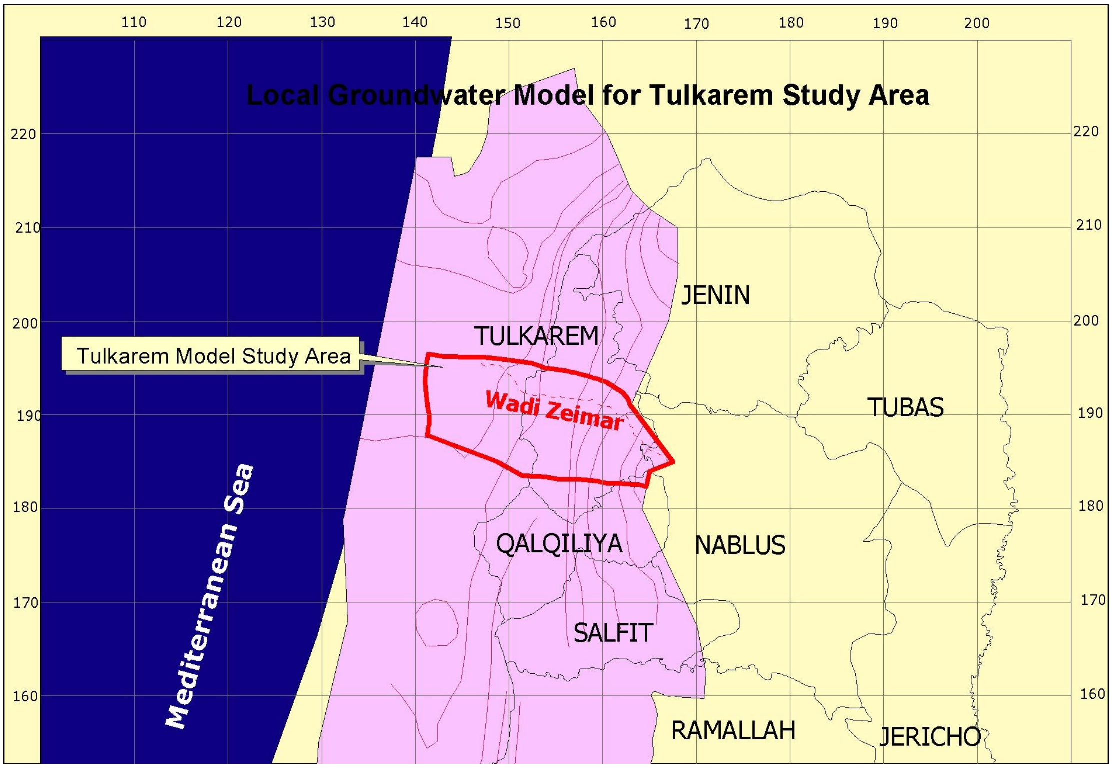

Figure 20: Local Groundwater Model for Tulkarem Area

Simulations of groundwater flow pathways and the movement of a conservative pollutant were modeled using the MODPATH and MT3D models respectively. MODPATH is a particle tracking model which represents the advective flow pathways from user-defined starting points. For this study, a set of start points in the eastern recharge area of the aquifer were used. MT3D contains a finite-difference solver for the advection-dispersion equation. The simulations were run for a conservative contaminant representing chloride. The steady-state groundwater flow model was used to determine the flow field, and transient transport simulations were run for constant concentration contaminant boundary conditions from specified sources. The purpose of the simulations was to determine the expected general flow directions and long term pollutant distributions for a continuing source input.

The aquifer properties affecting pollutant movement are porosity and dispersivity. A value for (effective) porosity of 0.1 was used (SUSMAQ, 2003), representing an intermediate value allowing for a relatively high amount of secondary porosity (total porosity would be expected to be higher). A dispersivity value of 50 m was used, which is typical of karstic system which have a large range of length scales affecting water flow pathways at the sub-REV (Representative Elementary Volume) scale.

Two simulations were run, to investigate and demonstrate the behaviour of the system for two of the main types of pollutant source identified. Firstly, a line source of 600 mg/l was specified along the upper part of Wadi Zeimar, representing high levels of infiltrating water from the Wadi, originating from wastewater discharges from the upstream Nablus discharges. A background concentration of 50 mg/l was used. Secondly, spatial pollutant sources of 150 mg/l beneath all Palestinian localities (population centres) were specified, representing direct inputs to the aquifer from unlined household cesspits and untreated municipal sewage systems.

4.5 Simulation Results

Groundwater flow pathlines in the Steady State Model starting from the upper (eastern) part of the model are shown in Figure 21, using the MODPATH particle tracking model. The pathlines are constrained by the regional groundwater flow direction, which is generally from east to west. There is no influence from recharge from the Wadi on the flow simulation. The dominant influence on the flow paths is from the Israeli Mekarot water supply wells, which form capture points for the particle tracking simulations. The far smaller abstractions from the Palestinian wells have negligible influence on the regional flow pathlines, although they would be expected to capture pollutants locally.

Figure 22 shows the long-term (after several decades) development of pollutant concentrations from the line source along Wadi Zeimar (Modeled Chloride concentrations from a Wadi source). The regional flow pathlines in this area closely follow the line of the Wadi, so there is little movement of the pollutant away from the Wadi. Some spreading occurs due to dispersion, but high levels of the pollutant remain only near to the Wadi.

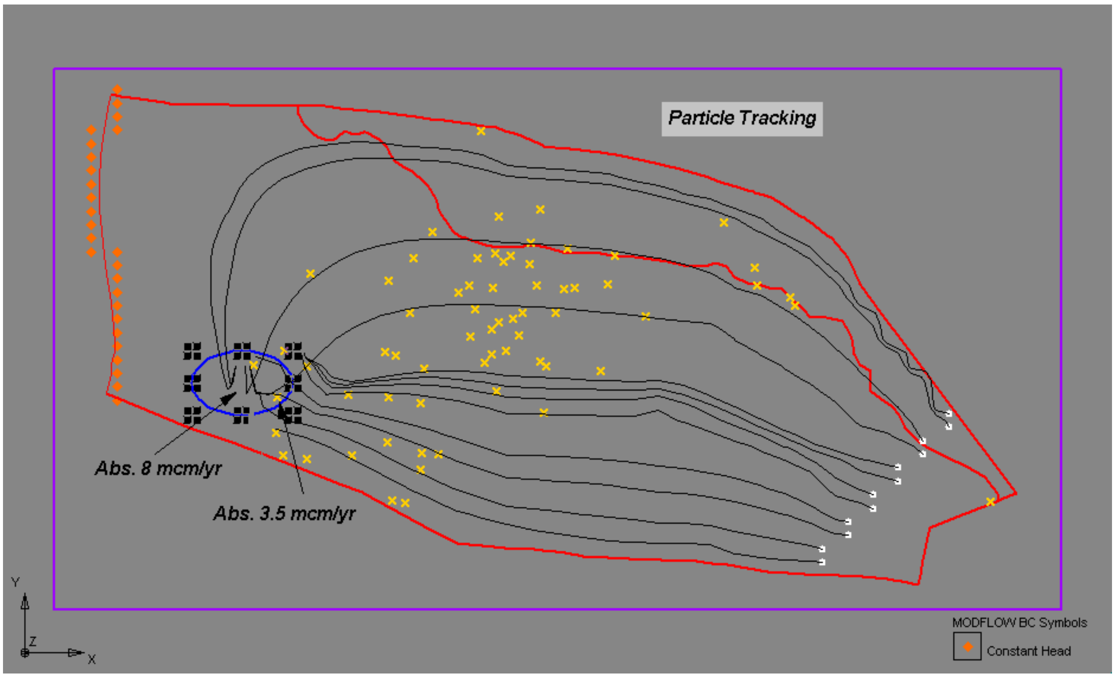

Figure 21: Particle Tracking Results for Tulkarem Area

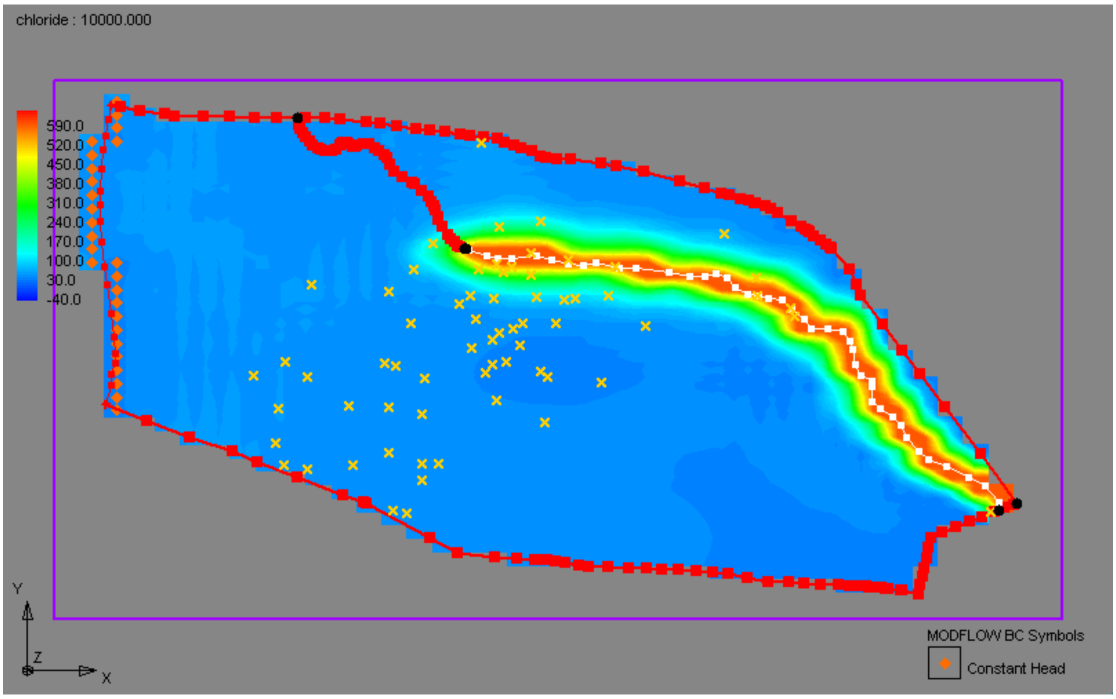

Figure 22: Chloride Concentrations from a Line Source along Wadi Zeimar, Tulkarem

Figure 23 shows the long-term development of pollutant concentrations from distributed sources associated with the main population centers (Modeled Chloride concentrations from population center sources). The highest concentrations remain beneath the population centres where they are continually replenished, with a migration of the pollutant plumes towards the Mekarot wells. The background concentrations in the upper parts of the aquifer have reduced due to gradually flushing by the high recharge rates in the outcrop areas.

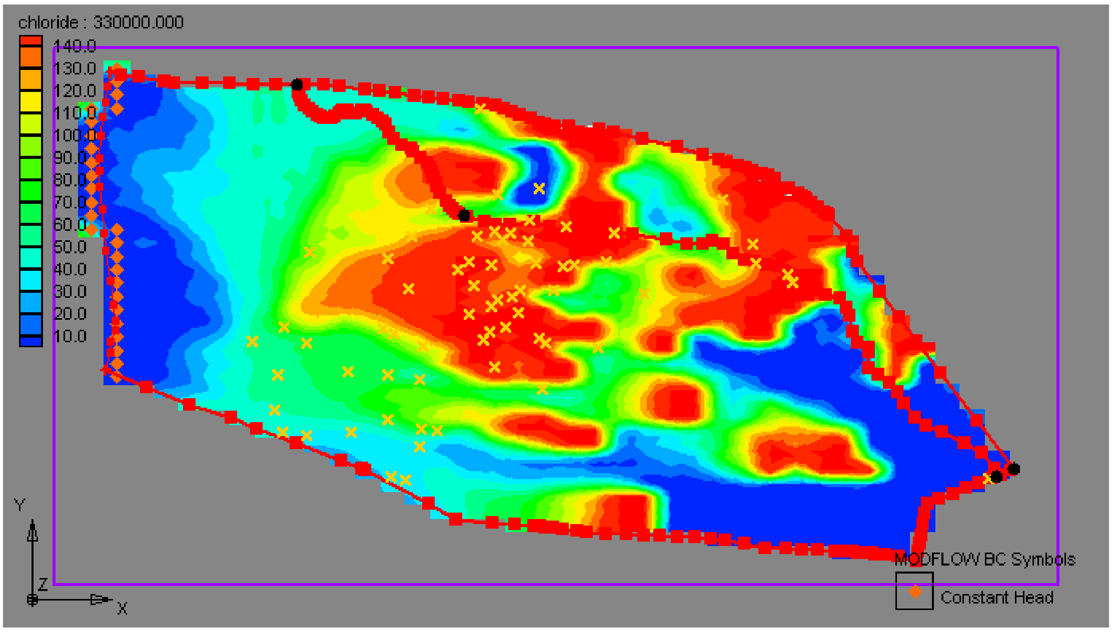

Figure 23: Chloride Concentrations from Distributed Sources Beneath Localities in Tulkarem Area

4.6 Discussion

The groundwater has been subjected to severe exposure to pollution sources from both nations (Palestine& Israel). The improper discharge of domestic wastewater, the intensive use of agricultural chemicals (fertilizers, herbicides and pesticides), the disposal of untreated industrial wastewater through sewage networks and cesspits, in addition to the dumping of solid wastes in unprotected dumping sites are major sources of potential groundwater pollution over the aquifer. The karstic nature of this limestone aquifer, which is characterized by fractures, may allow quick and unpredictable movement of such pollutants. All these practices may endanger the quality of water in this aquifer and may eventually result in damage to this major source of fresh water, which will affect Palestinians as well as Israelis.

The results above have demonstrated the interaction between groundwater flow fields and pollution sources in areas of significant abstraction, and help to emphasis that Wadi development is one of the key elements of water resources planning. The quality of groundwater in the Tulkarem area indicates a gradual increase in chloride and nitrate with time. Since the aquifers in Tulkarem districts are highly vulnerable due to their karstic nature, continued disposal of untreated domestic and industrial wastewater into the Wadi will lead to unacceptably poor water quality in drinking water, which may ultimately require expensive treatment if significant health problems are to be avoided. Improvements are required in wastewater treatment at the municipal and domestic levels, the latter requiring increased public awareness of the issues, as well as improved understanding of the hydrogeological behaviour of the aquifers. Possible actions which can be recommended to address these issues (many of which are being built into national approaches to water resources in Palestine (PECDAR, 2001) include:

- Develop aquifer management procedures supported by modeling
- Identify the most sensitive areas for protection of water resources
- Identify all sources of pollution
- Establish a quality-monitoring network
- Control and monitoring of agrochemical fertilizers and pesticides
- Implement treatment of industrial effluent
- Conduct environmental impact assessment for new developments
- Address historical hazardous waste dumps
- Develop and implement a monitoring and management program for cesspits.

Chapter 5

Assessment of Groundwater Vulnerability to Wastewater Pollution

5.1 Objective and Concept of Vulnerability

Vulnerability of groundwater to pollution is the tendency and likelihood for general contaminants to reach the water table after introduction at the ground surface. Groundwater pollution as a result of dumping raw sewage is a serious issue. The objective of this chapter is to develop a vulnerability map for the study area based on methods reported in the literature. This chapter will first introduce vulnerability assessment and factors affecting vulnerability then apply that to the study area.

The vulnerability potential of an aquifer to groundwater contamination is in large part a function of the susceptibility of its recharge area to infiltration. Areas that are replenished at a high rate are generally more vulnerable to pollution than those replenished at a slower rate. Unconfined aquifers that do not have a cover of dense material are susceptible to contamination. Bedrock areas with large fractures are also susceptible by providing pathways for contaminants. Confined, deep aquifers tend to be better protected with a dense layer of clay material. Wells that connect two aquifers increase the chance of cross contamination between the aquifers.

In addition to serving as a source of drinking source, a well can act as a direct pathway from land surface into the water supply. Thus a major consideration in groundwater contamination is the position and condition of the well. Most of the contaminants that commonly cause concern originate above ground, often as the result of human activities.

Soil overlying the water table provides the primary protection against groundwater pollution. Bacteria, sediment and other insoluble forms of contamination become trapped within the soil pores. Some chemicals are absorbed or react chemically with various soil constituents, thereby preventing or slowing the migration of these pollutants into groundwater. In addition, plants and soil micro-organisms use some potential pollutants, such as nitrogen, as nutrients for growth, thereby depleting the amount that reaches the groundwater.

Natural filtering capacity of soil can be overloaded when large amounts of potential pollutants are concentrated in a small area, which can cause localized groundwater contamination, depending on the depth and type of soil above the water table.

After an aquifer has been contaminated it is difficult to entirely define or isolate a contaminant plume. It is also difficult and extremely costly to remove it. Even after the source of contamination has been removed, an aquifer may remain contaminated for anywhere from years to a few centuries. Thus, it is often unrealistic to talk about a "cure" for groundwater contamination. Prevention is the key, and prevention includes finding the major sources of contamination, and learning to control them.

A map, which identifies the vulnerability of ground water in Palestine, must be prepared. In this research a vulnerability map for the Tulkarem area is developed. It is beyond the scope of this thesis to cover the entire West Bank, but the scope is rather to present the methodology of developing the vulnerability map to waste water pollution and there is no example better than choosing an area within which a permanent Wadi of sewage runs. Wadi Zeimar was taken as the case study in this research.

5.2 Assessing Vulnerability

The assessment of vulnerability is not comprehensive and different countries use different methods of assessment. In the literature a lot of methods have been developed for assessing groundwater vulnerability. Different approaches and methods have been developed in response to situations and pressures of individual countries.

Robins (1994) explained in detail the different methods of assessing vulnerability. Robins (1994) and MacDonald (2001) summarized the most important methods as:

1. Those methods that use indices to weight critical factors such as depth to groundwater, recharge, aquifer type, soil type, topography, and impact of hydraulic conductivity in the unsaturated zone. This method normally underestimates vulnerability in fractured aquifers and requires large aquifers.

2. Overlay method, which display interpreted information but do produce, combined indices. The main parameters of this method are soil type composition of unsaturated zone and depth to water table. In practice, the vulnerability maps developed by using this method usually do not have depth to water table. However, geological data are present in the map, therefore it is reasonably transparent.

3. Complex models of the physical, chemical and biological processes in the unsaturated zone. This method is used mainly for site specific pollution because data is not available for models over wider areas. These models in general are of little use in karstic area where groundwater can flow rapidly from the surface to the aquifer.

The method used in this study (the overlay) is rather a combination of geological formations based on their potentiality to recharge from rainfall.

5.3 Factors Affecting Vulnerability Assessment in the Study Area

1. Soil Zones

Thin soil zones will reduce the effect of attenuation and other biological processes. Bigger soil zones (unsaturated Zones) can cause reduction in the rate of subsurface flow and hence increase the travel time of pollutants in the groundwater system, which will eventually reduce the effect of pollution. The thicker the soil zone is, the lesser chance of groundwater resources pollution will be. The thickness of the soil zones in the study area is in the range of a few centimeters to about ten meters, which makes it difficult for sewage pollutants to enter the unsaturated rocky zone with strongly diluted concentrations.

2. Depth to Groundwater tables from Ground Levels

Shallow water tables mean that the time for a pollutant to reach the groundwater body will be less than that required to reach deep water levels. Less travel time will mean more chance of pollution. Consequently, on the way to reach water levels there will be less contact between the pollutant and the formation materials in the case of shallow water table in comparison with the degree of contact that takes place in the case of deep water levels. Less contact will mean less purification processes that may result in the reduction of the pollutant concentration (see Figure 24 below)

Water tables in the study area are considered shallow as far as the Upper Aquifer is concerned.

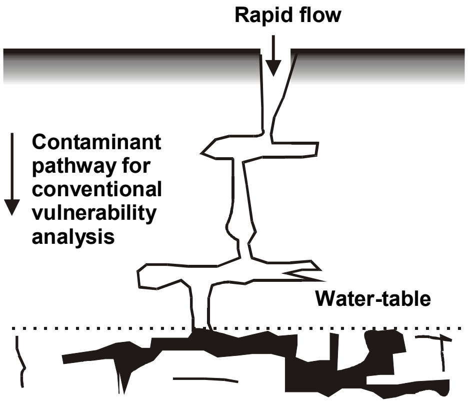

Figure 24: Contaminant Pathway
Source: MacDonald (2001)

3. Transmissvity of Aquifers

In principle carbonate rocks are not ideal for disposal of wastes to the ground because they can have high degrees of fracture and solution porosity (secondary permeability). (See Figure 25 below).

In karst formations, it is likely that rapid and larger quantities of pollution to take place, Low aquifer transmitivity and flat terrain mean that there is little regional groundwater flow. The difference between karstic of fissured rocks (secondary permeability) and the porous permeable rocks (primary permeability) is (a) the difference in the degree of contact between the contaminant and the rock matrix and (b) the difference in the amount of delay or travel time. The attenuation effects are better in primary permeability rocks than those in secondary permeability rocks.

It should be noted that the chalks of the Cretaceous- Tertiary transition age are not sensitive to pollution because of the impermeable nature they exhibit in the Tulkarem area. Fracturing, faulting, jointing and karstification are not efficient in chalk rocks and therefore, such rocks have almost no secondary permeability. These rocks also show low primary permeability. The rocks of Jerusalem, Bethlehem and Hebron show also low primary permeability but they have very high and well-established secondary permeability in terms of karstification. The very good aquifers of Jerusalem, Bethlehem, and Hebron outcrop in Wadi Zeimar. In deed these outcrops represent a major recharge proportion to the Upper Aquifer.

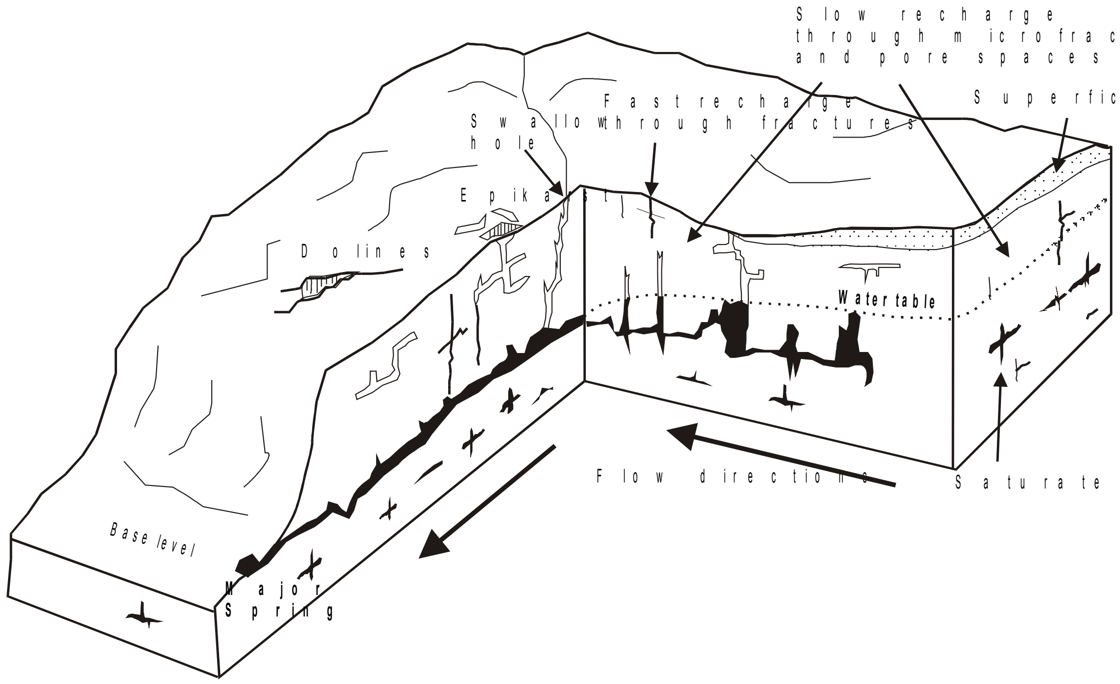

Figure 25: Karst in Aquifers
Source: MacDonald (2001)

4. Rainfall Infiltration

It is expected to have more risk of groundwater pollution in the areas where there are high rates of rainfall infiltration.

The study area is located on the most sensitive zone to groundwater recharge (< 250 mm/year). Therefore, the aquifer system in the vicinity of the study area is very sensitive to pollution. Annual precipitation rate is in the range of 640 mm in the Tulkarem area.

5.4 Vulnerability Mapping

5.4.1 Procedure Used to Develop the Vulnerability Map of the Tulkarem Area

Aquifers in the Tulkarem district have to be considered the most vulnerable natural sources in terms of pollution through wastewater. Since, the type of geological formations, like limestone, dolomite and chalk, and geological faults, are generally characterized by a high permeability. At the same time the aquifers depend on the high percolation rates of the geological formation for the recharge of the groundwater resources by rainfall.

The procedure used in this study is as follows:

1. A detailed geological map for the area was prepared.
2. The geological formations were classified according to their potential to recharge from rainfall.
3. The geological formations with similar potentiality were grouped.
4. A hydrogeological map was prepared by grouping the formations into auriferous and non-auriferous units.
5. The groundwater potentiality map was developed (e.g., the zones of groundwater utilization).
6. A land use map for the area was prepared.
7. Based on steps from 1-6 a vulnerability map was developed.
8. The above information (from 1-7) was compared to provide an insight of vulnerability of the aquifers in the study area to pollution.

5.4.2 Groundwater Resources Assessment

The first step in groundwater resources assessment (with regard to vulnerability mapping) is to study the hrdorgeological setting of the study area. This includes steps 1-5 from the above procedure:

Step 1: the geological map prepared by Rofe and Raffety (1965) for the study area was prepared. Rofe and Raffey's (1965) geological maps provide details of the individual geological formations. The geological maps developed by the Geological Services of Israel were also consulted for comparison.

Step 2: Classification of geological formations with respect to their recharge from rainfall. Under the SUSMAQ project activities (the following SUSMAQ reports should be consulted: Recharge modeling for the West Bank Aquifers; Conceptual model of the Natuf Catchment) such as the potential of the geological formations to recharge from rainfall was classified based on studying the following features: topography, climatic conditions, relief and land use. These features represent the main factors to classify the geological formations with respect to recharge from rainfall. The SUSMAQ studies such as (SUSMAQ, 2003) made the ranking for the Natuf catchment, a similar approach was used for ranking the recharge potential of the formation in the study area as shown in Table 18:

Table 18: Classification of Geological Formations in Study Area

Formation	**Potential for recharge**	**Ranking**
Jenin series 3	+	3
Abu Dis 5	-	5
Jerusalem 2	++	2
Bethlehem 2	++	2
Hebron 1	+++	1

Step 3: The above formations were grouped with regard to their hydrogeological origin forming the hydrogeological map for the study area. This map is shown in

Figure 26. The Upper aquifer formations (Jerusalem, Bethlehem and Hebron) are outcropping in the study area where there is no existence of the Lower Aquifer formations there. This adds extra significance to protect the groundwater resources because the Upper Aquifer in some places is connected vertically through fractures and faults with the Lower aquifer. This means that any pollution that takes place in the Upper aquifer is likely to reach the lower aquifer unless there is a strong hydraulic separation between the two aquifers. The Eocene outcrops in the upper tip of the study area while the Senonian formation is scattered in a few places as seen in Figure 26.

Step 5: development of groundwater potentiality map: Figure 27 is the groundwater potentiality map of the study area. Figure 27 shows the following 3 longitudinal strips. The western strip is located mainly in the recharge zone of the study area, while the middle strip is a hybrid between still functioning as a recharge area and towards its western position the discharge zone exists with moderate productivity. The western zone is considered the productive zone of the study area and as seen from Figure 27 most of the Palestinian wells are located in this zone. SUSMAQ (2001: Volume 1 of the compiled base data of the Western Aquifer) made full analysis about the potentiality of the Western Basin and Figure 27 is just a localization to the study area from of the full analysis on the Western Aquifer Basin. The method was based on on an integrated evaluation of the following parameters: drawing for the Western Aquifer Basin many geological cross sections from East to West, determining the geometry of the formations, dipping of formations, aquifer type and its saturated thickness, depth to water table, areas where outcrops extend and hence determination of recharge areas, aquifer hydraulic properties and existing abstractions. Based on these analyses, Figure 27 was developed. In terms of sensitivity to aquifer pollution the three strips are considered equally significant.

Step 6: Land use map. Land use map for the study area was discussed in section 3.5 in this thesis. All the land use activities (mainly agricultural and urban) in the area are considered to form risk of groundwater pollution because they are active on all zones of Figure 27. From analyzing the land use map of the study area (Figure 12) it is noticed that the majority of the study area is suitable for cropping and agriculture with arable lands to the west. Also the urban areas in the west (The city of Tulkarem) and villages scattered in the domain of the study area. Therefore, the major pollution threat comes from agricultural activities and urban sewage. The problem with that is the fact that the bulk of the study area is sensitive to highly sensitive to pollution as illustrated by the vulnerability map. To add to the critical situation, Wadi Zeimar runs on recharge and productive (discharge) zones of groundwater and therefore the entire study area needs to be protected.

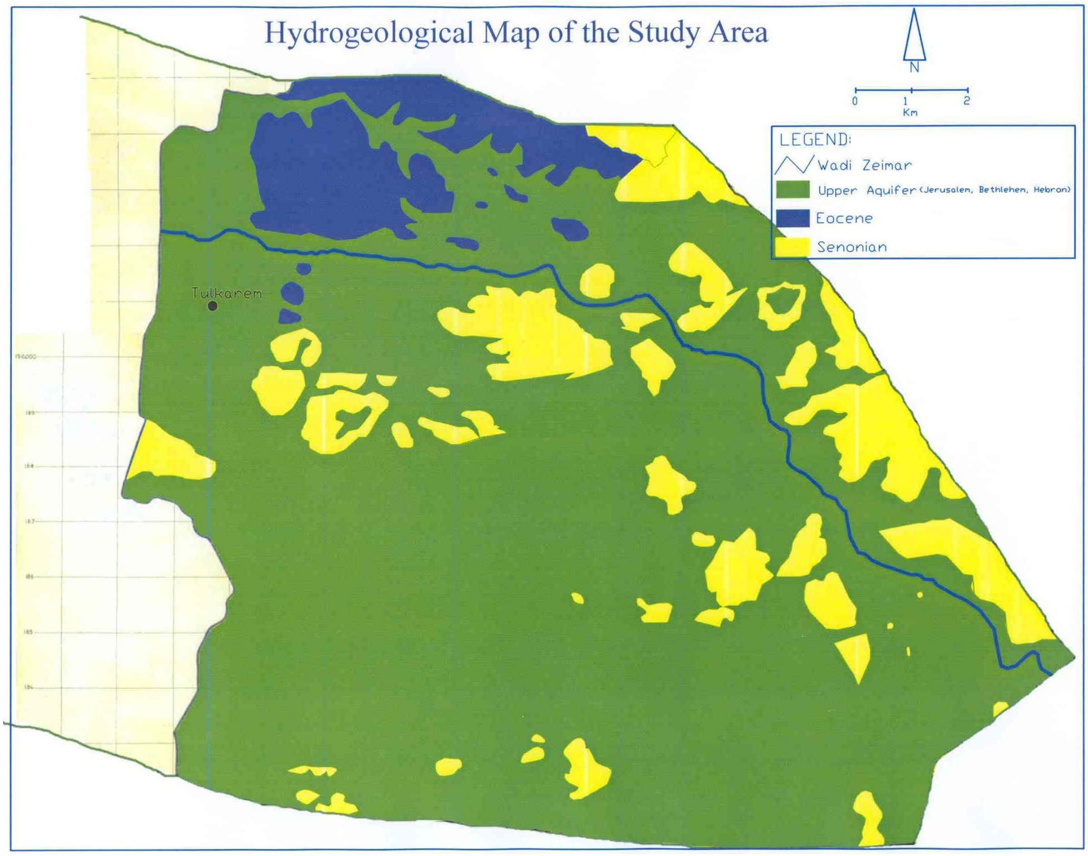

Figure 26: Hydrogeological Map of Study Area

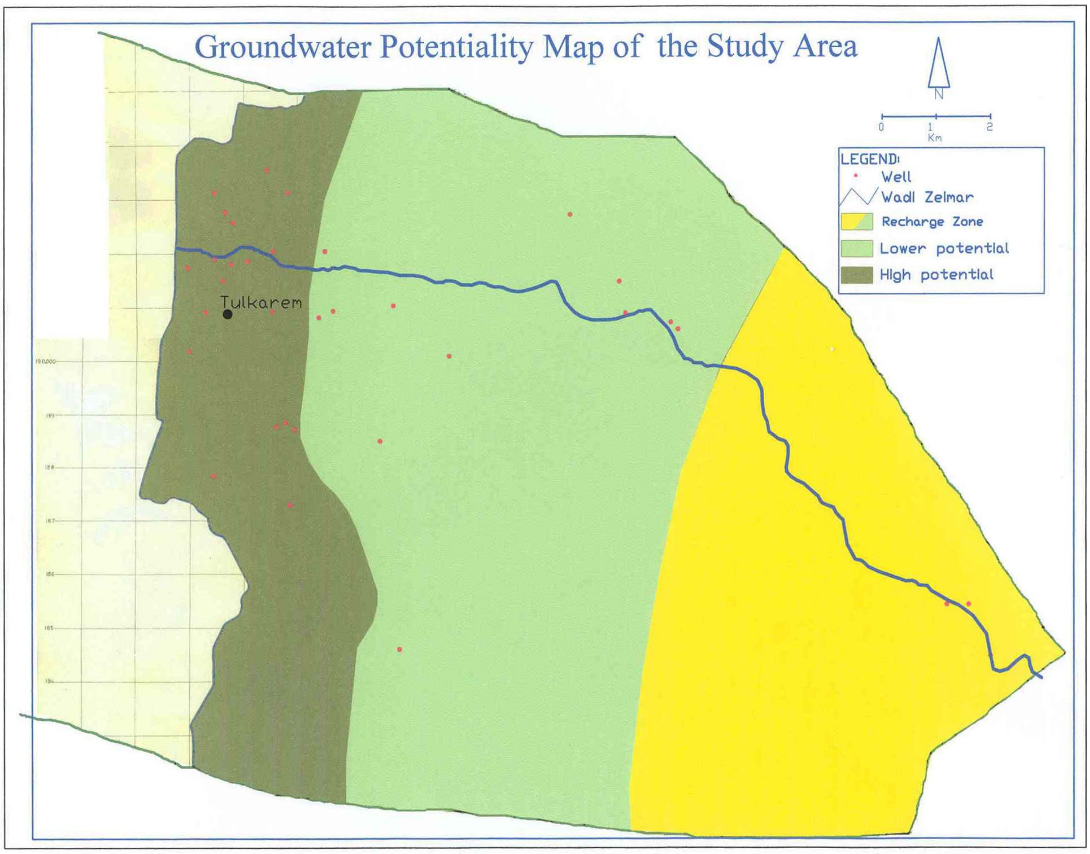

Figure 27: Groundwater Potentiality Map of Study Area

5.4.3 Groundwater Vulnerability to Pollution

The groundwater vulnerability to pollution is an intrinsic property of the aquifer to protect it from pollution. As explained earlier, the vulnerability of the aquifers to pollution in the study area took into consideration leaching capacity of the upper soil, depth to groundwater, transmissivity values, and rate of recharge.

Based on steps 1 to 6 by adopting the ranking in step 2 with regard to potential of the different geological formation to infiltration capacity, a groundwater vulnerability map for the study area is developed and shown in Figure 28.

To assess the threats to the groundwater aquifer by infiltration (from unlined cesspits and from the sewage Wadi itself) a general assessment based on available maps and information gathered for steps 1 to 6 was conducted by adopting the following classification in terms of potential pollution to the aquifer:

- Higly sensitive:Kch, Upper Cenomanian: Rank 1
- Sensitive: Kcb, Ktj, Qha, Turonian-Upper Cenomanian: Rank 2
- Medium sensitivity: Te-lu, Eocene: Rank 3
- Not sensitive: K/T-c, Senonian : Rank 5

Where:
Kch = Hebron Formation
Kcb = Bethlehem Formation
Ktj = Jerusalem Formation
Qha = Alluvial

The vulnerability of these aquifers to pollution is well recognized, and the Tulkarem area has been classified in a broad regional vulnerability study as being sensitive to highly sensitive.

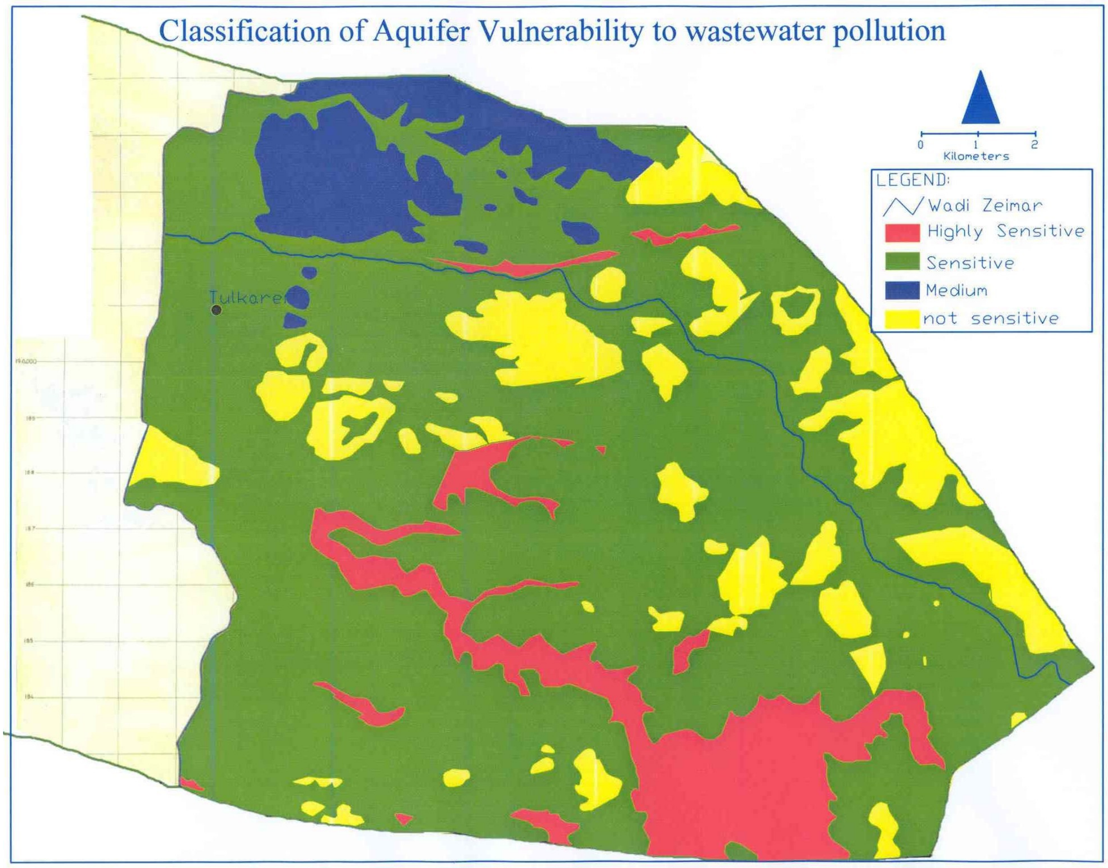

Figure 28: Classification of Aquifer Vulnerability to Wastewater Pollution

In order to protect groundwater resources in the study area:

1. Groundwater is polluted by the wastewater running in Wadi Zeimar. Nearly the whole course of Wadi Zeimar is running through areas sensitive to highly sensitive to groundwater pollution (Kcb, Ktj and Qha formations). On long term no raw wastewater should be discharged into Wadi Zeimar. If treated wastewater is discharged to the Wadi it should be treated to the required extent as necessary to protect the groundwater aquifer or conveyed by means of pipes with respective quality.
2. Groundwater is polluted by wastewater from unsealed cesspits, which exist to a large extent in the study area. On long term the villages located in sensitive areas should be connected to the sewerage network. In sensitive areas the connection to a sewer is not feasible, proper cesspits should be installed and frequent emptying ensured.
3. Groundwater is most likely polluted from wastewater discharged into the existing wastewater treatment ponds of Tulkarem (Qha formation) because there is no lining and percolation into the sub-soil is most likely. If used for the regional plant, the ponds should be lined.
4. Groundwater is potentially polluted by irrigation water from agricultural fields located in medium to highly sensitive areas. Proper management of the application of irrigation water should be enforced.

5.5 Specific Protection

This section is important when analyzing Figure 27 to decide to undertake further measures (including field work) to protect the highly productive strip where most of the abstractions exist. This can only be protected if its recharge zone is protected from pollution. This study recommends further analysis to protect the productive zones and this section is only providing some useful information to conduct such analysis.

Specific protection mainly concerns with the protection of part of the recharge area for water supply well fields. This level of protection is normally executed under the responsibility of provincial and local authorities. The goal of specific protection is to guarantee a groundwater quality that fits with the need for public water supply (UNESCO, 2002).

Measures to achieve this goal include limitation on activities at the land overlying the recharge areas. Zonation of protection areas is based on lines of equal travel time. Detailed hydrogeological studies and the application of numerical models are required to define the boundaries of the protection areas. The distinction between the different zones, leading to different protection measures. Restrictions on land use are more severe coming closer to the well field; Figure 29 below shows schematic representation of a groundwater protection area.

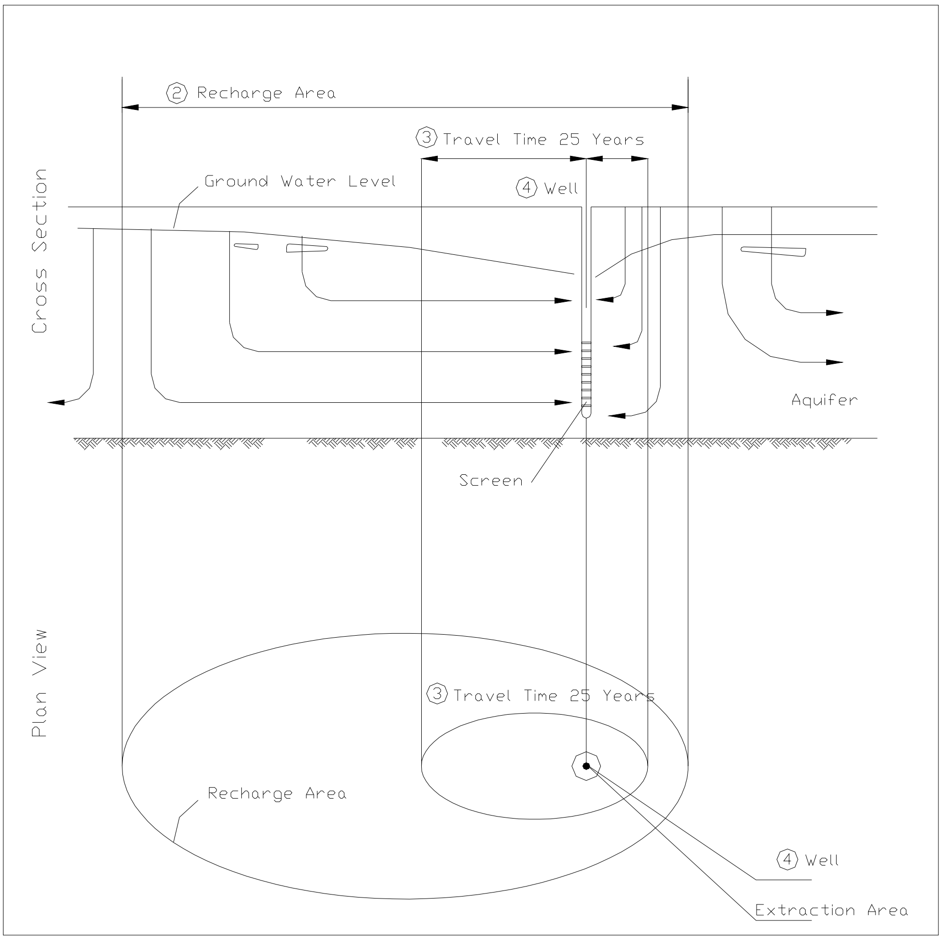

Figure 29: Schematic Representation of a Groundwater Protection Area

Travel time is the time it takes a water drop to flow from the point of infiltration to the wells. It is the average linear velocity of flowing groundwater using Darcy's law (Figure 30).

V = k/ne. dh/dx

Where

ne = effective porosity

K = permeability

dh/dx = groundwater gradient

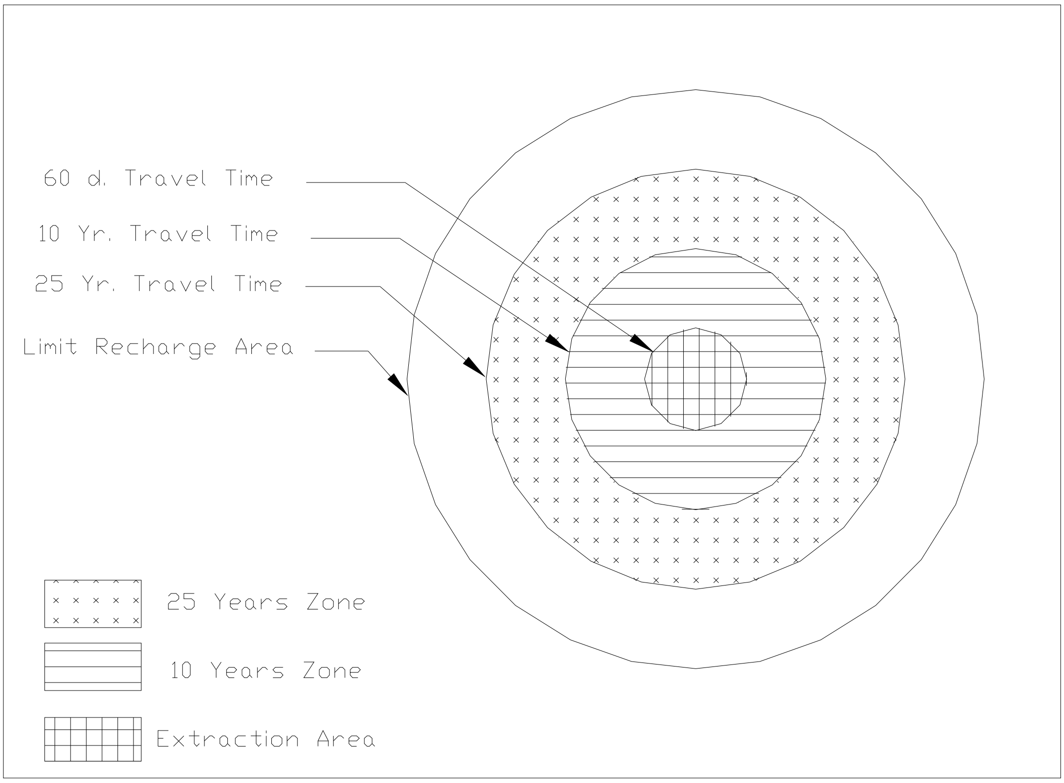

Figure 30: Travel Time

In specific protection areas restrictions can be imposed on:

- The use of fertilizers
- Use of certain pesticides
- Discharge of effluent
- Waste disposal or other harmful substances on or in the soil;

- Construction of roads, parking places, canals, railroads, cemeteries and recreation areas.

Chapter 6

Conclusions and Recommendations

6.1 Conclusions

Pollution is a major challenge in controlling the gap between available water resources and demand. The northern districts of the West Bank and subsequently the Tulkarem area are the major focus of this study. Pollution in these areas will place the available water resources at a major risk and therefore will substantially increase the gap between supply and demand. There have been many years of neglect with regard to dumping raw sewage on rocks and groundwater surfaces that are sensitive to pollution which lead eventually to polluting the ground and surface water resources in Palestine. Also, the combination of high recharge rates to the aquifers of the study area, the karstic nature of these aquifers, and uncontrolled sewage disposal mean that water supply boreholes in this area are at high risk of contamination from pollution.

The main pollution sources in the study area:

- Raw wastewater and industrial discharges (from plastic industry, stone cutting, olive mills and leather tanning) in wadis;
- Wastewater infiltration into the groundwater from unsealed cesspits and absorption holes, including the disposal of untreated industrial wastewater through sewage networks and cesspits.
- Wastewater infiltration into the groundwater from Tulkarem wastewater ponds and sewer networks.
- Infiltration of irrigation water into the groundwater containing fertilizers and pesticides.

The quality of water in Wadi Zeimar is extremely poor and the Zeimar catchment area is considered one of the serious potential pollution sources over the highly permeable recharge area in the Western Basin.

This study develops a steady-state numerical flow and solute transport models for the Tulkarem area. The steady-state modeled groundwater levels were consistent with those produced by the regional model. The study shows that the aquifer properties affecting pollutant movement are porosity and dispersivity.

The simulation results show that pollutant spreading occurs due to dispersion, and high levels of the pollutant remain are located near to the Wadi.

The results of this study have demonstrated the interaction between groundwater flow fields and pollution sources in areas of significant abstraction, and help to emphasis that Wadi development is one of the key elements of water resources planning. The quality of groundwater in the Tulkarem area indicates a gradual increase in chloride and nitrate with time. Since the aquifers in Tulkarem districts are highly vulnerable due to their karstic nature, continued disposal of untreated domestic and industrial wastewater into the Wadi will lead to unacceptably poor water quality in drinking water, which may ultimately require expensive treatment if significant health problems are to be avoided.

The study shows that nearly the whole course of Wadi Zeimar is running through areas sensitive to highly sensitive to groundwater pollution.

6.2 Recommendations

On long term no raw wastewater should be discharged into Wadi Zeimar. If treated wastewater is discharged to the Wadi it should be treated to the required extent as necessary to protect the groundwater aquifer or conveyed by means of pipes with respective quality.

Improvements are required in wastewater treatment at the municipal and domestic levels, the latter requiring increased public awareness of the issues, as well as improved understanding of the hydrogeological behaviour of the aquifers. The following are recommended possible actions to address these issues (many of which being built into national approaches to water resources in Palestine), (PECDAR, 2001):

- Develop aquifer management procedures supported by modeling
- Identify the most sensitive areas for protection of water resources
- Identify all sources of pollution
- Establish a quality-monitoring network
- Control and monitoring of agrochemical fertilizers and pesticides
- Implement treatment of industrial effluent
- Conduct environmental impact assessment for new developments
- Address historical hazardous waste dumps
- Develop and implement a monitoring and management program for cesspits.

Appropriate management of wastewater should be the focus in the planning and development plans of the Palestinian National Authority.

In order to protect groundwater resources in the study area:

1. No raw wastewater should be discharged into Wadi Zeimar. If treated wastewater is discharged to the Wadi it should be treated to the required extent as necessary to protect the groundwater aquifer or conveyed by means of pipes with respective quality.
2. On long term the villages located in sensitive areas should be connected to the sewerage network. In sensitive areas the connection to a sewer is not feasible, proper cesspits should be installed and frequent emptying ensured.
3. Existing wastewater treatment ponds of Tulkarem should be lined since groundwater is most likely polluted from wastewater discharged into these ponds of Tulkarem because there is no lining and percolation into the sub-soil is most likely.
4. Proper management of the application of irrigation water should be enforced since groundwater is potentially polluted by

irrigation water from agricultural fields located in medium to highly sensitive areas

REFERENCES

1. Aliewi, A., and Shaheen, H.,1996. Assessment of the Sensitivity of Aquifers and Identification of Requirements for the Disposal of Treated Wastewater of the proposed two sites of wastewater Treatment Plants for the Nablus Area.

2. Aliewi, A., and Younger, P., 1999. Assessment of Vulnerability of the Turonian-Upper Cenomanian Aquifer to wastewater disposal from the City of Nablus, Palestine.

3. Anderson, M., and Woessner, W., 1992. Applied Groundwater Modeling, Simulation of Flow and Advective Transport.

4. ARIJ, 1996.Environmental Profile for the West Bank: Tulkarem District.

5. BOSS International, 2000.GMS (Groundwater Modelling System), User's Manual.

6. CDM / Morganti, 1997. Task 19: Two Stage Well development Study for additional Supplies in the West Bank: Stage 2, Well Development Study.

7. CH2MHILL, 2002. Integrated Water Resources management Plan.

8. CH2MHILL, 2003. Management analysis Tool.

9. DAR-UG, 1998. Deutsche Abwasser Reinigungs- Gesellschaft & Universal Group. Sewerage Project Tulkarem – Region, Inception and Strategy. Report 1, November 1998.

10. DAR-UG, 1999. Deutsche Abwasser Reinigungs- Gesellschaft & Universal Group. Sewerage Project Tulkarem – Region, Draft Feasibility Study-Report 3, November 1999.

11. GTZ, 1996. Middle East Regional Study on Water Supply and Demand Development, Phase II Report.

12. GTZ, 1997. Middle East Regional Study on Water Supply and Demand Development, Phase III Report.

13. McDonald, M., and Harbaugh, A., 1988. MODFLOW, A modular 3-dimensional finite-difference groundwater flow model, US Geological Survey Open-File Report 83-875, Chapter A-1.

14. MacDonald, 2001. Technical note: groundwater protection and aquifer vulnerability, British Geological Survey.

15. MOPIC (Ministry of Planning and International Cooperation), 1998. Sensitive Water Resources Recharge Areas in the West Bank Governorates. Emergency Natural Resources Protection Plan.

16. PCBS, 1999. Small Area Population.

17. PECDAR, 2001. Palestinian Water Strategic Planning Study. Palestinian Economic Council for Development and Reconstruction and the Palestinian Water Authority, Palestine.

18. PWA, 2001.Technical Background on Water Issues for the Final Status Negotiations-Technical Report. Palestinian Water Authority, Ramallah, Palestine.

19. Robins, 1994. Groundwater pollution, aquifer recharge and vulnerability, Geological Society, London special publications.

20. Rofe and Raffety, 1965. Geological Maps.

21. SUSMAQ, 2001. Data Review on the West Bank Aquifers.

22. SUSMAQ, 2001. Volume 1 of the compiled base data of the Western Aquifer.

23. SUSMAQ, 2003. Steady State Flow Model of the Western Aquifer Basin.

24. SUSMAQ, 2003. Recharge Modeling of the West Bank Aquifers.

25. The Hebrew University & Palestine Consultancy Group, 1999. Environmental protection of the shared Israeli-Palestinian Mountain Aquifer, Final Report.

26. UNESCO, 2002. Development of Groundwater Protection Criteria.

Bibliography

1. Aliewi, A., and Assaf, K., 2003. Assessment of Demand Management and Pollution Control in Palestine. Proceedings of Water Demand and Pollution Control Conference, Sharm El Sheikh, Egypt.

2. Aliewi, A., Salih, K., and Yaqubi, A., 2004. Assessment of Palestinian Water Policies towards Sustainable Management of Water Resources. Proceedings of the Arab Water 2004 Conference. Cairo, Egypt.

3. Al Khatib, I., 2003. Water – Health relationships in developing Countries: A case study in Tulkarem District in Palestine.

4. ARIJ, 1996.Environmental Profile for the West Bank: Nablus District.

5. ARIJ, 1996. Environmental Profile for the West Bank: Jenin District.

6. ARIJ, 1997. Water Resources and Irrigated Agriculture in the West Bank

7. ARIJ, 2002. Analysis of Waste Management Policies in Palestine: Data Collection Report.

8. Bachmat, Y., and Wollman, S., 2000. Evaluation of the Vulnerability of the Western Mountain Aquifer to Pollution, Israel.

9. Environment Agency, 2001. Conference Proceedings, Protecting Groundwater.

10. Fekry, A., and Smidt, E., Groundwater Protection in Egypt: Recent Developments and Future Applications.

11. Hydrological Service of Israel, 1999. Development of utilisation and status of water resources in Israel until Fall 1998. Ministry of National Infrastructure. Water Commission. (In Hebrew).

12. Ministry of Environmental Affairs (MEnA), 2000. The Palestinian Environmental Assessment Policy.

13. MOPIC, 1998. Sensitive Water Resources Recharge Areas in the West bank Governorates.

14. PASSIA, 2003.Water in Palestine: Problems – Politics – Prospects.

15. PCBS, 1997. "General Census".

16. PCBS, 2000.Wastewater Statistics in the Palestinian Territory.

17. PWA, 2003. Effects of the Israeli occupation on the Palestinian Wastewater Infrastructure with special emphasis on related compensations.

18. PWA, 2003. Wastewater Management Plan.

19. RIGW, 1999.Contributions to Environmental Management of Egypt's Groundwater Resources, final report EMGR Project.

20. Sawalhi, B., Mimi, Z., and Aliewi, A., 2001. Multi-Criteria Decision Tool for Allocating the Waters of the Jordan Basin between all Riparians. Proceedings of AWRA/IWLRI Conference on Globalization and Water Resources management: The changing Value of water. Dundee August 6-8.

21. UNEP, 2003. Desk Study on the Environment in the Occupied Palestinian Territories.

Geology in Tulkarem Study Area
N
145
150
155
160
165
195
190
185
Wadi Zeimar
Mediterranean Sea
Western Basin
Dead Sea
Study Boundary
Wadi Zeimar
West Bank Border
Geology
Eocene
Quaternary
Senonian
Turonian
Upper Cenomanian
0
4
8 Kilometers


Localities in the Tulkarem Study Area
N
145
150
155
160
165
195
190
185
AL JARUSHIYA
SHUWEIKA
AL MASQUFA
BAL'A
IKTABA
TULKARM
NUR SHAMS CAMP
TULKARM CAMP
KAFR RUMMAN
DINNABA
'ANABTA
'IRTAH
AL HAFFASI
KAFR EL LABAD
FAR'UN
'IZBAT SHUFA
RAMEEN
SHUFA
KH.JUBARA
BEIT LID
SAFFARIN
AR RAS
KAFR SUR
Mediterranean Sea
Western Basin
Dead Sea
Wadi Zeimar
West Bank Border
Localities in Tulkarem Study Area
Study Boundary
0
4
8 Kilometers

Sources of Pollution affecting Wadi Zeimar
N
Wadi Zeimar
Mediterranean Sea
Western Basin
Dead Sea
145
150
155
160
165
195
190
185
Dumping Site
Gas Station
Quarry
Wadi Zeimar
West Bank Border
Study Boundary
0
4
8 Kilometers


Rainfall Zones in Tulkarem Study Area
N
Wadi Zeimar
Mediterranean Sea
Western Basin
Dead Sea
Wadi Zeimar
West Bank Border
Study Boundary
Average Rainfall
500-550
550-600
600-650
0
4
8 Kilometers
145
150
155
160
165
195
190
185


Tulkarem Study Area
N
S
W
E
Study Area
TULKAREM
Wadi Zeimar
JENIN
TUBAS
QALQILIYA
NABLUS
SALFIT
RAMALLAH
JERICHO
JERUSALEM
BEITLEHEM
HEBRON
WESTERN BASIN
Mediterranean Sea
DEAD SEA
0 10 20 Kilometers
Wadi Zeimar
Study Area
West Bank Districts
Western Basin

Water Level in the Study Areas
Tulkarem Model Study Area
Wadi Zeimar
TULKAREM
JENIN
TUBAS
QALQILIYA
NABLUS
SALFIT
RAMALLAH
JERICHO
Mediterranean Sea
110
120
130
140
150
160
170
180
190
200
220
210
200
190
180
170
160

Local Groundwater Model for Tulkarem Study Area
Tulkarem Model Study Area
Wadi Zeimar
Mediterranean Sea
JENIN
TULKAREM
TUBAS
QALQILIYA
NABLUS
SALFIT
RAMALLAH
JERICHO
110
120
130
140
150
160
170
180
190
200
220
210
200
190
180
170
160


Chloride Concentration in Wells
N
Wadi Zeimar
Mediterranean Sea
Western Basin
Dead Sea
Wadi Zeimar
West Bank Border
Study Boundary
Chloride Concentration
0 - 20
20 - 40
40 - 80
80 - 120
120 - 180
180 - 500
500 - 1000
1000 - 3000
0 4 8 Kilometers
145 150 155 160 165
195 190 185

Nitrate Concentration in Tulkarem Wells
N
Wadi Zeimar
Mediterranean Sea
Western Basin
Dead Sea
145
150
155
160
165
195
190
185
Nitrate Concentration
0 - 7
8 - 25
26 - 38
39 - 57
58 - 87
Wadi Zeimar
West Bank Border
Study Boundary
0
4
8 Kilometers

Nitrate Concentration in Tulkarem Wells
N
Wadi Zeimar
Mediterranean Sea
Western Basin
Dead Sea
Nitrate Concentration (mg/l)
0 - 7
8 - 25
26 - 38
39 - 57
58 - 87
Wadi Zeimar
West Bank Border
Study Boundary
0 4 8 Kilometers

Wells Location in Tulkarem Study Area
N
Wadi Zeimar
Mediterranean Sea
Western Basin
Dead Sea
145
150
155
160
165
195
190
185
Well
Wadi Zeimar
West Bank Border
Study Boundary
0
4
8 Kilometers