An-Najah National University

Faculty of Graduate Studies

Identification and Assessment of Potential Environmental Impacts of Cesspits on Selected Groundwater Wells in Tulkarm District using Groundwater Modeling

By

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This Thesis is Submitted in Partial Fulfillment of the Requirements for the Degree of Master in Water and Environmental Engineering, Faculty of Graduate Studies, An-Najah National University, Nablus, Palestine.

2012

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This thesis was defended successfully on 10/6/2012 and approved by:

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DEDICATION

I dedicated this thesis to my beloved Homeland and to all the Palestinian People.

My supervisor Dr. Muhammad Almasri thank you for your supporting, patience and motivation me to make my thesis the best possible.

My mother and father, you have given me so much, thanks for your faith in me, and for teaching me that I should never surrender.

I lovingly dedicate this thesis to my husband, who has been a great source of motivation, endless inspiration and supported me each step of the way.

My brothers and sisters, thank you for being a great source of support and encouragement. I am grateful to all of you for your love, moral support, and patience.

My husband family thanks for your love, supporting and encouraging me during the study.

I dedicated this thesis also to my dearest friends; Nada, Rasha, Barihan, Abir and Yasmeen that I lived with them beautiful days of my life.

Finally, this thesis is dedicated to all those who believe in the richness of learning.

ACKNOWLEDGEMENTS

First and foremost I would like to thank God to given me the power to believe myself, pursue my dreams and helping me in making this thesis possible.

I would like to express my sincere gratitude to Dr. Muhammad Almasri for his supervision, continuous support of my thesis study, patience, motivation, enthusiasm, and immense knowledge. His guidance helped me in all the time of working and writing my research to make the thesis the best possible.

I owe my deepest gratitude to Dr. Muath Abusaada for supporting my thesis, helping me in providing data and give me fruitful suggestions.

I would thank to Palestinian Water Authority (PWA) and Austrian project for funding my master study and helping me in providing the data. Special thanks go to Eng. Adel Yasin, Dr. Subhi Samhan, Hazem Kitana and Eng. Deeb Abdelghafour.

I would thank also to Water and Environmental Studies Institute (WESI) staff especially to Atef Abu Jeish.

I am deeply indebted to my parents for giving birth to me at the first place and supporting me spiritually throughout my life. My deepest gratitude and love for their dedication for many years of support during my life and study. My gratitude is also extended to my brothers and sisters who stood beside me through their support and love.

No words can express my sincere thank for my husband Dorgham for his understanding and love during my study. His support and encouragement would have been impossible for me to complete my thesis. I cannot find the words to thank him enough.

الاقرار

أنا الموقع أدناه مقدم الرسالة التي تحمل العنوان :

Identification and Assessment of Potential Environmental Impacts of Cesspits on Selected Groundwater Wells in Tulkarm District using Groundwater Modeling

أقر بأن ما اشتملت عليه هذه الرسالة إنما هي نتاج جهدي الخاص، باستثناء ما تمت الإشارة إليه حيثما ورد، وأن هذه الرسالة ككل، أو أي جزء منها لم يقدم لنيل أية درجة أو لقب علمي أو بحثي لدى أية مؤسسة تعليمية أو بحثية أخرى .

Declaration

The work provided in this thesis, unless otherwise referenced, is the researcher's own work, and has not been submitted elsewhere for any other degree or qualification.

Student's Name :	**اسم الطالب :**
Signature :	**التوقيع:**
Date:	**التاريخ:**

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Identification and Assessment of Potential Environmental Impacts of Cesspits on Selected Groundwater Wells in Tulkarm District using Groundwater Modeling

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Abstract

Groundwater is the major source of water to the Palestinians. The quality of groundwater may be deteriorated over time due to the cumulative effects of several years of practices. The work of this thesis focused on the identification and assessment of potential impacts of cesspits on groundwater wells in Tulkarm District. A particle-tracking model was developed using MODPATH and different scenarios were worked out in order to delineate the contributing areas of contamination to each well of interest. Results confirm that the cesspits considered as one of the main sources of pollution for many groundwater wells in the study area. A wellhead protection zone was delineated for selected groundwater wells in the study area in order to arrive at effective management plan to minimize the risk of groundwater contamination. Overall, the recommendations call all relevant authorities to assume their responsibilities and to take immediate actions to control an if possible to prevent the groundwater contamination.

Chapter One
Introduction

1.1 General Background

Groundwater is considered the main fresh water resource in the West Bank and definitely the only reliable source for water supply for Palestinians **(Alfred, 2007).** Because of that, protecting groundwater from pollution is a priority and a major concern as well.

To protect groundwater from pollution, investigating and targeting the potential sources of pollution is vital. One of these sources is cesspits that are considered as concentrated point sources of pollution yet widespread **(Kouli et al., 2007).**

Most groundwater contamination is due to human activities. Contaminants can seep into groundwater from leaking underground tanks, cesspits, landfills, pesticides and fertilizers (Fetter, 1994). Since contaminants that reach the groundwater generally move very slowly, continued leakage in one spot will lead to a gradual increase in the levels of contaminants **(Aliewi and Mimi, 2005).**

In many rural Palestinian areas, wastewater is not collected via a sewage network but rather it is being disposed of through cesspits. There are many associated problems that transpire from such a practice, which is in fact very common, and these problems can be summarized as follows:

1. Loss of wastewater that can be collected, treated, and later reused.

2. Cesspits are not frequently evacuated and the untreated wastewater will eventually reach groundwater resources and cause pollution.

A cesspit (see Figure 1.1) is a large subsurface hole with an open bottom or perforated sides used for disposal of sanitary waste from toilets, sinks, and washing machines. Wastewater enters the cesspits and percolates down through the bottom and may thereafter reach groundwater if hydrogeological conditions permit.

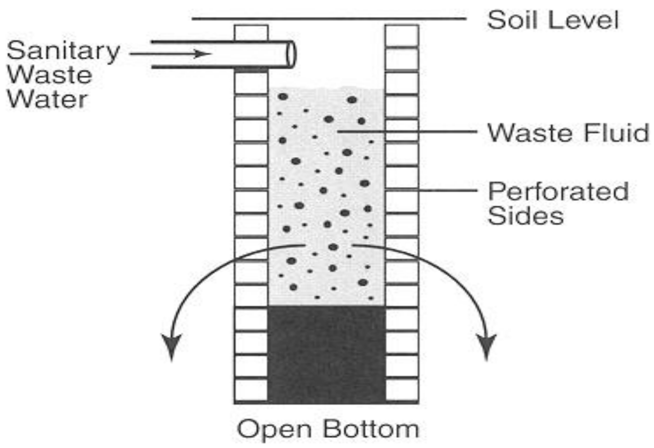


Figure (1.1): Representation of cesspits that are commonly used in communities of the West Bank (http://water.epa.gov).

Cesspits are considered as point sources of pollution that are widespread in the West Bank. The majority of cesspits that are in use in the West Bank are not coated or lined and thus wastewater will leach down and percolate and may negatively affect the quality of groundwater **(SUSMAQ, 2005).**

Disposal of wastewater from cesspits into the shallow subsurface is a common practice that introduces contaminants as nitrates, bacteria, and organic contamination into the water resources that might be used for providing drinking water **(MacQuarrie et al., 2001).**

In high-density residential areas with no sewer systems, cesspits produce significant amounts of nitrogen that leaches to the subsurface especially in the form of ammonium and organic-N **(Almasri, 2007).**

In urban areas, the infiltration of wastewater from cesspits into the groundwater accelerates the pollution problems. This pollution is a concern to rural homeowners who use shallow groundwater wells for drinking water that can be easily contaminated with sewage effluent **(Yintao Lu et al., 2008).**

Elevated nitrate concentration in drinking water can cause methemoglobinemia in infants and stomach cancer in adults. As such, the US Environmental Protection Agency (US EPA) has established a maximum contaminant level (MCL) of 10 mg/L NO_3-N. Nitrate may indicate the presence of bacteria, viruses, and protozoa in groundwater if the source of nitrate is animal waste or effluent from cesspits **(Barbara and Nancy, 2005).**

The presence of coliform bacteria and organic matter indicates that the water is potentially polluted from cesspits.

When such contaminants reach the sources of water persistently, contaminant concentrations increase. High concentration of contaminants in drinking water can cause serious diseases when this impaired water is consumed by human beings (see Table 1.1).

Table (1.1): The common water borne diseases that affect human beings (Ashbolt, 2004)

Type of Organism	***Disease***	***Effects***
Bacteria	Typhoid fever	Diarrhea, severe vomiting, enlarged spleen, inflamed intestine
	Cholera	Diarrhea, severe vomiting, dehydration
	Bacterial dysentery	Diarrhea, rarely fatal except in infants without proper untreated
Viruses	Infectious hepatitis (Type B)	Fever, sever headache, abdominal pain, jaudice, enlarged liver
Parastitic protozoa	Amoedic dysentery	Sever diarrhea, headache, abdominal pain, chills, fever, bowel perforation
	Giardiasis	Diarrhea, abdominal cramps, flatulence, belching, fatigue
	Cryptosporidium	Sever dirrhea and possible death for people with weakened immune systems
Parasitic worms	Schistosomiasis	Abdominal pain, skin rash, anemia, chronic fatigue, and chronic genral ill health

Contamination of groundwater is a serious problem for many communities in the West Bank **(Tagar, 2004).** An example of that is *Nazlet Issa* Village where the groundwater well that is being used for potable water supply was contaminated from wastewater that seeps down from the cesspits of the village as will as from the surrounding villages.

Therefore, identification of areas with heavy contamination loading from point sources as cesspits is important. When high-risk areas are identified, preventive measures can be implemented to minimize the risk of groundwater contamination. However, to verify the contributing areas of contamination to a well, groundwater modeling would aid in this regard.

The flow path lines provide an important representation of the flow direction and the path that the contaminant would potentially follow from a specific location until it reaches a groundwater well given that the hydrogeological conditions permit (Pollock, 1994).

Contributing areas of wells and springs when intersect contamination sources like cesspits can stimulate and provoke the mobilization of contaminants toward them. This very idea is the cornerstone of this thesis.

1.2 Problem Description

Pollutants originating from landfills, cesspits, overuse of fertilizers and pesticides can pollute groundwater. If groundwater becomes polluted, it will no longer be safe to drink unless treated **(Nas and Berktay, 2006).**

Since there are no adequate sewage networks in the West Bank, the wastewater generated from different sources is either collected through sewage collection networks and discharge untreated to wadis or collected through cesspits where the wastewater may infiltrate and percolates until it reaches the groundwater (see Figure 1.2) (SUSMAQ, 2005).

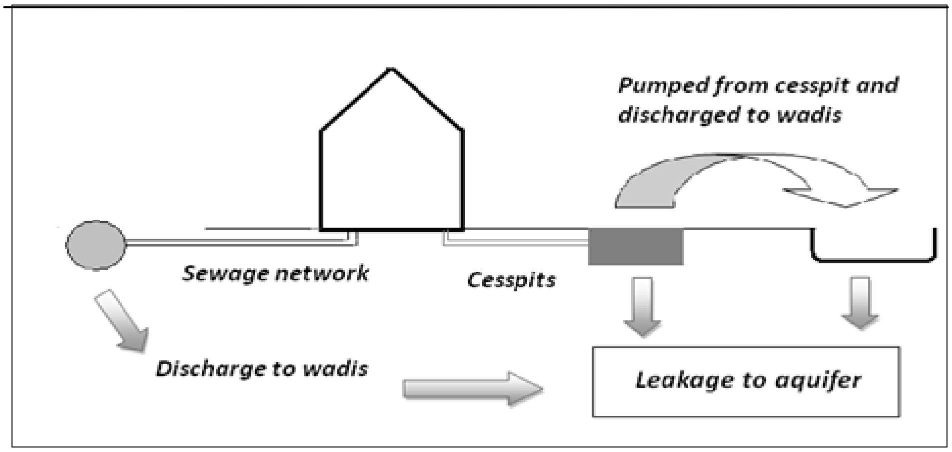


Figure (1.2): Schematic components of domestic wastewater discharge (SUSMAQ, 2005)

The percentages of household that using cesspits in the West Bank by type of locality and region are 59.7% in urban areas, 93.4% in rural areas and 29.1% in refugee camps **(PCBS, 2007).**

Cesspits are considered as point sources of pollution that are widely used in the majority of the communities in the West Bank. In high density residential areas with no sewer networks, cesspits produce significant amounts of contaminants such as nitrates, bacteria, and organic matter. This form of pollution is a concern to rural homeowners who use groundwater wells for domestic use **(Almasri, 2007).**

The traditional disposal method of using unlined cesspits results in leachate that leaks and penetrates the ground, which can ultimately reach the groundwater. Cesspits may also be pumped periodically, with discharges usually being directly disposed of into wadis without treatment.

From a conceptual point of view the figures below (Figure 1.3 and 1.4) depict the effect of cesspits on groundwater wells.

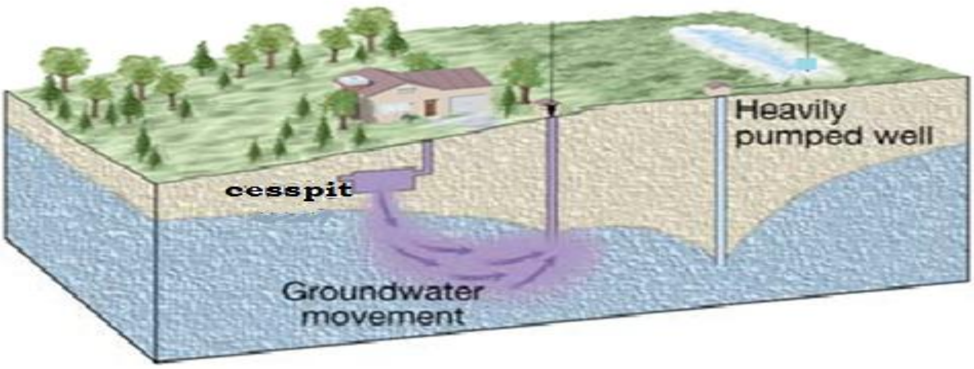


Figure (1.3): Effect of the contaminants originating from cesspits on close groundwater well (http://geophysics.ou.edu)

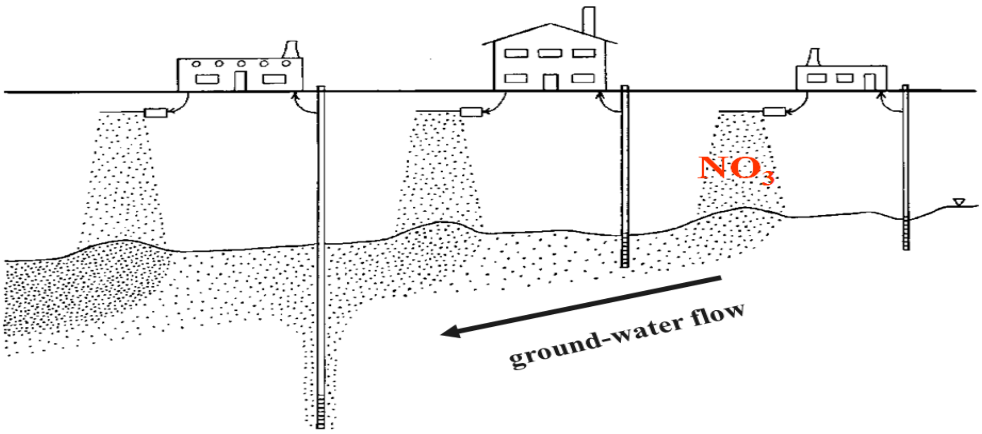


Figure (1.4): Representation of the transport of nitrate from cesspits to a groundwater wells

1.3 Research Hypothesis

The key hypothesis of the thesis is that the cesspits might be considered as a main source of pollution for many groundwater wells in the study area (Tulkarm District).

1.4 Research Motivations

The following are the main motivations for carrying out the research:

1. Groundwater is the most important water resource in the West Bank, and thus understanding the issues affecting its quality and protecting it from pollution is important and needful.

2. Identification of areas with heavy contamination loadings from point sources as cesspits is important for land use planners and environmental regulators.

1.5 Objectives of the Research

The following are the research key objectives:

1. To identify the wells and springs in the West Bank aquifers that encounter contamination.

2. To develop a simple yet realistic methodology that can be utilized to assess the potential contamination of groundwater wells and springs due to cesspits.

3. To implement this methodology by developing a particle-tracking model using the available MODFLOW model for the Western Aquifer Basin (WAB) and MODPATH for a specific case study within this aquifer.

4. To delineate wellhead protection zones for selected groundwater wells in the study area and to develop preventive guidelines and operational controls necessary to ensure better management of wells.

1.6 Research Overall Methodology

The figure below (Figure 1.5) describes the methodology that was followed in this research.

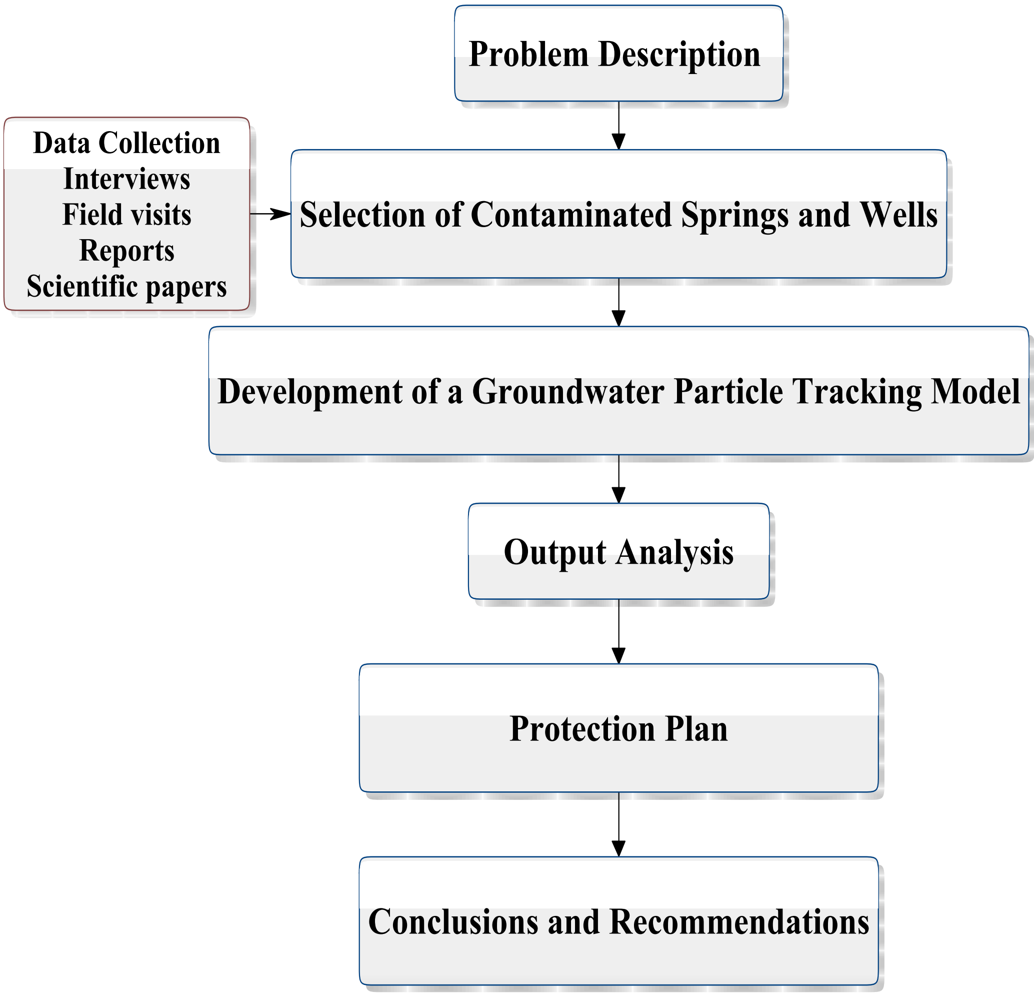


Figure (1.5): A flowchart that depicts the methodology of the research

The methodology starts by a description of the problem followed by an identification of the location of the contaminated springs and wells in the West Bank aquifers and in the study area. That was carried out by comparing concentrations against the Palestinian Standards of Drinking Water **(PSI, 2005).**

Data collection was carried out for the selected study area. The data were obtained from the main previous studies and the relevant databases of the Palestinian Water Authority (PWA), Palestinian Hydrology Group (PHG), along with other sources. The collected data was analyzed using Microsoft Excel and GIS.

After that the methodology proceeded by the development of a groundwater model for particle tracking using MODPATH, different scenarios were worked out in order to delineate the contributing areas of contamination to each well of interest. Both MODFLOW and MODPATH software were utilized in the model development and indeed through the use of GIS.

The outcomes from the MODPATH model were analyzed especially the capture zones for the groundwater wells and the flow path lines that provide an important representation of the flow direction and the expected path that the contaminant will follow from a specific originating location such as cesspits until it reaches the groundwater well.

The MODPATH results were assessed and protection zones for selected wells were delineated. A variety of figures and charts were also developed using MS Excel based on MODPATH outcomes.

The methodology concludes by setting up a brief summary of the detailed conclusions of the main chapters. The major recommendations were made regarding the potential implementation of the planning and management options to control contamination of groundwater resources.

1.7 Thesis Outline

The thesis consists of eight chapters. Literature review is given in chapter two. Chapter three describes the study area of the research. Chapter four discusses the selection of the contaminated wells and springs in the West Bank and in the case study. The modeling approach and development of MODPATH for the case study is provided in chapter five. Chapter six demonstrates the results and analysis. Chapter seven provides the management plan for the selected wells of the study area. The key conclusions and recommendations are provided in the last chapter.

Chapter Two
Literature Review

2.1 Local Studies of Groundwater Quality

Abed Rabbo et al. (1999) assessed the water quality of the West Bank springs from 1995 to 1997. About 400 samples were collected and analyzed. The main contaminants in springs were nitrate and coliform bacteria from sewage. The majority of the samples for microbiological analyses were found to be contaminated by infectious sources. It is likely that the contamination is due to the spring's location close to downstream from infectious sources such as sewage from cesspits, sewer network leakages, or sewage discharged directly to wadis and open ground.

Abed and Wishahi (1999) implemented field study on the geology of Palestine. This study includes an assessment of water resources, geologic formation, groundwater basins of Palestine, and many other disciplines. This study also assessed the quality of drinking water in Palestine. They found that nitrate contamination of groundwater is caused by infiltration of fertilizers and raw sewage.

Anayah (2006) assessed nitrate and chloride concentrations in the West Bank groundwater resources. The research focuses on the long-term degradation of water quality in the West Bank aquifers. GIS technology is utilized to facilitate the analysis. The results confirm that the nitrate concentration across the West Bank aquifers has an increasing trend after the year 1985. As for chloride, the wells of the Jordan Valley have the highest concentrations.

Samhan et al. (2010) assessed the domestic water quality in the West Bank aquifers for major parameters such Chloride, Nitrate, Sodium, Potassium, Sulfate, and other biological indicators such as T. Coliform and F. Coliform. About 90 springs and wells used for domestic purposes were analyzed. The study showed that the main sources of contamination encountered in domestic sources in the West Bank aquifers are from domestic wastewater, agriculture activities and direct discharge of wastewater in wadis without any type of treatment.

Abdul-Jaber et al. (1997) studied the effect of contamination from wastewater on the shallow aquifer in the northern West Bank. The outcomes from this study showed that most of the springs and wells within the high density residential areas were contaminated with wastewater by infiltration from cesspits and the open conduits of raw sewage.

Scarpa et al. (1998) found that the wide distribution of cesspits, uncontrolled disposal of wastewater and excessive use of fertilizers were considered the sources of the biological contamination and the increasing of nitrate, chloride, and potassium levels in many wells that tap the unconfined aquifers in the northern West Bank.

Marei and Haddad (1998) found that the nitrate levels for drinking water were above the WHO standard (i.e. > 50 mg/l) in up to one-third of the sampled wells in the Jordan Valley, Nablus, Jenin, and Tulkarm Districts. They concluded that the nitrate contamination of groundwater is caused by raw sewage and infiltration of fertilizers.

2.2 Application of Groundwater Simulation Models

Gharbi et al. (1994) adapted an embedding optimization modeling approach to aid groundwater quantity and quality management of the complex nonlinear multilayer of Salt Lake valley aquifers, Utah, US. Finite difference approximations of the two-dimensional advection-dispersion transport equation are embedded directly as constraints in the model. The simulation abilities of this embedding approach are useful for coarse management of groundwater flow and dispersed groundwater contamination.

Aliewi et al. (1997) made an assessment of the vulnerability of the upper part of the northeastern aquifer to wastewater disposal from the City of Nablus. They showed that the magnitude and direction of hydraulic gradient indicate that pollution can be expected. They supported this view by their numerical simulation. They ascribed existing pronounced variations in groundwater quality to pollution that has already occurred.

Almasri (2007) presents a general conceptual framework for the management of groundwater contamination from nitrate. The management framework utilizes models of nitrate fate and transport in the unsaturated and saturated zones to simulate nitrate concentration at the critical receptors.

Najem (2008) developed a nitrate fate and transport model for the Eocene Aquifer. The calculations indicated that the excessive applications of fertilizers for agriculture and the seepage of untreated wastewater from cesspits are the main causes of the high concentrations of nitrate.

Chapter Three
Description of The Study Area

3.1 Tulkarem Governorate. The Research Case Study

3.1.1 General Features of Tulkarem District

Tulkarem Governorate is located at the northwestern part of West Bank with a total surface area of nearly 268 square kilometers. It is bounded by the Jenin and Nablus district in the north, west and south and by the 1948 cease-fire line in the east. There are approximately 40 grouped communities within the study area (see Figure 3.1). Approximately 169 thousand Palestinians live in Tulkarem Governorate **(PCBS, 2011).**

The topography elevation is ranging between less than 50 meters above sea level (a.s.l) near Tulkarem Municipality to about 450 m above sea level in Bala'a Municipality **(ARIJ, 1996).**

The climate in Tulkarem Governorate can be characterized as hot and dry during the summer and cool to warm in winter. The average annual rainfall reaches 600 mm **(ARIJ, 1996).**

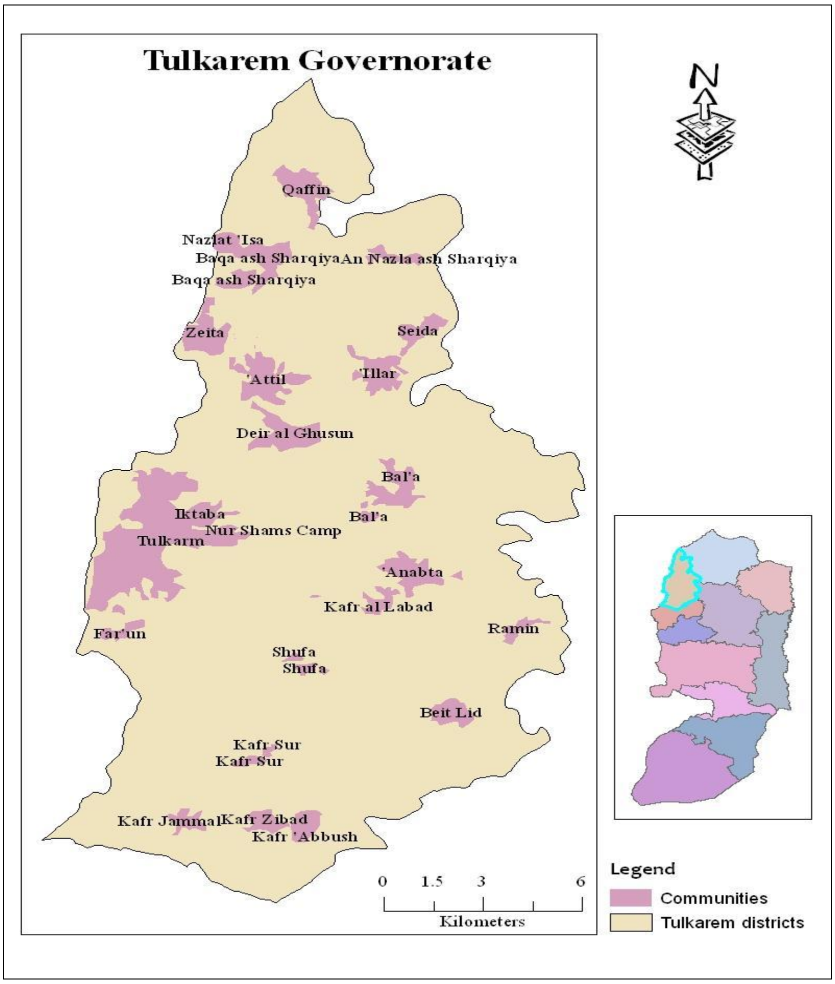


Figure (3.1): The main communities located within Tulkarem Governorate

3.1.2 Groundwater Resources in Tulkarem District

Tulkarm Governorate area is part of the WAB. Renewable groundwater resources are considered the main potential water resources available in the study area. Groundwater in the area is exploited by several public and private groundwater wells. The total number of functional wells in the governorate reaches about 66 wells (see Figure 3.2). Depth of these wells is ranging between 60 and 400 meters. Domestic water is mainly taken from 17 municipal wells, the rest of wells mainly used for agricultural purposes.

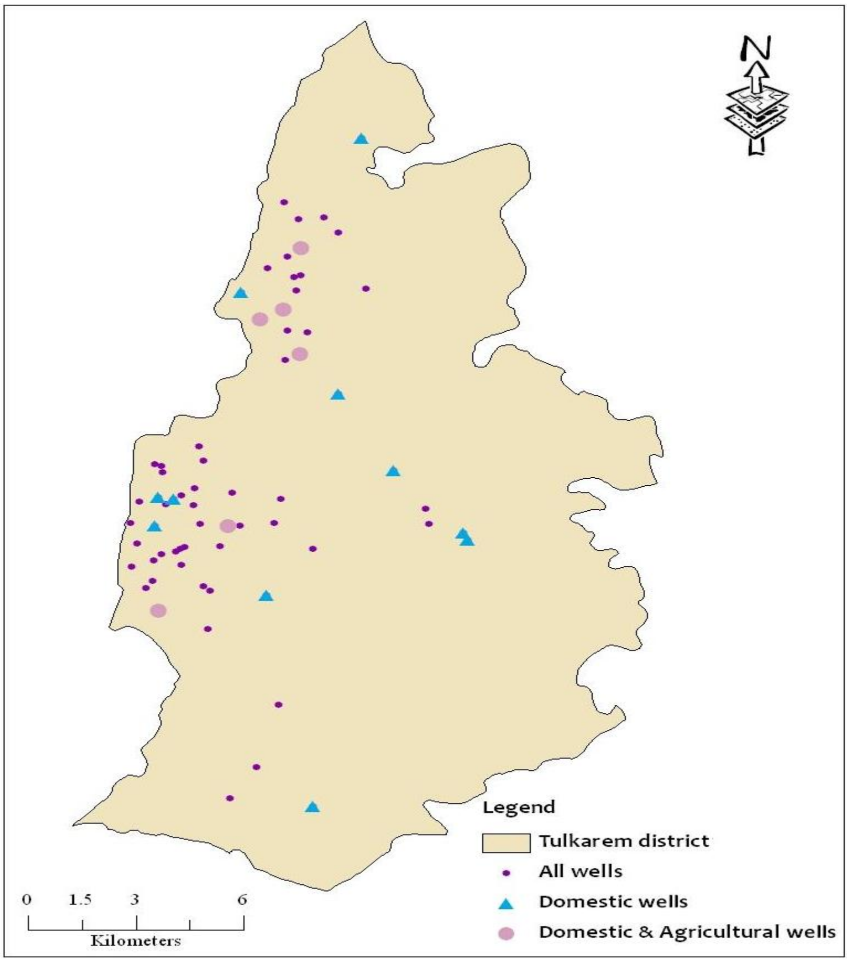


Figure (3.2): Well locations in the Tulkarem Governorate

3.1.3 Current Status of Wastewater Collection

Wastewater collection in Tulkarem Governorate is still underdeveloped. Most of the communities are using cesspits to dispose of their wastewater. However, Tulkarem City and two other towns have partial wastewater collection networks **(ARIJ, 1996).**

Cesspits are frequently evacuated by private tankers that dispose of in nearby wadis or by the sides of the roads. Many of the cesspits seep into the streets especially at the center of the villages where houses are dense. It causes social, health and environmental problems at these locations.

Such method of disposal increases the chance of sewage infiltration into the groundwater, along with contacts of pollutions, such bacteria and viruses resulting in deterioration of water quality.

3.2 Western Aquifer Basin Description

Groundwater resources in the West Bank are derived from three aquifer basins through wells and natural springs. These aquifer basins are: the Eastern, Western, and Northeastern aquifer basins as shown in Figure 3.3 **(SUSMAQ, 2004).**

Figure (3.3): Groundwater aquifer basins of the West Bank and Gaza Strip (UNEP, 2002)

The WAB is located in the western parts of the Palestine. The WAB is the largest basin in terms of area, storage capacity and sustainable yield. The majority of the wells of the WAB yields fresh water and thus is being used for drinking. The aquifer is mainly recharged from rainfall over the replenishment areas in the western mountains of the West Bank **(Abusaada, 2006).**

The WAB extends northward from area south of the Egyptian border all the way up to the foothills of the Carmel Mountain and from the West Bank mountains in the east heading westward towards the Coastal Plain of the Mediterranean Sea with a total area of 9000 km² **(Abusaada, 2006).**

The topographic nature of the WAB varies from sea level on the Mediterranean coast in the western side of the aquifer to an elevation close to 1000 m in the West Bank Mountains on the eastern side of the basin **(SUSMAQ, 2001).**

The basin is characterized by its Mediterranean Sea climate. Its climate ranges from an arid desert condition in the Al Naqab desert to a sub-humid Mediterranean Sea climate in the center and north of the basin. The temperature is moderate with intermediate precipitation that mostly lies during the coldest half of the year (October-April). Generally, the mean annual precipitation rate over the replenishment areas of the aquifer is approximately 560 mm **(Abusaada, 2011).**

Currently, there are 493 wells, where the majority taps from the upper aquifer. The annual pumping rates depend on the rainy season **(SUSMAQ, 2001).**

The WAB falls in the middle Cretaceous Judea Group. It is divided into two main aquifers (upper and lower) separated by a lower permeability layer (Yatta formation). The upper and lower aquifer rocks are mainly composed of a sequence of hard, karstic and permeable limestone and dolomite with a thickness of 600–1000 m **(SUSMAQ, 2001).**

The figure below (Figure 3.4) depicts the main surficial geological formations for the WAB.

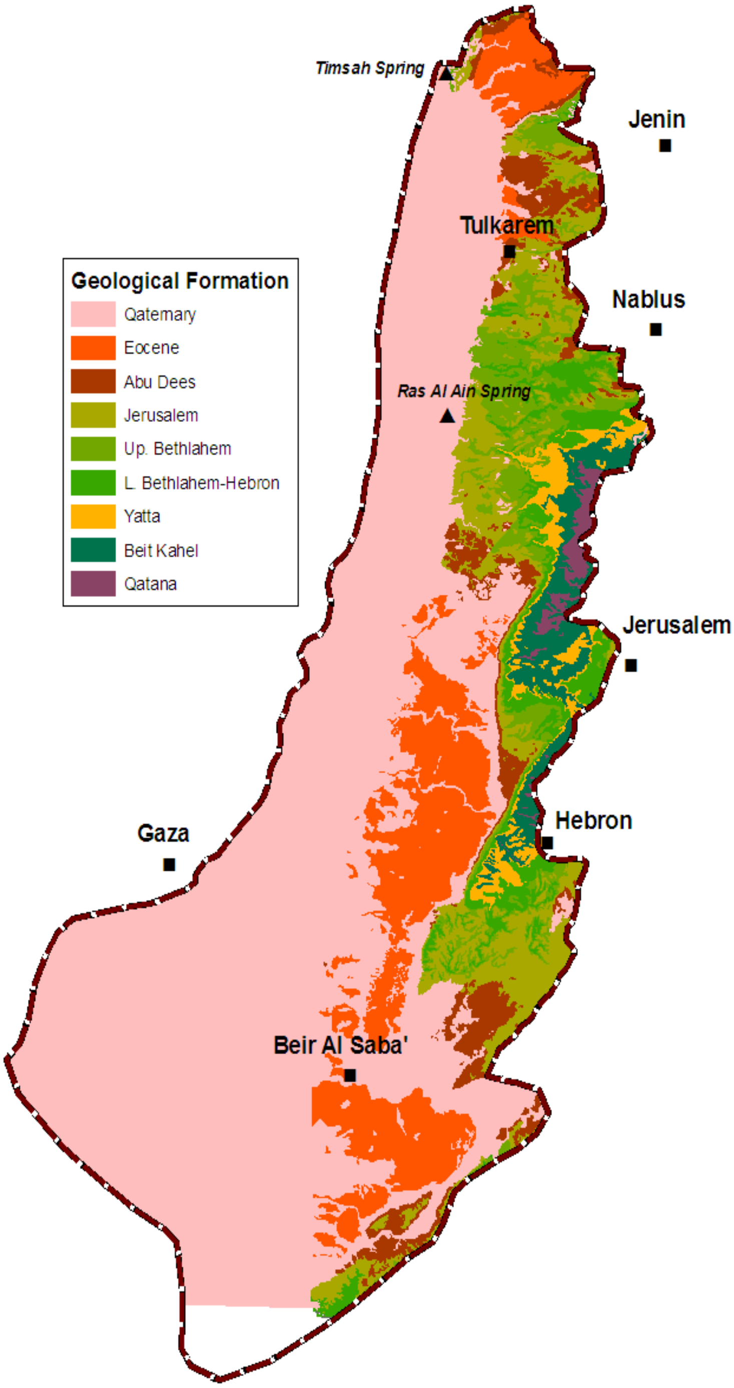


Figure (3.4): The geological map of the WAB **(Abusaada, 2011)**

The figure below (Figure 3.5) represents the main stratigraphic units for the WAB.

<table>
<tr><th>Period</th><th>Age</th><th colspan="2">Formation</th><th colspan="2">Lithology</th><th colspan="2">Hydrostatigraphy</th></tr>
<tr><td rowspan="7">Cretaceous</td><td>Senonian</td><td colspan="2">AbuDees</td><td colspan="2">Chalk, Chert,Marl</td><td colspan="2">Aquitard</td></tr>
<tr><td>Turonian</td><td>Daliya</td><td>Jerusalem</td><td rowspan="6">Chalky Marl</td><td>Limestone</td><td rowspan="6">Aquitard</td><td rowspan="3">Upper Aquifer</td></tr>
<tr><td rowspan="3">Cenomanian</td><td rowspan="5">Undifferentiated Talme Yafe</td><td>Bethlehem</td><td rowspan="2">Dolomite, Limestone, Marl, Chalk</td></tr>
<tr><td>Hebron</td></tr>
<tr><td>Yatta</td><td>Chalk, Marl, Limestone</td><td>Aquitard</td></tr>
<tr><td rowspan="2">Albian</td><td>Beit Kahel</td><td>Dolomite, Limestone,Marl</td><td>Lower Aquifer</td></tr>
<tr><td>Qatana</td><td>Marl, Clay</td><td>Aquitard</td></tr>
</table>

Figure (3.5): Stratigraphic column of the WAB (Gvirtzman, 2005)

Chapter Four
Selection of The Contaminated Wells and Springs

4.1 Introduction

Groundwater contamination is a critical issue due to the importance of groundwater supply and quality in water security for basic needs. Overall, groundwater contamination has become a major concern in the recent years worldwide **(Kalivarapu and Winer, 2008).**

Wastewater is one of the major sources of pollution in the West Bank. Sewage collection networks are limited to major cities and most of them are poorly designed and old. So, leakage and flooding exist in these systems **(SUSMAQ, 2005).** In the West Bank wastewater is usually collected and discharged without any treatment into open areas in valleys.

Many contaminated wells and springs by nitrate and coliform bacteria in the West Bank aquifers no longer fit consumption use without prior treatment **(Samhan, 2010).**

Drinking water quality is required to meet stringent microbiological and chemical standards of quality to prevent water borne diseases and health risks from toxic chemicals.

The main objectives of this chapter are to identify the domestic wells and springs in the West Bank and in the study area that encounter contamination and to export GIS maps that highlight their locations.

4.2 Domestic Water Quality in the West Bank Aquifers

There are increasing problems of contamination in the West Bank aquifers caused by the lack of adequate infrastructure to mange and treat wastewater.

The groundwater wells and springs in the West Bank are certainly influenced by the domestic wastewater leaching from the widespread cesspits and runoff in the rural and urban areas. In addition, the leachate from the solid waste landfills and hazardous chemicals from agriculture and industry contributes to the ongoing contamination of the groundwater resources **(SUSMAQ, 2005).**

Water quality in the West Bank aquifers (The Eastern, North Eastern, and Western) was characterized for Chloride, Nitrate, F-Coliform and T-Coliform.

The data for water quality in the West bank aquifers are available from the central laboratory of Palestinian Water Authority (PWA) for 145 domestic wells and springs, although some of these have missing measurements.

The figures below (Figure 4.1 and 4.2) depict the location of the contaminated domestic wells and springs by nitrate, F-Coliform and T-Coliform in the West Bank aquifers during the period from 2000 to 2006.

It can be concluded from these figures that the highest nitrate concentrations are mainly encountered in the wells and springs that are located in the north specifically in Jenin, Tubas, and Nablus Districts as well as some wells located in Hebron District. In addition, many of wells located in Tulkarm and Qalqilya Districts encounter such high nitrate concentrations. Those Nitrate concentrations exceed the MCL of 50 mg/l. These observations may be due to the agricultural activities that are associated with the elevated on-ground nitrogen loadings due to the use of fertilizers. In addition, the detrimental effect of cesspits and the effect of direct discharge of wastewater to wadis without any type of treatment contributed to nitrate pollution of groundwater as the case of Al-Zumer that carries the wastewater from Nablus toward Tulkarm.

A variety of biological indicators such as T-Coliform and F-Coliform are present in wells and springs in the West Bank aquifers near the areas of cesspits, such as the communities of Nablus, Tulkarem, Ramallah, and Jenin which are un-served by sewage networks. The contamination concentrations depend on the contributing communities that area without a sewage network. In addition, such contamination is likely due to the location of springs and wells close to downstream from infectious sources, such as sewage from cesspits, sewer network leakages, or sewage discharged directly to wadis.

The highest chloride concentrations are encountered in the east, specifically in Jericho wells, where intensive evapotranspiration occurs, in addition, the excessive agricultural activities. Some wells located in Jenin District had indicating high occurrence of chloride contamination. Those chloride concentrations exceed the MCL of 200 mg/l. Wastewater discharges, leachate from waste deposits and industrial effluent may also contribute significantly to the elevated chloride concentrations in groundwater resources of the West Bank aquifers.

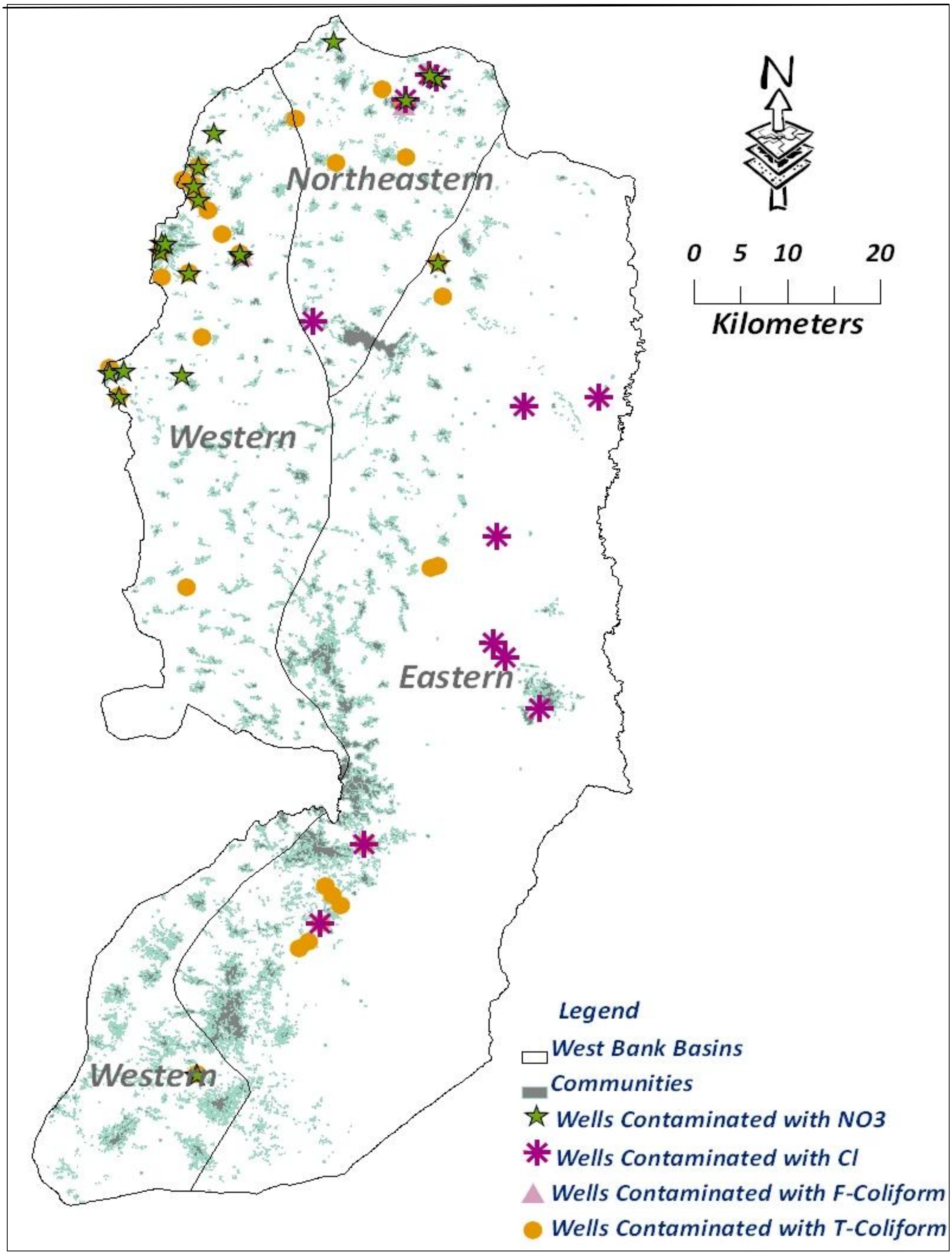


Figure (4.1): GIS map that highlights the locations of the contaminated domestic wells in the West Bank aquifers

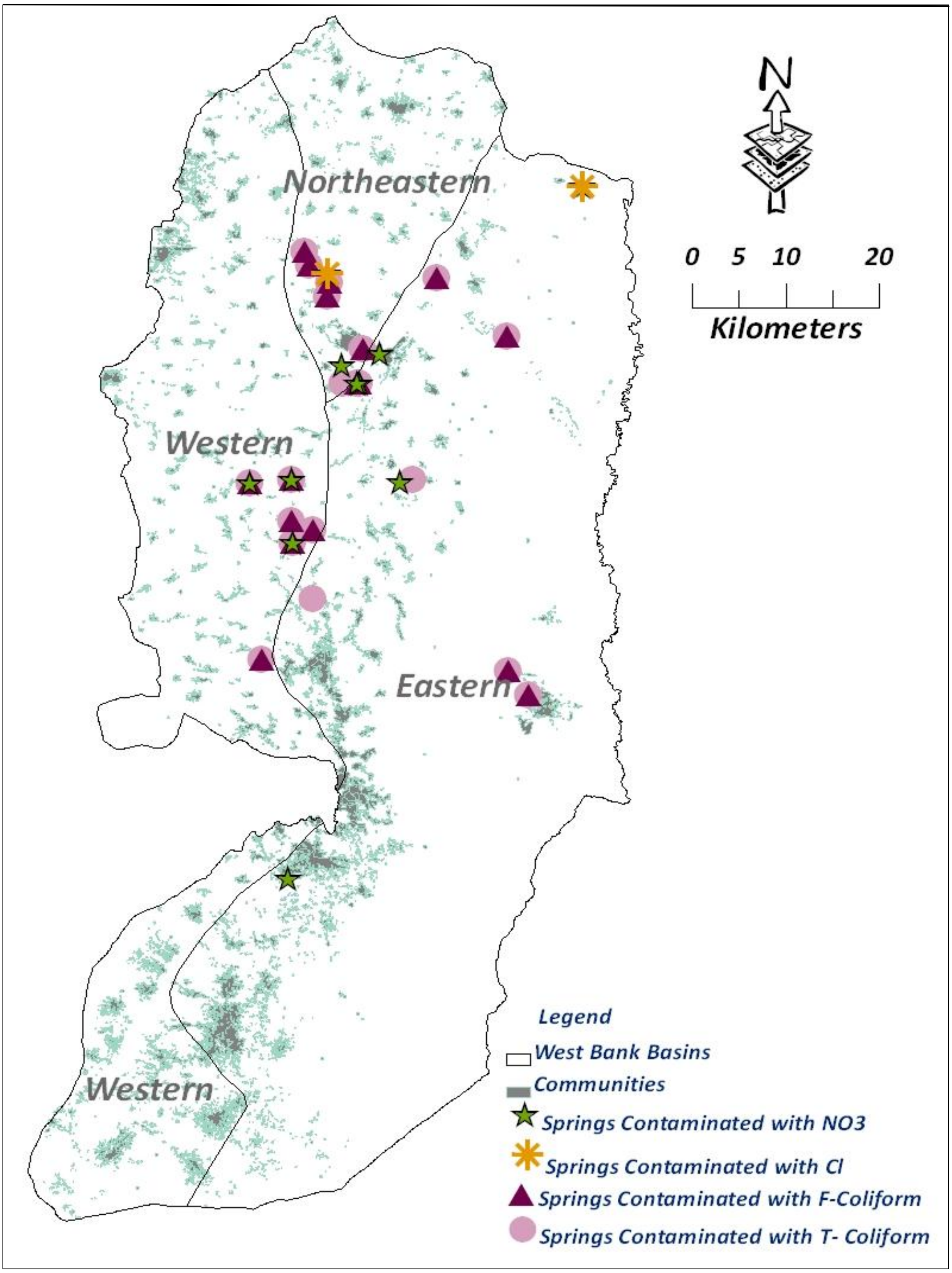


Figure (4.2): GIS map that highlights the locations of the contaminated domestic springs in the West Bank aquifers

4.3 Domestic Water Quality in Groundwater Wells in the Research Study Area (Tulkarem Governorate)

As there are no springs in the study area, groundwater is being utilized through wells constructed to tap the aquifer. There are 17 groundwater wells used for domestic purposes in the study area as summarized in Table 4.1.

Table (4.1): Groundwater domestic wells in Tulkarem Governorate

Well No.	*Well-ID*	*Name*	*Locality*	*Use*
1	16-19/001	Anabta Municipality	Anabta	Domestic
2	16-19/002	Anabta Municipality	Anabta	Domestic
3	15-19/035	As'ad Rabee' & Partners	Attil	Domestic and Agricultural
4	15-19/036	Attil Cooperative Society	Attil	Domestic and Agricultural
5	15-19/041	Muhammad Nemer Barakat	Attil	Domestic and Agricultural
6	15-19/048	Bal'a Village Council	Bal'a	Domestic
7	15-20/002A	Muhammad Abu Shams	Baqa ash Sharqiya	Domestic and Agricultural
8	15-19/047	Deir Al Ghusun Village Council	Deir al Ghusun	Domestic

9	15-19/038	As'ad Taffal & Ahmad Khraishah	Dennabeh	Domestic and Agricultural
10	15-18/006	Muhammad 'Abed Al Haleem	Far'un	Domestic and Agricultural
11	15-18/015	Kamel Al Salem & Partners	Kafr Zibad	Domestic
12	15-20/008	Qaffin Village Council	Qaffin	Domestic
13	15-18/024	Shufa Water Cooperative Committee	Shufa	Domestic
14	15-19/017	Tulkarm Municipality	Tulkarm	Domestic
15	15-19/018	Tulkarm Municipality	Tulkarm	Domestic
16	15-19/046	Tulkarm Municipality	Tulkarm	Domestic
17	15-19/010	Zeita Village Council	Zeita	Domestic

All groundwater wells in the study area are potentially affected by contamination sources which are summarized as follow:

- The un-served communities which dispose of their wastewater in cesspits and later in nearby wadis or by the sides of the roads (see Figure 4.3 and 4.4).

Figure (4.3): Wastewater disposal by the sides of the roads

Figure (4.4): Wastewater disposal nearby wadis

- Wastewater wadis in Al-Zumer catchment area where the communities and industrial sector disposed their wastewater (see Figure (4.5).

Figure (4.5): Wastewater wadis in Al-Zumer

- Uncontrolled and illegal dumping sites of solid wastes (see Figure 4.6).

Figure 4.6: Uncontrolled and illegal dumping sites

- Fertilizer application in agricultural fields.

- The Israeli settlements in the study area. These settlements are usually intended for intensive industrial or agricultural activities.

The water quality for the domestic wells in Tulkarem Governorate was analyzed in the central laboratory of PWA. To select the contaminated wells, the data for all domestic sources was targeted for the last 10 years. These sources were categorized according to the important major parameters for the analysis such as NO_3, K, Cl, Na, Ca, Mg, TDS, SO_4, F-Coliform, and T-Coliform, considering the Palestinian Standards of Drinking Water **(PSI, 2005).**

The figure below (Figure 4.7) depicts the GIS map for the contaminated wells in Tulkarem District during the period from 1996 to 2006.

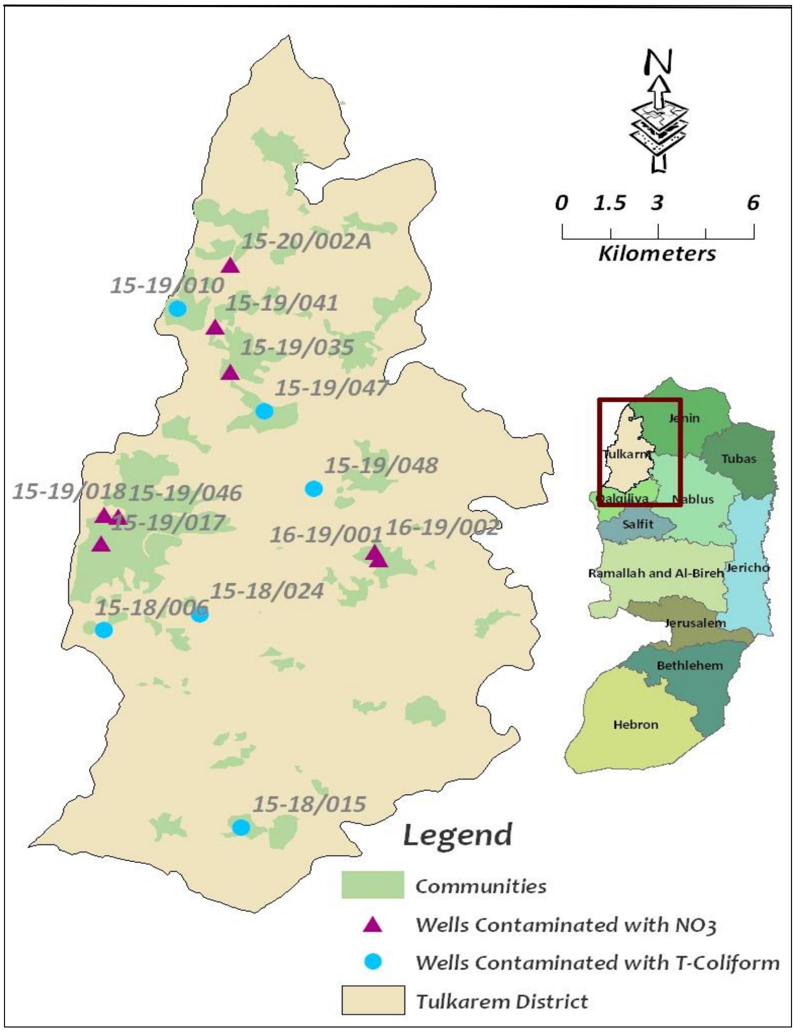


Figure (4.7): A GIS map that highlights the locations of wells with high concentration of NO_3 and coliform bacteria in Tulkarem Governorate

The figure below (figure 4.8) depicts the annual nitrate concentration for some of the groundwater wells in the study area. The nitrate concentrations are of increasing with time. The detrimental effect of cesspits and agricultural practices considered as the main sources of nitrate contamination of groundwater wells in the study area.

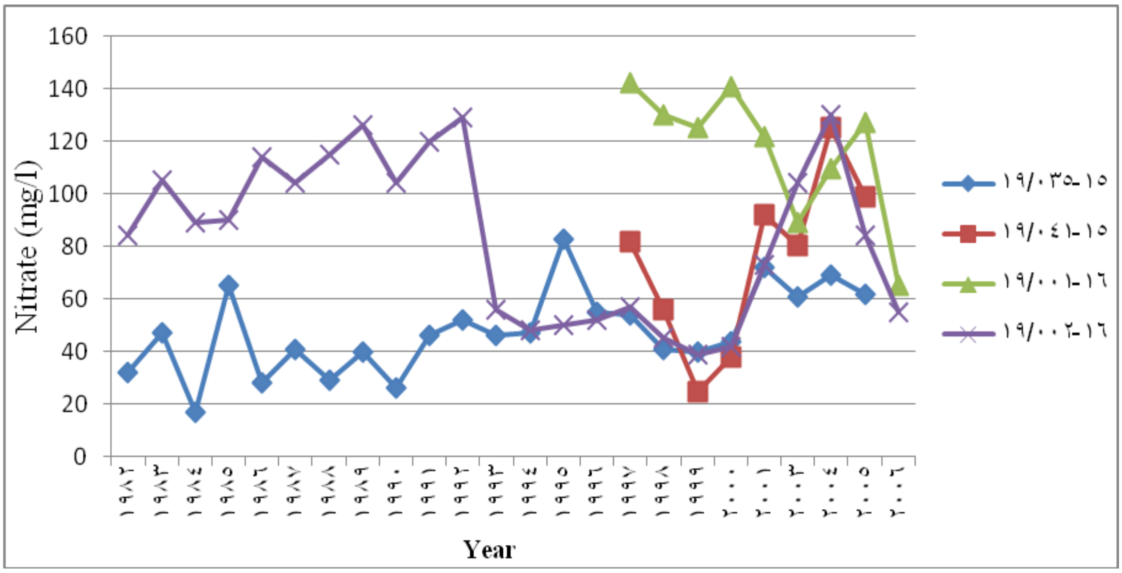


Figure (4.8): Annual nitrate concentration of the groundwater wells in the study area.

From chemical and biological analyses, most wells in Tulkarem District have shown high concentrations of nitrate and organic pollutants in areas with cesspits (see Table 4.2).

Table (4.2): The communities that have the contaminant wells with high concentration of organic pollution and nitrate and the percent of cesspits that used in these communities

Community	*Population (2007)*	*Percent of Cesspits*	*Contaminated Groundwater Well*	*Well ID*
Far'un	3100	100%	Muhammad 'Abed Al Haleem	15-18/006
Baqa ash Sharqiya	4101	100%	Muhammad Abu Shams	15-20/002A
Attil	9038	100%	As'ad Rabee' & Partners	15-19/035
			Muhammad Nemer Barakat	15-19/041
Shufa	2194	100%	Shufa Water Cooperative Committee	15-18/024
Zeita	2853	20%	Zeita Village Council	15-19/010
Kafr Zibad	1087	100%	Kamel Al Salem & Partners	15-18/015
Deir al Ghusun	8242	100%	Deir Al Ghusun Village Council	15-19/047
Bal'a	6604	100%	Bal'a Village Council	15-19/048
Anabta	7329	30%	Anabta Municipality1	16-19/001
			Anabta Municipality2	16-19/002

Wastewater quality from cesspits in different location of the study area were analyzed in the Water and Environmental Studies Institute (WESI) laboratory at An- Najah National University. The results are illustrated and summarized in the following table (see Table 4.3).

Table (4.3): Results of analysis for cesspit samples distributed in different communities of Tulkarem District

Test	*BOD_5*	*COD*	*TSS*	*T. Nitrogen*	*EC*	*PH*	*T. Coliform*	*F. Coliform*
Location of Sampling	mg/l				µs/cm	-	Cfu/100ml	
Anabta	162	400	8000	433.3	2510	8.08	1.20E+11	7.00E+10
Baqa Al-Sharquia	648	2080	10010	866.8	2520	7.36	1.30E+10	7.00E+09
	735	1760	4600	752	1820	7.04	1.50E+12	9.00E+10
Nazlet Issa	421	3840	1640	382.3	450	6.86	9.00E+10	5.00E+10
	491	3520	2000	446.1	1720	7.8	8.00E+10	3.00E+10

Cfu: Colony Forming Unit

The value of BOD5 to COD ratio is commonly used as indicator of biodegradability for wastewater from cesspits.

The table below (Table 4.4) summarized the value of BOD5/COD for cesspits samples.

Table (4.4): The BOD_5/COD values for cesspits.

Location of Sampling	BOD_5/COD
Anabta	0.405
Baqa al-Sharquia	0.312
	0.418
Nazlet Issa	0.110
	0.139

As BOD_5 to COD ratio is larger than 0.3 and less than 0.5 in both Anabta and Baqa al Sharquia, samples indicate that the wastewater from cesspits is considered as biodegradable. However, Low BOD_5 /COD value in Nazlet Issa (less than 0.3) considered the wastewater from cesspits as non degradable.

Chapter Five
The Modeling Approach

5.1 General Introduction

The development of predictive groundwater models provides adequate tools to evaluate the proposed management actions **(Moore, et al., 1979).**

The best tool available to help groundwater hydrologist meet the challenge of prediction is usually a groundwater model. The groundwater model is a tool that approximates a field situation. Models are the best available alternative for analyzing complex resource problems **(Anderson, et al., 1992).**

5.2 The Selected Code for the Numerical Model

MODFLOW-2000 (USGS) was selected and utilized for the development of the numerical model. The model is public domain and can be downloaded from http://water.usgs.gov/nrp/gwsoftware/modflow.html. MODFLOW is a three dimensional finite-difference groundwater model that has a modular structure that can be easily modified to adapt for a particular application due to the many packages that can be simultaneously utilized in the development of the numerical model.

In this chapter, groundwater particle tracking model using MODPATH for the specific case study in the West Bank (Tulkarem District) is developed.

The MODPATH was linked to the available MODFLOW model for the Western Aquifer Basin which was developed by Abusaada (2011).

5.3 Description of MODPATH

5.3.1 General Background

MODPATH is a particle tracking post-processing program designed to compute three-dimensional flow paths using output from groundwater flow simulations by MODFLOW **(Pollock, 1994).**

The MODPATH package has been widely applied to MODFLOW based groundwater flow simulation studies. It is useful to help understand flow patterns in simulated groundwater flow systems. It also has been widely used to delineating capture zone or areas of influence for source and drawing flow path line and transport of contaminants simulated with MODFLOW **(Pollock, 1994).**

MODPATH tracks the trajectory of a set of particles from user-defined starting locations using the MODFLOW solution as the flow field **(Pollock, 1994).**

Output from steady-state or transient MODFLOW simulations is used in MODPATH to compute paths for imaginary "particles" of water or contaminant moving through the simulated groundwater system (**Pollock, 1994).**

MODPATH uses analytical particle tracking scheme that allows an analytical expression of the particle's flow path to be obtained within each finite-difference grid cell. The particle path is computed by tracking particles from one cell to the next until the particles reach a goal **(Pollock, 1994).**

Particles can be tracked either forward in time that generate particles at source, or backward in time which generate particles at selected cells commands. It is possible to perform a wide range of analyses and variety of applications.

The flow path lines provide an important representation of the flow direction and the path that the contaminant will follow from a specific location. Backwards particle tracking can also be used to indicate where the contaminant is coming from. Display options include viewing all path lines as a projection through the entire model, viewing only those path lines that start in the current layer, or viewing only the path line segments which occur in the current layer **(Pollock, 1994).**

5.3.2 Concept of the Particle Tracking Method

The partial differential equation describing conservation of mass in a steady-state, three-dimensional groundwater flow systems can be expressed as,

$$\frac{\partial}{\partial x}(nv_x)+\frac{\partial}{\partial_y}(nv_y)+\frac{\partial}{\partial_z}(nv_z)=W \qquad (1)$$

where v_x, v_y, and v_z, are the principal component of the average linear groundwater velocity vector, n is the porosity and W is the volume rate of water created or consumed by internal sources and sinks per unit volume of aquifer. Equation (1) expresses conservation of mass for an infinitesimally small volume of aquifer. The finite difference approximation of equation (1) can be thought of as a mass balance equation for a finite-sized cell of aquifer that accounts for water flowing into and out of the cell, and for water generated or consumed within the cell.

The average linear velocity component across each face in a cell is obtained by dividing the volume flow rate across the face by the cross sectional area of the face and the porosity of the material in the cell. In the discussion that follows, the six cell faces are referred to as $x_1, x_2, y_1, y_2, z_1, z_2$. Face x_1 is the face perpendicular to the direction at $x=x_1$. Similar dentitions hold for the other five faces.

$$v_{x_1} = \frac{Q_{x_1}}{(n\Delta y\Delta z)} \qquad v_{x_2} = \frac{Q_{x_2}}{(n\Delta y\Delta z)} \tag{2}$$

$$v_{y_1} = \frac{Q_{y_1}}{(n\Delta x\Delta z)} \qquad v_{y_2} = \frac{Q_{y_2}}{(n\Delta x\Delta z)} \tag{3}$$

$$v_{z_1} = \frac{Q_{z_1}}{(n\Delta x\Delta y)} \qquad v_{z_2} = \frac{Q_{z_2}}{(n\Delta x\Delta y)} \tag{4}$$

where Q is a volume flow rate across a cell face, and Δx, Δy, and Δz are the dimensions of the cell in the respective coordinate directions.

Figure 5.1, depicts a finite-sized cell of aquifer and the components of inflow and outflow across its six faces.

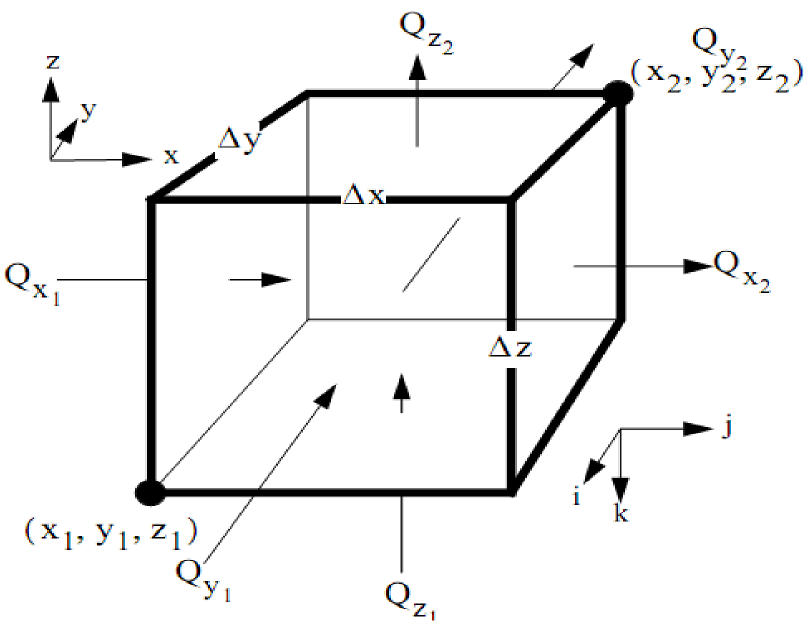


Figure (5.1): Representation of Finite-difference cell showing definitions of x-y-z

Consider the movement of a particle (p), through a three-dimensional finite-difference cell. The rate of change in the particles of x-component of velocity as it moves through the cell is given by,

$$\left(\frac{dv_x}{dt}\right)p = \left(\frac{dv_x}{dx}\right)\left(\frac{dx}{dt}\right)p \tag{5}$$

To simplify notation, the subscript (p), is used to indicate that a term is evaluated at the location of the particle denoted by the x-y-z coordinates (x_p, y_p, z_p).

5.3.3 Forward and Backward Particle Analysis

Forward or backward tracking particles can be easily assigned for determining transport of contaminant flow pathways and delineating well capture zones (see Figure 5.2). This graphical tool allows to easily assigning single particles, lines of particles and a circle of particles anywhere in the model domain **(Pollock, 1994).**

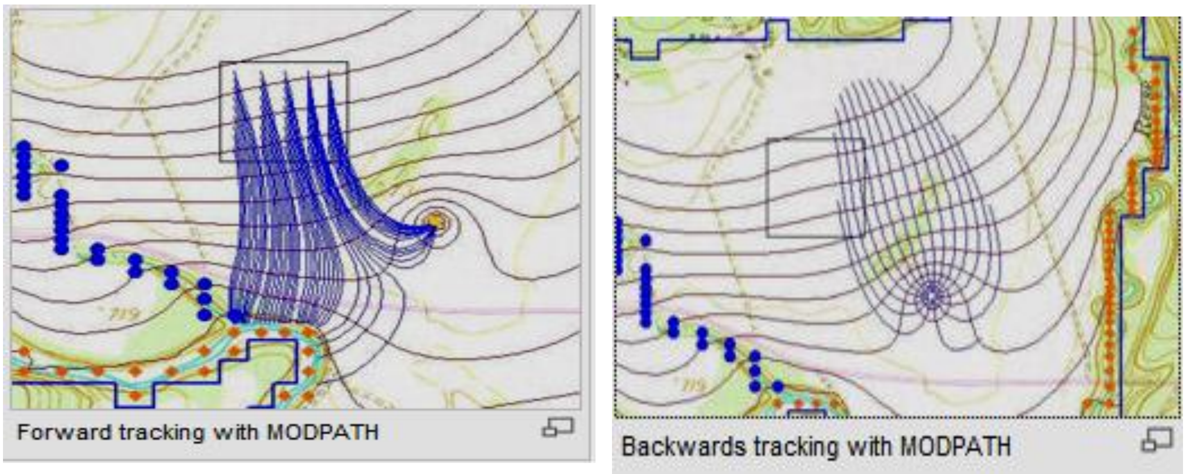


Figure (5.2): Forward and backward tracking with MODPATH (www.xmswiki.com)

5.4 General Description of the Study Area Model

5.4.1 Model Outline

As mentioned earlier, a steady-state numerical model of the Western aquifer basin was developed using MODFLOW groundwater model by Abusaada (2011). The boundary of the study area was extracted from the model domain. It contains Tulkarem District and part of Jenin District. The boundary is set to include all the communities where their cesspits may affect the groundwater wells. There are 17 municipal groundwater wells and 49 communities in the study area (Figure 5.3).

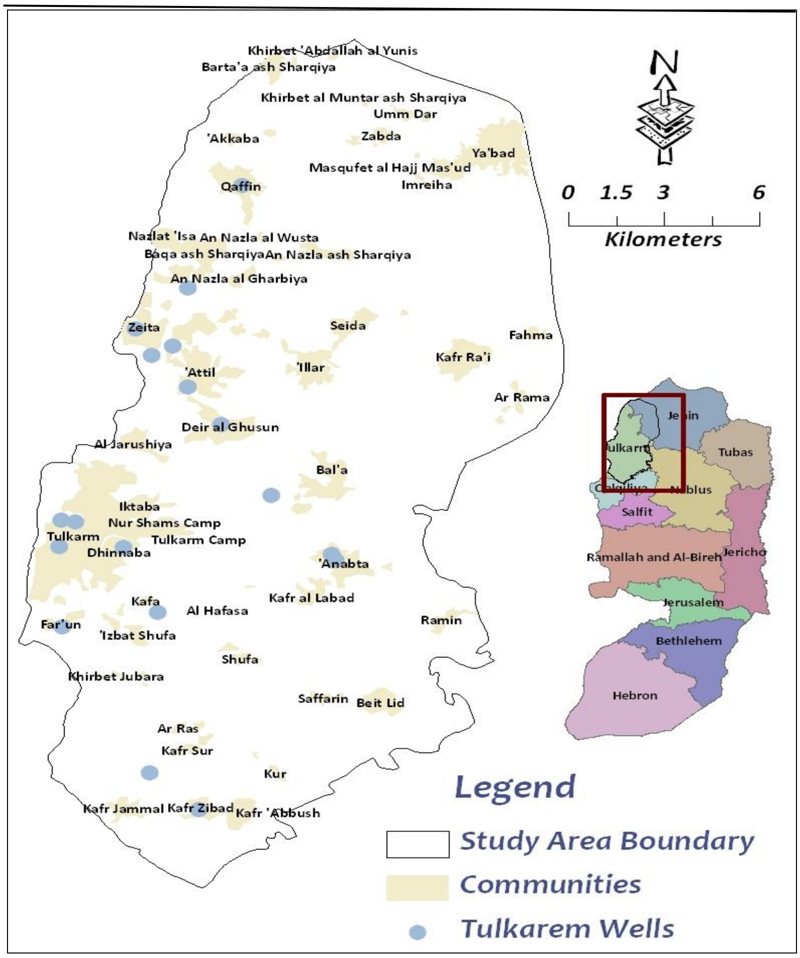


Figure (5.3): The spatial distribution of the wells and communities in the study area

The table below (Table 5.1) summarizes the communities in the model domain, the percent of cesspits that used in these communities, the groundwater wells which served these communities and the annual wastewater generated from these communities.

Table (5.1): The communities in the model domain, the groundwater wells that serve these communities, the wastewater generated from these communities along with the percentage of cesspits

N0.	Name	Governorate	Population (2007)	Well ID	Wastewater Generated (m^3/year)	Percent of Cesspits (%)
1	Khirbet Abdallah al Yunis	Jenin	138	-	2,040	62
2	Barta'a ash Sharqiya	Jenin	4,176	BA/006 (Spring)	61,732	47
3	Khirbet Mas'ud	Jenin	47	water Tank	-	100
4	Khirbet al Muntar ash Sharqiya	Jenin	7	water tank	-	100
5	Umm Dar	Jenin	557	water tank	-	90
6	Al Khuljan	Jenin	509	water tank	-	81
7	Dhaher al 'Abed	Jenin	363	water tank	-	97
8	Zabda	Jenin	944	water tank	-	87
9	Ya'bad	Jenin	13,640	16-20/003	41,073	78
10	Imreiha	Jenin	423	water tank	-	68
11	Fahma	Jenin	2,486	-	18,375	93
12	Kafr Ra'i	Jenin	7,364	Mekorot and water tank	52,413	79
13	Ar Rama	Jenin	964	Mekorot	15,042	100
14	'Akkaba	Tulkarm	254	water tank	-	100
15	Qaffin	Tulkarm	8,387	15-20/008	199,747	100
16	Nazlat 'Isa	Tulkarm	2,334	15-20/003	42,808	100
17	An Nazla ash Sharqiya	Tulkarm	1,514	16-20/005	22,795	100
18	Baqa ash Sharqiya	Tulkarm	4,101	15-19/001	92,057	100

				15-19/005 15-20/002A		
19	An Nazla al Wusta	Tulkarm	340	15-20/004	-	100
20	An Nazla al Gharbiya	Tulkarm	937	15-20/004	18,468	100
21	Zeita	Tulkarm	2,852	15-19/010	187,442	35.3
22	Seida	Tulkarm	2,929	.15-19/010	-	100
23	'Illar	Tulkarm	6,190	15-19/010	110,143	100
24	'Attil	Tulkarm	9,038	15-19/035 15-19/036 15-19/041	232,570	100
25	Deir al Ghusun	Tulkarm	8,242	15-19/047	191,781	100
26	Al Jarushiya	Tulkarm	932	15-19/046	26,279	100
27	Masqufet al Hajj Mas'ud	Tulkarm	260	15-19/046	2,776	90
28	Bal'a	Tulkarm	6,604	15-19/048	171,745	100
29	Iktaba	Tulkarm	2,665	15-19/043	72,954	80
30	Nur Shams Camp	Tulkarm	6,479	15-19/046	150,758	0.2
31	'Anabta	Tulkarm	7,329	16-19/001 16-19/002	236,745	37
32	Kafr al Labad	Tulkarm	4,074	15-19/028	82,529	100
33	Kafa	Tulkarm	404	15-19/046 15-18/008	4,866	100
34	Al Hafasa	Tulkarm	157	15-18/020	-	85
35	Ramin	Tulkarm	1,806	16-19/002	29,664	100
36	Far'un	Tulkarm	3,100	15-18/006 15-19/007	63,647	100

37	Shufa, 'Izbat Shufa	Tulkarm	2,194	15-18/024	117,719	100
38	Khirbet Jubara	Tulkarm	293	water tank	-	100
39	Saffarin	Tulkarm	760	BA/034 (Spring)/Nablus	-	100
40	Beit Lid	Tulkarm	4,994	Mekorot	47,849	100
41	Ar Ras	Tulkarm	540	Mekorot	11,530	91
42	Kafr Sur	Tulkarm	1,117	Mekorot	48,925	100
43	Kur	Tulkarm	262	water tank	-	100
44	Kafr Zibad	Tulkarm	1,078	15-18/015	30,947	100
45	Kafr Jammal	Tulkarm	2,424	Mekorot	41,089	100
46	Kafr 'Abbush	Tulkarm	1,457	15-18/015	34,700	100
47	Tulkarm City	Tulkarm	51,300	15-19/017 15-19/018	1,699,298	25
48	Dhinnaba	Tulkarm	8,433	15-18/025	212,385	80
49	Tulkarm Camp	Tulkarm	10,641	15-19/046	267,994	0.1

The groundwater level for domestic wells in the study area varies between 15-30 meters above sea level (a.s.l) (see figure 5.4). Mostly of these wells exploited from the upper cenomanian aquifer indicate that the study area is vulnerable of contamination due to the depth of these wells.

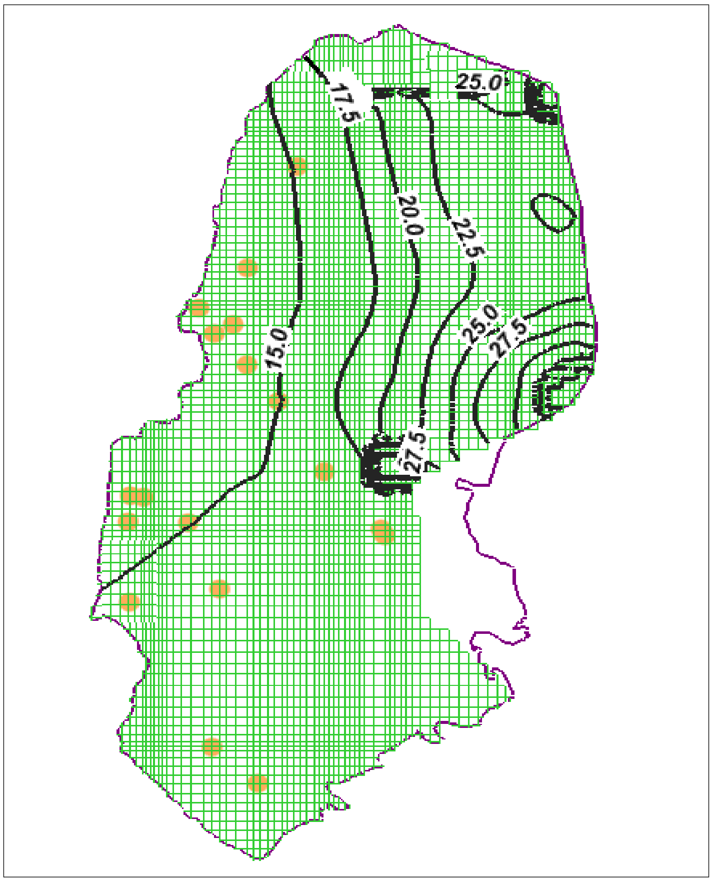


Figure (5.4): The Contours of water level for groundwater wells above sea level (a.s.l) in the study area

5.4.2 Hydrostratigraphic Units

The study-area geometry was constructed with four distinctive layers as follows to comprise layers representing for hydrogeological units of the study area **(Abusaada, 2011).**

1. The top layer (Layer 1) includes the Abu Dees formation and all other overlying formations. This layer is modeled as an aquitard layer with very low vertical and horizontal conductivities.

2. Layer 2 corresponds to the upper aquifer (Hebron, Bethlehem and Jerusalem formations).
3. The upper and lower sub-aquifers are separated by Layer 3 (the Yatta formation).
4. Layer 4 corresponds to the lower aquifer (Beit Kahel formation).

Layer 1 and 2 described above outcrop within the outline of the study area as can be seen from Figure 5.5. The outcropping formations largely dictate the direct recharge of contaminant to the different layers.

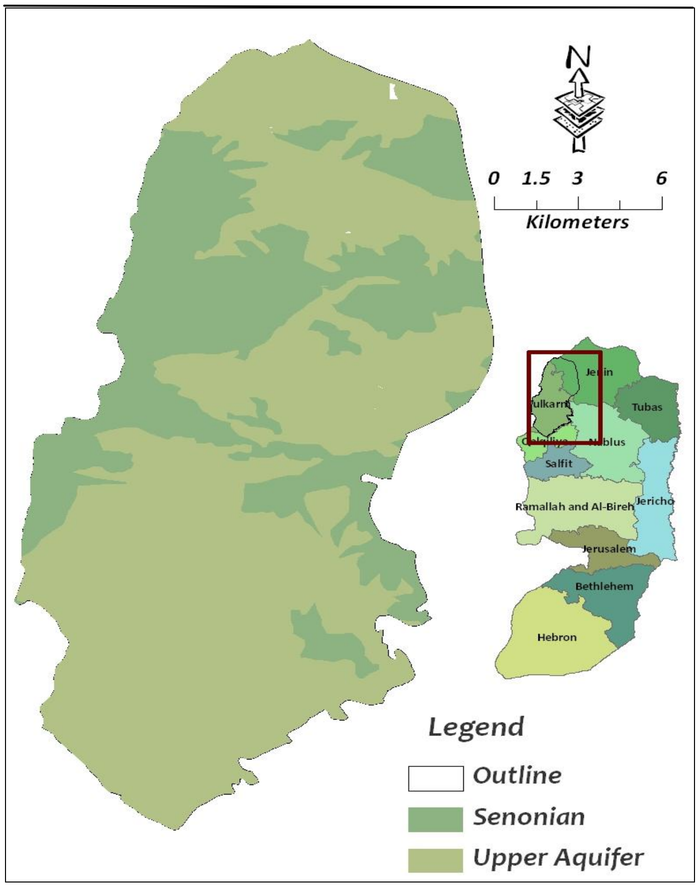


Figure (5.5): The outcropping formations in the study area

The cross-section that describes the study area is shown in Figure 5.6.

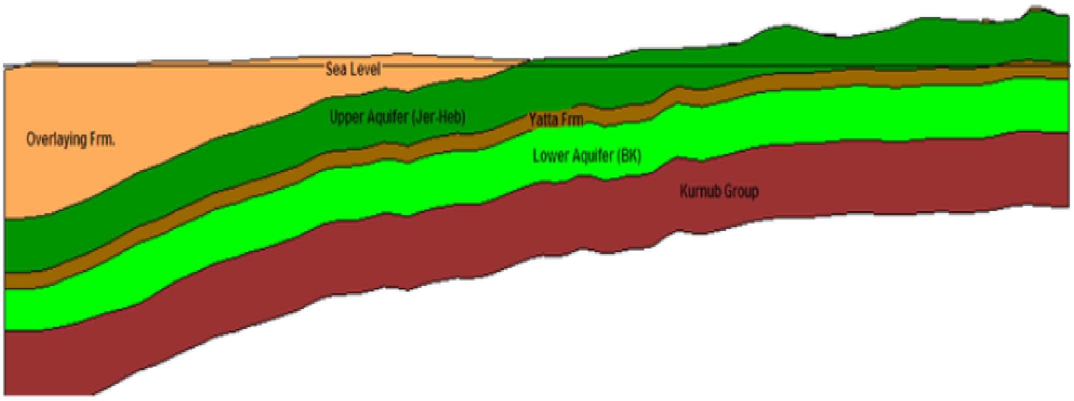


Figure (5.6): A hydrogeological cross section for study area **(Abusaada, 2011).**

5.4.3 Discretization

A finite difference grid was created for the model domain. Figure (5.7) depicts the model grid for the study area boundary with 200 by 750 meter cell sizes. The smaller grid sizes were used for the cells of the wells. The total number of rows and columns equals 97 and 70, respectively.

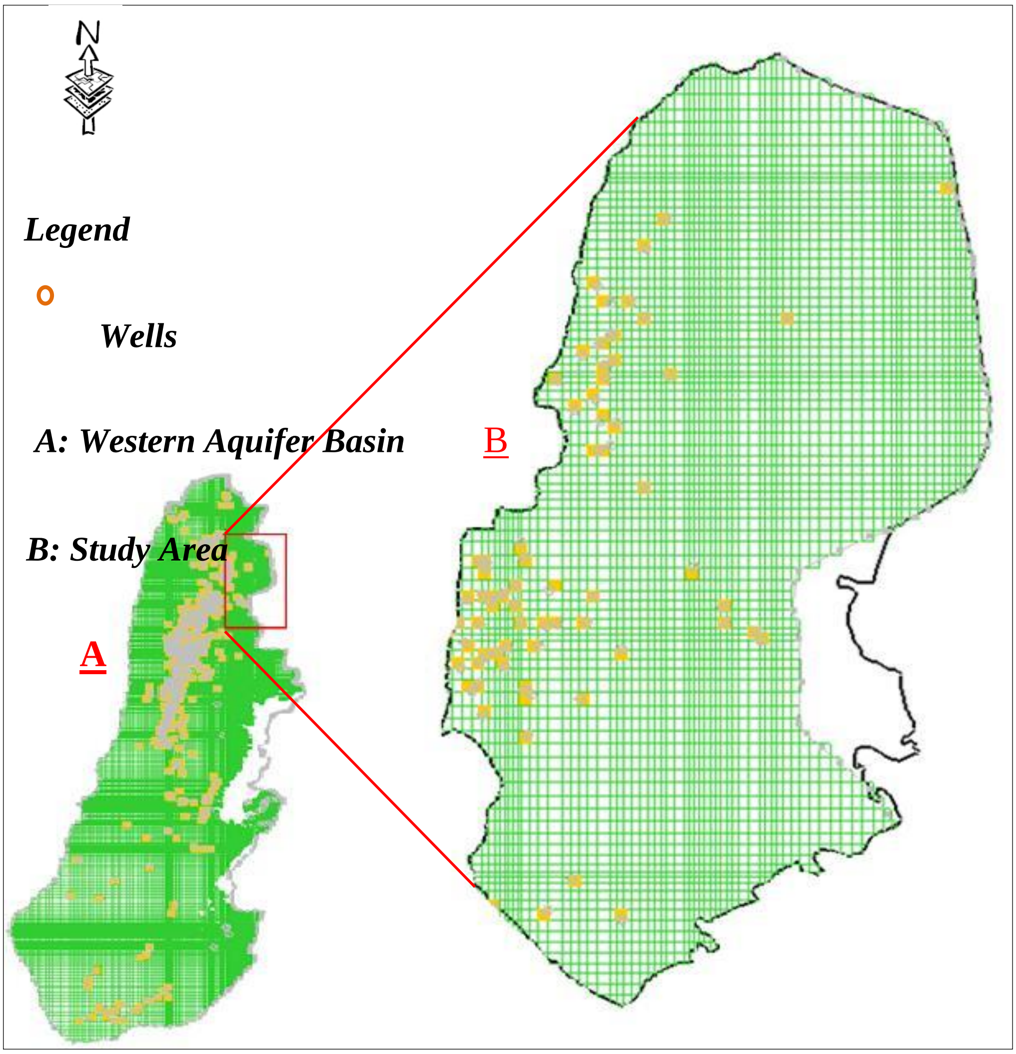


Figure (5.7): The finite-difference grid for the study area

5.5 Development of the MODPATH Model for the Study Area

Simulation of groundwater flow pathways was modeled for the study area using the steady-state groundwater flow model for the Western aquifer basin.

Different scenarios were worked out in order to see the influence of the contamination from cesspits on the groundwater wells. This was performed by developing a MODPATH model for the study area, which uses the flow field as computed by MODFLOW.

The first scenario analyzes the capture zones for the groundwater wells using MODPATH backward tracking command. A set of particles were designated in the cells that represent the location of the groundwater wells in the model domain. In this way it was possible to see which contributing areas of the wells intersect the contamination sources.

The following figure (Figure 5.8) depicts an example of backward tracking for Kamel Al Salem and Partners well in Kafr Zibad (15-18/015).

Figure (5.8): Backward tracking for Kamel Al Salem and Partners well (15-18/015) with MODPATH

The second scenario analyzes the flow path lines of the contamination from cesspits. This was performed by forward tracking where the starting location of the particles was considered at the location of the communities in the study area. In this way the flow path lines of the contaminant provide an important representation of the flow direction and the path that the contaminant will follow from a specific originating location until it reaches the groundwater wells.

The figure below (Figure 5.9) depicts an example of forward tracking for Izbat Shufa village (The Tulkarem Municipality well (15-19/017) intersect the contributing area of contaminant from Izbat Shufa village).

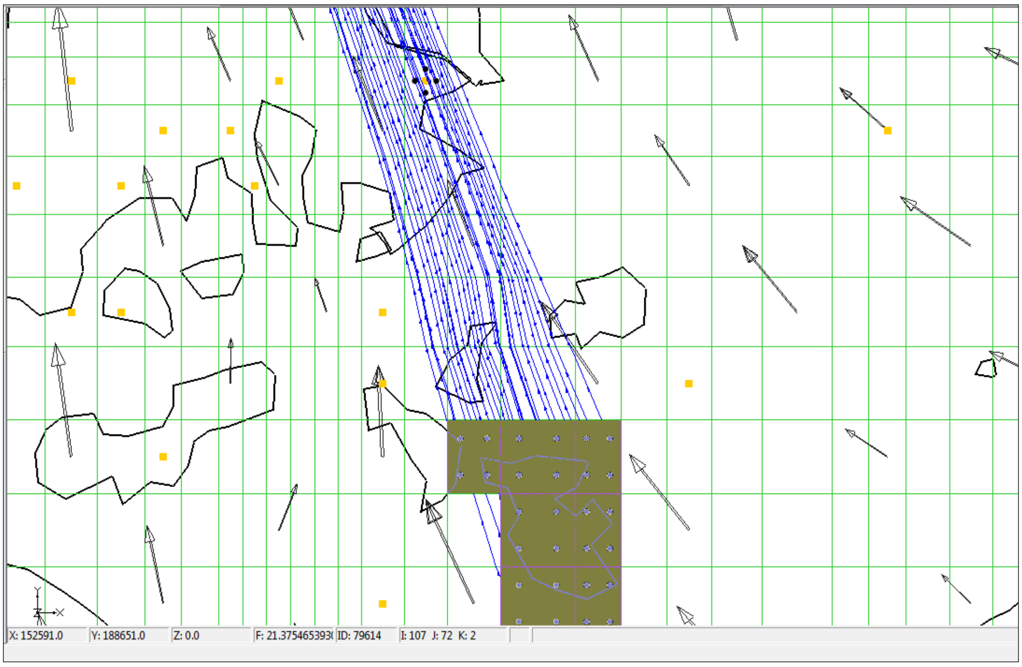


Figure (5.9): Forward tracking for Izbat Shufa village with MODPATH

Chapter Six
Results, Analysis, and Discussion

6.1 Scenario Analysis Results

A number of different simulations were tested in order to show the influence of wastewater generated from cesspits on the groundwater wells. The purpose of the simulation for these scenarios was to determine the expected general wastewater flow pathways from communities and to delineate the capture zone for the groundwater wells in the study area.

The results from the backward and forward tracking performed with MODPATH are discussed in the following sections.

6.1.1 Backward Tracking Scenario and Analysis of the Results

The backward tracking approach was used to delineate the capture zones for 17 groundwater wells located in the study area.

A set of particle-starting locations was specified and particles were tracked backward to locate the origin of the flow paths for the groundwater wells. The results from MODPATH backward tracking analysis were presented in the figures below (Figure 6.1 and 6.2).

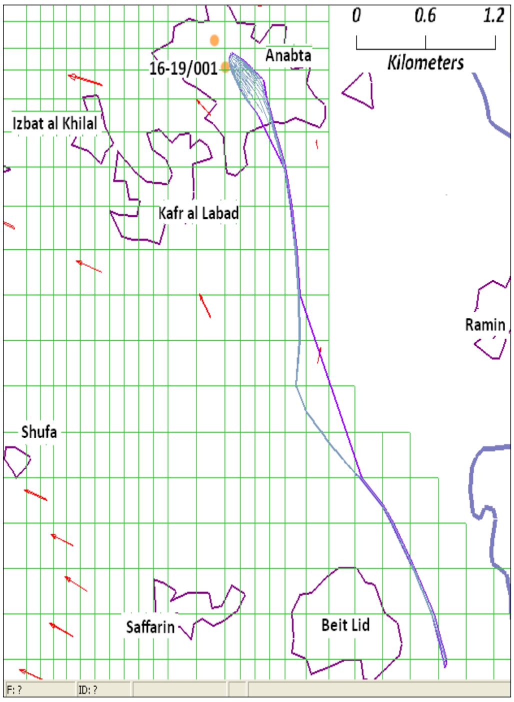
The figures show different shapes of the capture zones for groundwater wells in the study area. These shapes vary from one location to another and are affected by the hydraulic conductivity of the layers and the pumping rate of these wells.

The table below (Table 6.1) summarizes the area of capture zones and the pumping rate for groundwater wells.

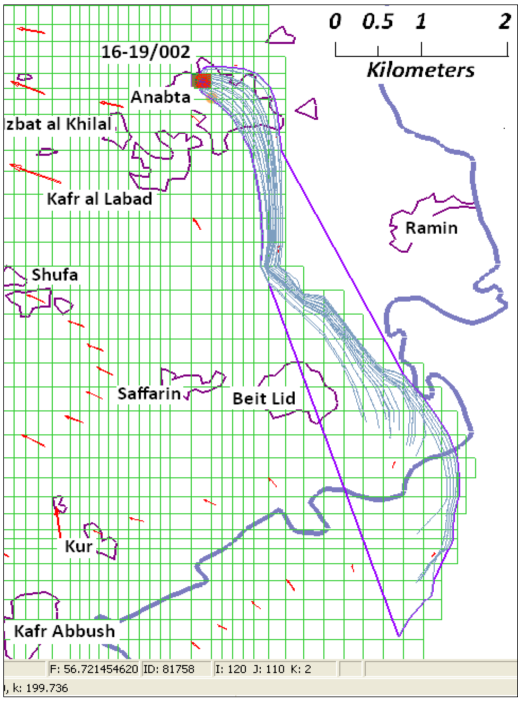
Table (6.1): The pumping rate and the area of capture zone for groundwater wells in the study area.

NO.	Well ID	Name	Pumping rate (m^3/year)	Area (Km^2)
1	16-19/001	Anabta Muncipility 1	81,624	1.86
2	16-19/002	Anabta Muncipility 2	311,595	8.55
3	15-19/035	As'ad Rabee' & Partners	318,434	1.53
4	15-19/038	As'ad Taffal & Ahmad Khraishah	221,699	3.01
5	15-19/036	Attil Cooperative Society	393,554	6.46
6	15-19/048	Bal'a Village Council	176,721	0.29
7	15-19/047	Deir Al Ghusun Village Council	394,440	0.71
8	15-18/015	Kamel Al Salem &Partners	62,586	0.42
9	15-18/006	Muhammad Abed Al Haleem	234,290	7.51
10	15-20/002A	Muhammad Abu Shams	571,000	12.87
11	15-19/041	Muhammad Nemer Barkat	437,333	5.26
12	15-20/008	Qaffin Village Council	342,234	1.50
13	15-18/025	Sal'eet	56,869	0.45
14	15-18/024	Shufa Water Cooperative Committee	90,190	1.13
15	15-19/017	Tulkarem Muncipility 1	990,196	12.83
16	15-19/046	Tulkarem Muncipility 2	513,011	4.28
17	15-19/010	Zeita Village Council	211,900	2.66

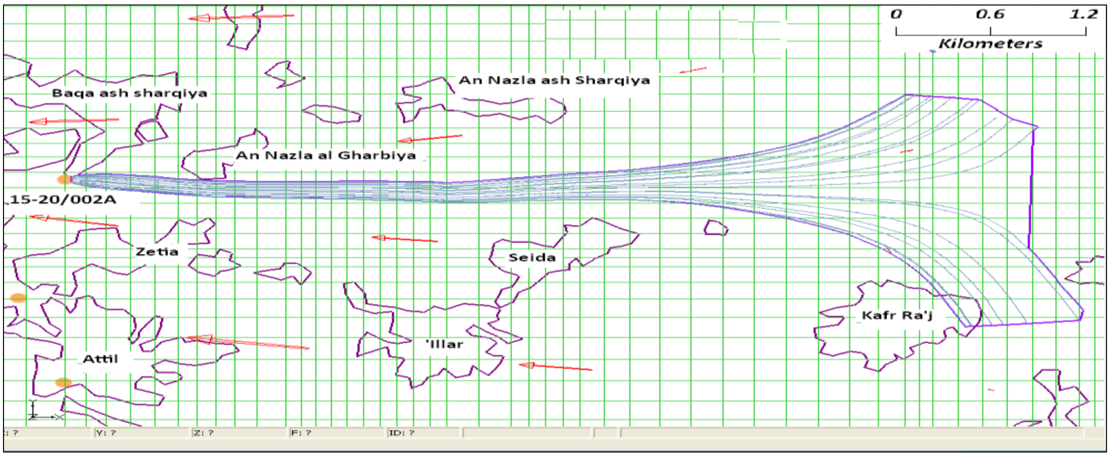
Contributing areas of wells and springs when intersect contamination sources like cesspits can stimulate and provoke the mobilization of contaminants toward them. The table below (Table 6.2) summarizes the communities that fall within the capture zones of the groundwater wells.



Capture Zone for Anabta Municipality 1 well

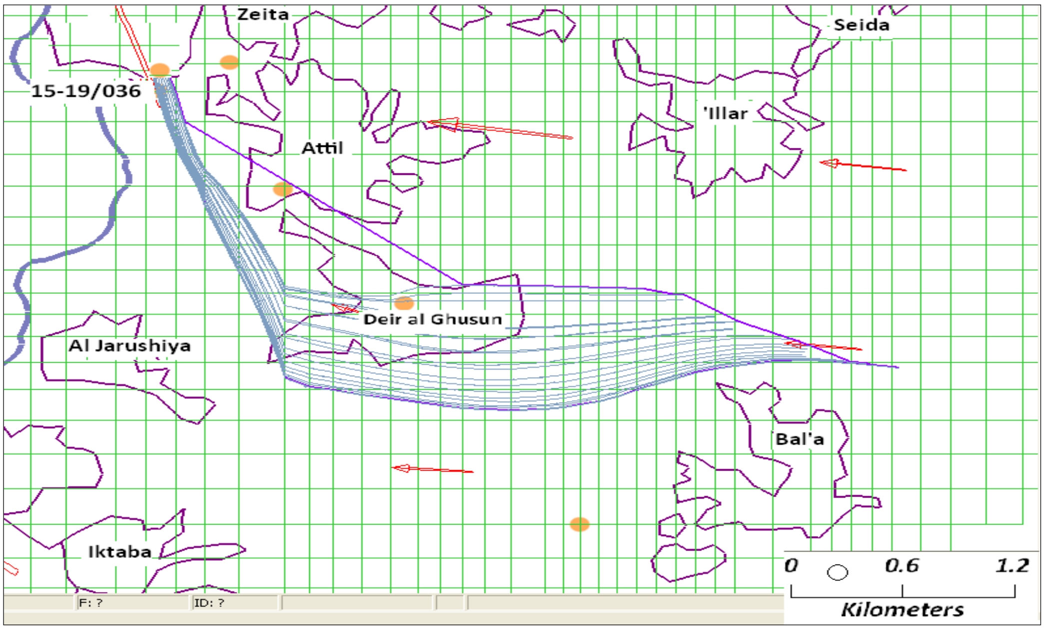


Capture Zone for Anabta Municipality 2 well

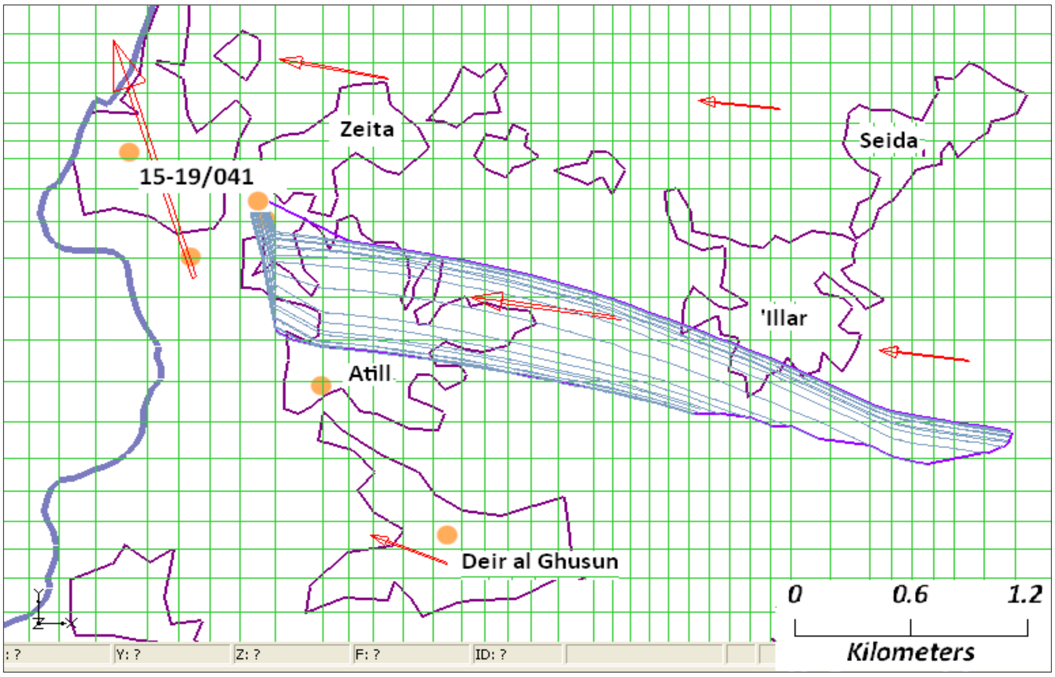


Capture zone for Muhammad Abu Shams well

Figure (6.1): Backward tracking for the groundwater wells in the study area with MODPATH



Capture zone for Attil Cooperative Society well



Capture zone for Muhammad Nemer Barkat well

Figure (6.2): Backward tracking for the groundwater wells in the study area with MODPATH

Table (6.2): The wells that are affected by communities that use cesspits and the population

Well ID	Name	Locality	Community that intersects the capture zone of the well	Population depending on groundwater well
15-18/015	Kamel Al Salem & Partners	Kafr Zibad	Kafr Zibad, Kafr 'Abbush	2,535
15-18/025	Sal'eet	Kafr Sur	Kafr Zibad	8,433
15-18/006	Muhammad 'Abed Al Haleem	Far'un	-	1,550
15-18/024	Shufa Water Cooperative Committee	Shufa	Shufa	2,194
15-19/017	Tulkarm Municipality	Tulkarm	Izbat Shufa, Kafa, part of Tulkarem City	25,650
15-19/018	Tulkarm Municipality		Kafa, Shufa, Part of Tulkarem City	25,650
15-19/046	Tulkarm Municipality		Dennabeh, Kafa, Shufa	18,514
16-19/001	'Anabta Municipality	'Anabta	Southern of 'Anabta City	3,665
16-19/002	'Anabta Municipality		Beit Lid, Eastern part of Anabta City	5,470
15-19/048	Bal'a Village Council	Bal'a	Part of Bala Village	6,604
15-19/047	Deir Al Ghusun Village Council	Deir al Ghusun	Eastern part of Deir al Ghusun	8,242
15-19/035	As'ad Rabee' & Partners	'Attil	Northern part of Deir al Ghusun	3,012

15-19/010	Zeita Village Council	Zeita	Southern part of Zeita	13,338
15-20/002A	Muhammad Abu Shams	Baqa ash Sharqiya	An Nazla al Gharbiya, Kafr Ra'i	1,367
15-20/008	Qaffin Village Council	Qaffin	Eastern part of Qaffin	8,387
15-19/036	Attil Cooperative Society	'Attil	Deir al Ghusun	3,012
15-19/041	Muhammad Nemer Barakat		Attil, part of 'Illar	3,012

The results from MODPATH backward tracking show some overlaps between the capture zones of the wells such as the capture zone for following wells (16-19/001 and 16-19/002), (15-18/024 and 15-19/046), (15-19/047 and 15-19/036), and (15-19/010 and 15-19/036). The overlaps between the contributing areas of groundwater wells increase the effect of contamination from cesspits toward the wells.

The water quality of the groundwater wells in the study area which were summarized in Table 4.2 emphasizes and supports the results from MODPATH backward tracking. The majority of the wells where their capture zones intersect communities, which use cesspits, were contaminated with coliform bacteria and NO_3.

The capture zone of Muhammad Abed Al Haleem well had no intersection with any communities that use cesspits and this well was contaminated with coliform bacteria. However, the capture zone of this well intersects with the location of a dumping site which may affect the water quality for this well.

6.1.2 Forward Tracking Scenario and Analysis of the Results

The forward tracking process was used to determine the transport of contaminants from cesspits introduced at the locations of the 49 communities distributed in the study area.

The results from the MODPATH forward tracking analysis are shown in the figures below (Figure 6.3 and 6.4).

The forward tracking analysis focused on the contributing areas of contamination as well as the pollutant transport from communities to the groundwater wells.

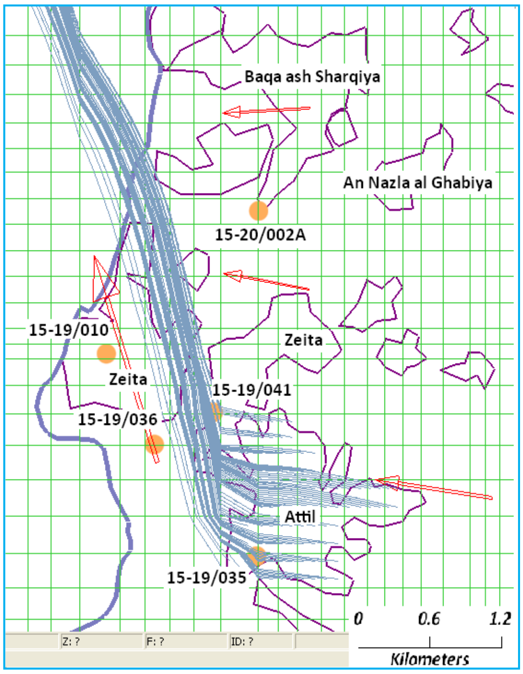
The table below (Table 6.3) summarizes the communities which the wastewater flow path lines of their cesspits intersect the locations of the groundwater wells.

Comparing the chemical and biological analysis for the groundwater wells in the study area (see Figure 4.7) and the results from the MODPATH forward tracking analysis, the majority of the wells in Tulkarem District that were contaminated with coliform bacteria indicate that the water is potentially polluted from cesspits and this is in full agreement with the results from MODPATH (Table 6.3).

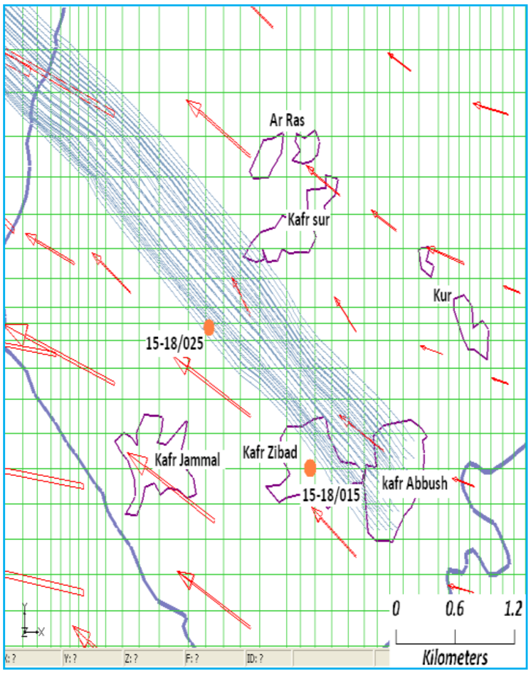
In addition, the cesspits are shown to contribute to nitrate pollution of groundwater wells. Figure 4.7 in chapter four depicts the wells that are contaminated with NO_3 in Tulkarem District and most of these wells intersect the contributing area of contamination (see Table 6.3).

The paths start from where the pollution source was located. Some of the wells (15-18/025, 15-19/036, and 15-19/038, 15-20/008) intersect the contributing area of contamination but these wells were not contaminated.

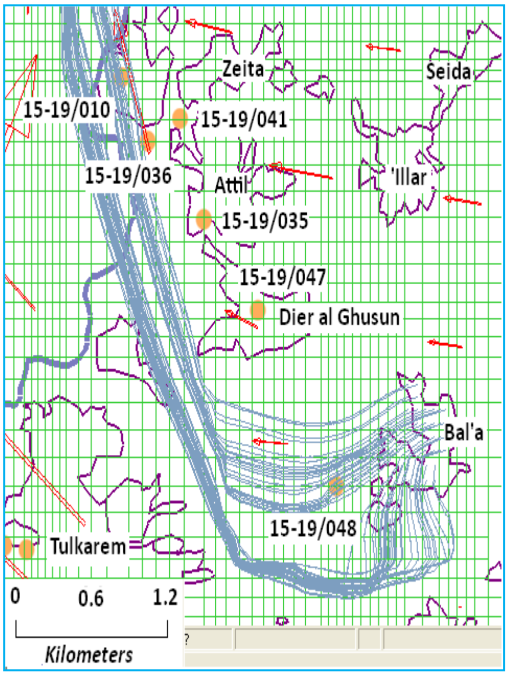
The reason for this occurrence might be due to the dissolve and dilution of pollutants along the flow path due to the mixing with non-contaminated water and would finally spread out such that the maximum concentration decreases with time and ends up in the groundwater well without affect the water quality.



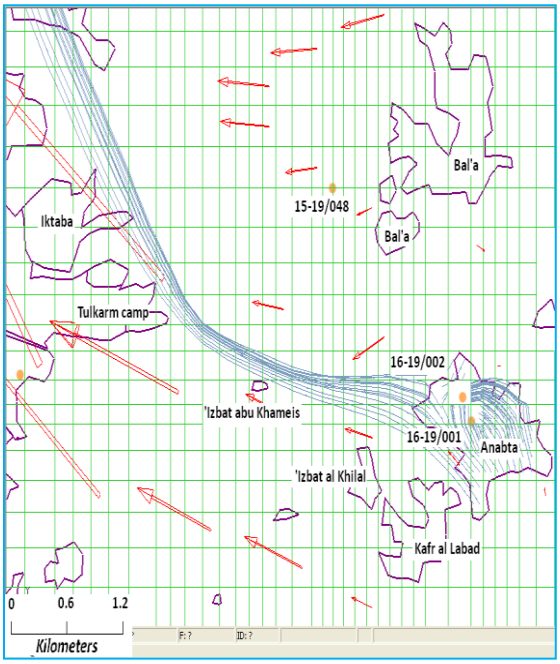
Path lines for pollutants from Attil Village



Path lines for pollutants from Kafr Abbush Village

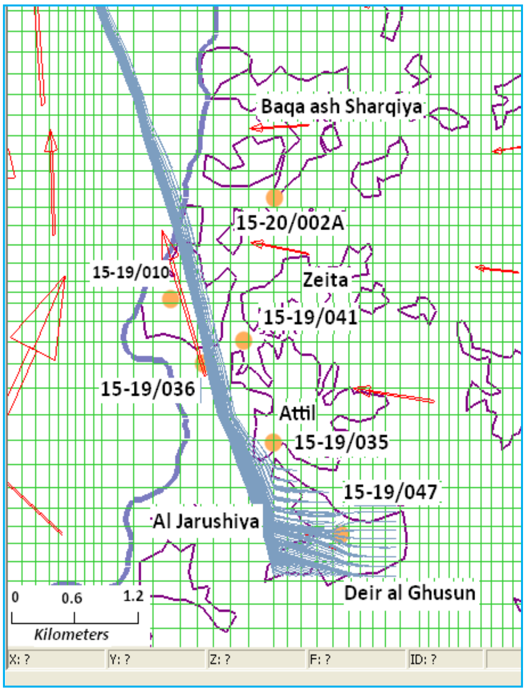


Path lines for pollutants from Bala Village

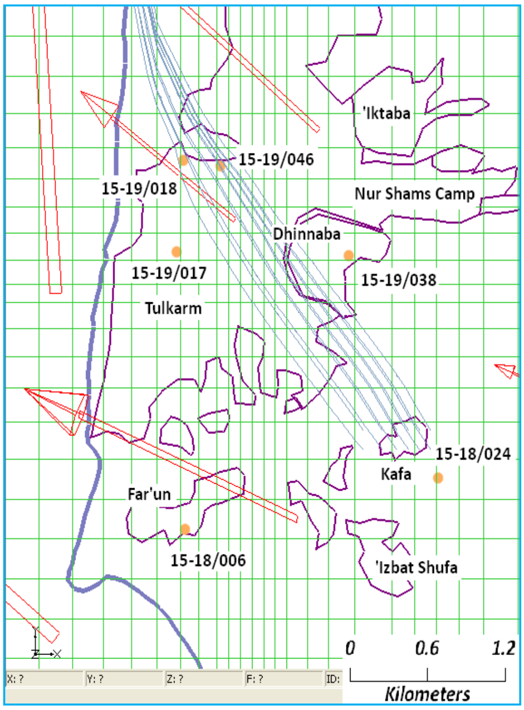


Path lines for pollutants from Anabta Village

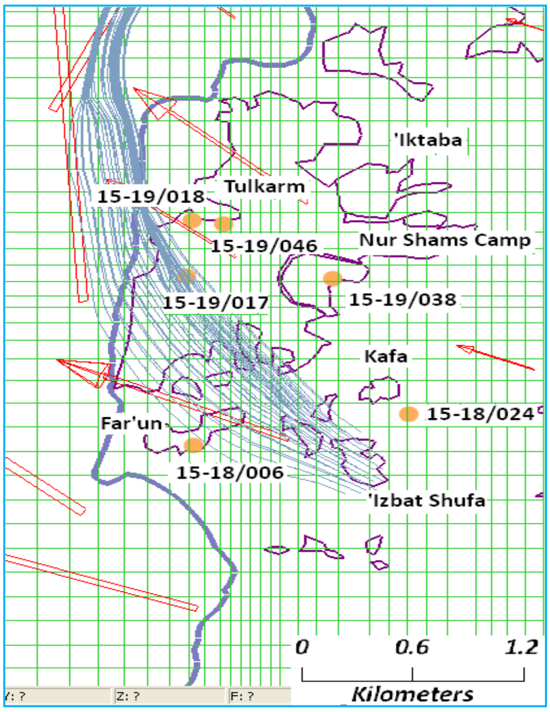
Figure (6.3): Forward tracking for the communities in the study area with MODPATH



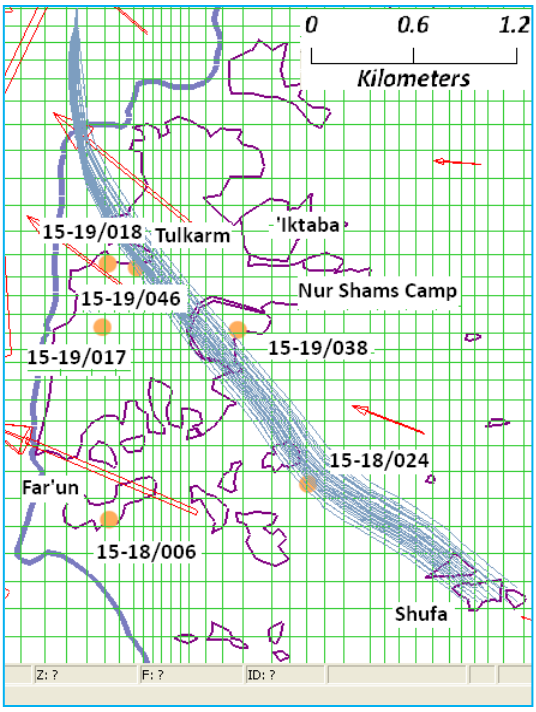
Path lines for pollutants from Deir al Ghusun Village



Path lines for pollutants from Kafa Village



Path lines for pollutants from Izbat Shufa Village



Path lines for pollutants from Shufa Village

Figure (6.4): Forward tracking for the communities in the study area with MODPATH

Table (6.3): The groundwater wells which intersect the contributing area of contaminant from communities.

Community	Well / Locality	Well ID
Tulkarem District		
Kafr 'Abbush	1. Sal'eet / Kafr Sur	15-18/025
Kafr Zibad	1. Kamel Al Salem & Partners / Kafr Zibad	15-18/015
	2. Sal'eet / Kafr Sur	15-18/025
Shufa	1. Shufa Water Cooperative Committee/ Shufa	15-18/024
	2. Tulkarm Municipality	15-19/046
Saffarin	1. As'ad Taffal & Ahmad Khraishah / Dennabeh	15-19/038
'Izbat Shufa	1. Tulkarm Municipality /Tulkarm	15-19/017
Kafa	1. Tulkarm Municipality /Tulkarm	15-19/018
	2. Tulkarm Municipality /Tulkarm	15-19/046
Anabta	1. Anabta Municipality /Anabta	16-19/001
	2. Anabta Municipality /Anabta	16-19/002
Bal'a	1. Bal'a Village Council / Bal'a	15-19/048
	2. Attil Cooperative Society /Attil	15-19/036
	3. Zeita Village Council / Zeita	15-19/010
Deir al Ghusun	1. Deir Al Ghusun Village Council / Deir al Ghusun	15-19/047
	2. Attil Cooperative Society / Attil	15-19/036
'Attil	1. As'ad Rabee' & Partners / Attil	15-19/035
	2. Muhammad Nemer Barakat / Attil	15-19/041
'Illar	1. Muhammad Nemer Barakat / Attil	15-19/041
Zeita	1. Zeita Village Council / Zeita	15-19/010

An Nazla al Gharbiya	1. Muhammad Abu Shams/Baqa ash Sharqia	15-20/002A
Jenin District		
Yabad	1. Qaffin Village Council/ Qaffin	15-20/008
Ar Rama	1. Deir Al Ghusun Village Council / Deir al Ghusun	15-19/047
	2. As'ad Rabee' & Partners / Attil	15-19/035
Ar Rama	3. Bal'a Village Council / Bal'a	15-19/048
	4. As'ad Taffal & Ahmad Khraishah / Dennabeh	15-19/038
	5. Tulkarm Municipality /Tulkarm	15-19/017
Fahma	1. Muhammad Abu Shams/Baqa ash Sharqia	15-20/002A
Kafr Rai'	1. Muhammad Abu Shams/Baqa ash Sharqia	15-20/002A
	2. Muhammad Nemer Barakat / Attil	15-19/041
	3. Zeita Village Council / Zeita	15-19/010

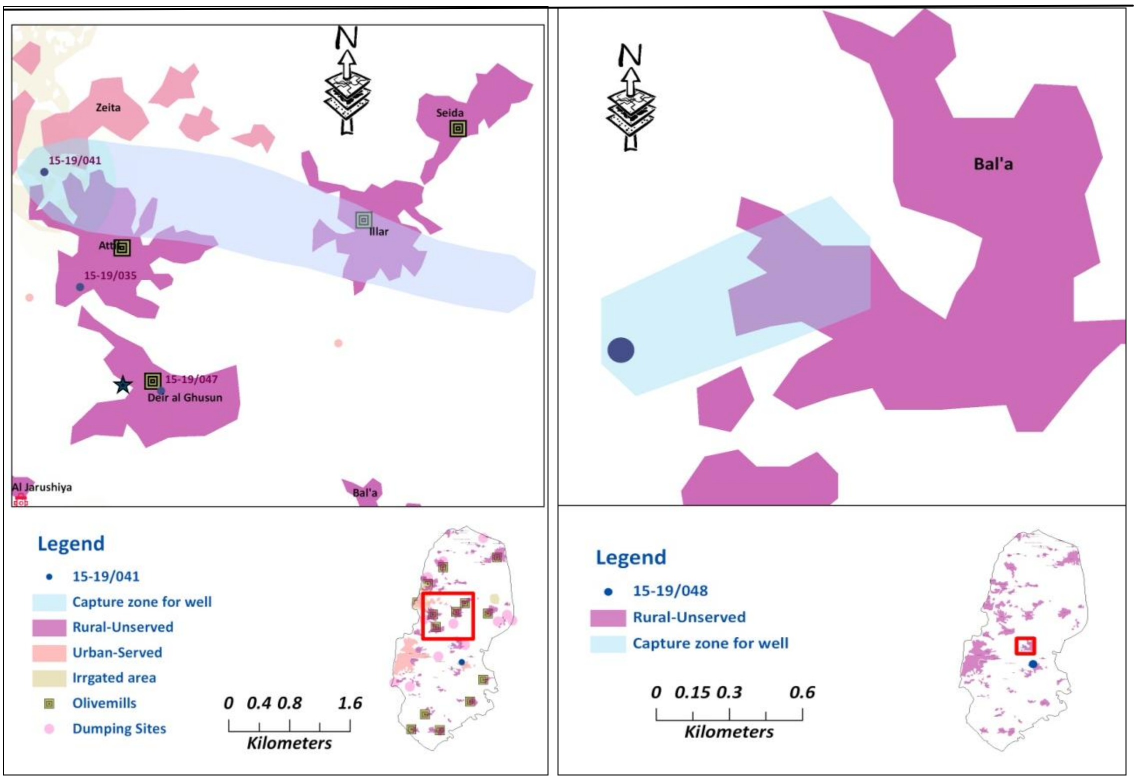
6.1.3 The Intersection of Capture Zone for Groundwater Wells with the Pollution Sources in the Study Area

As mentioned earlier, all groundwater wells in the study area are potentially affected by variety of contamination sources such as cesspits, dumping sites, wastewater discharged without any type of treatment, industrial and agricultural activities.

The figure below (Figure 6.5) depicts the pollution sources that fall within the capture zone for some of the contaminated groundwater wells in the study area.

The majority of capture zone for groundwater wells in the study area is intersecting with irrigated area and un-served communities which use cesspits and these wells are contaminated with coliform bacteria and NO_3.

The un-served communities located in critical zone around the wells where groundwater wells may be more easily contaminated that indicate that the water is potentially polluted from cesspits than other sources of pollution.



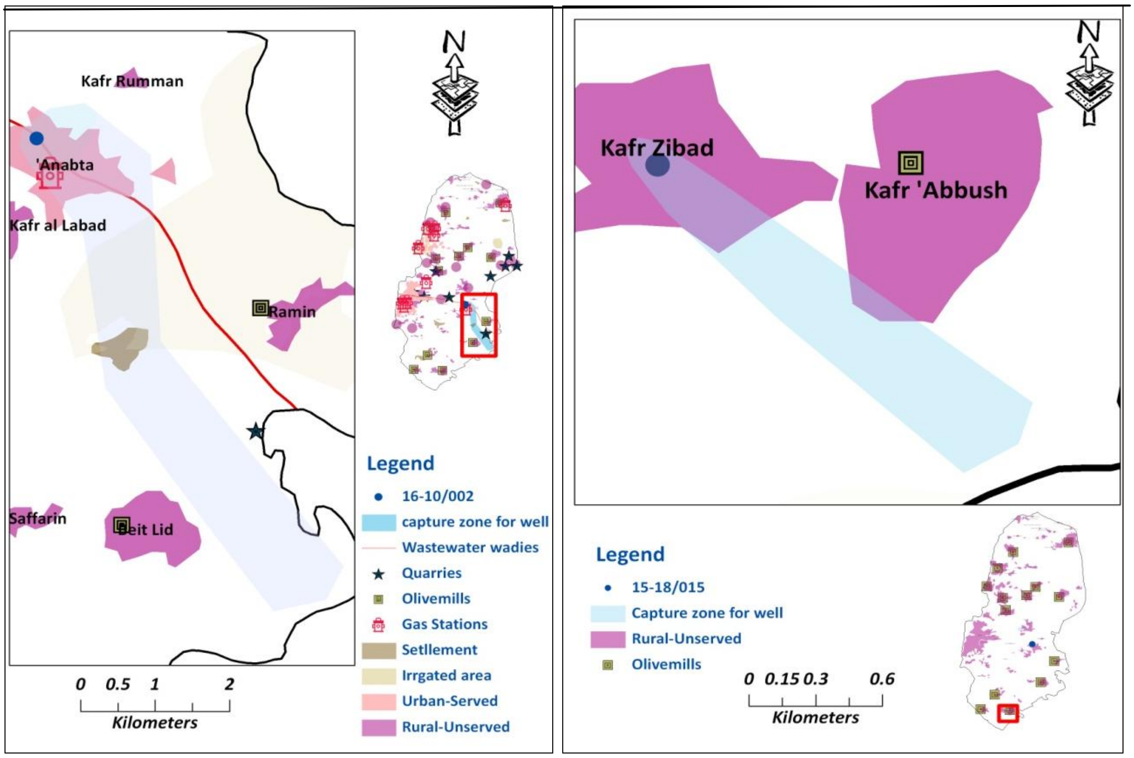


Figure (6.5): The capture zone for some of groundwater wells in the study area

6.2 Summary

The main aim for this chapter is to assess the potential impact to domestic groundwater wells in the event of a contamination occurrence inside the capture zone.

In light of the results and observations from the scenarios of MODPATH model, the following are general conclusions:

1. The path lines of contaminants in the study area are affected by the regional groundwater flow direction which was generally towards the west direction.

2. The capture zones for groundwater wells had shown different shapes. These shapes are affected by the hydraulic conductivity and the current pumping rates of the wells. When the area of the capture zone of a well increases this leads to the inclusion of more of contamination sources.
3. The contributing areas for the majority of the contaminated groundwater wells intersect with cesspits. On the other hand, the study area described above has outcropping formations which largely dictate the direct recharge of wastewater from cesspits to these groundwater wells. That means that the groundwater wells in the study area are highly vulnerable to pollution from cesspits.

Chapter Seven
A proposed Management Paln

7.1 Introduction:

Economic development in addition to human activities on land may create stresses on water resources in terms of both quality and quantity in the West Bank and elsewhere **(Khalaf and Hithnawi, 2007)**. On the other hand, population growth and accelerated urbanization place extra stress on the available water resources. Thus, the importance of taking a comprehensive approach to groundwater pollution protection and integrated management plan has been well established in the literature.

The groundwater wells in the study area are highly vulnerable to pollution from cesspits, dumping sites, wastewater discharged without any type of treatment, industrial and agricultural activities **(SUSMAQ, 2002)** (see Figure 7.1).

The main objectives of this chapter are to delineate the wellhead protection zone for each well of interest, identify the potential sources of contamination within each zone, and strategies and management plan that must be formulated for the decision makers and planners in order to protect the groundwater from pollution.

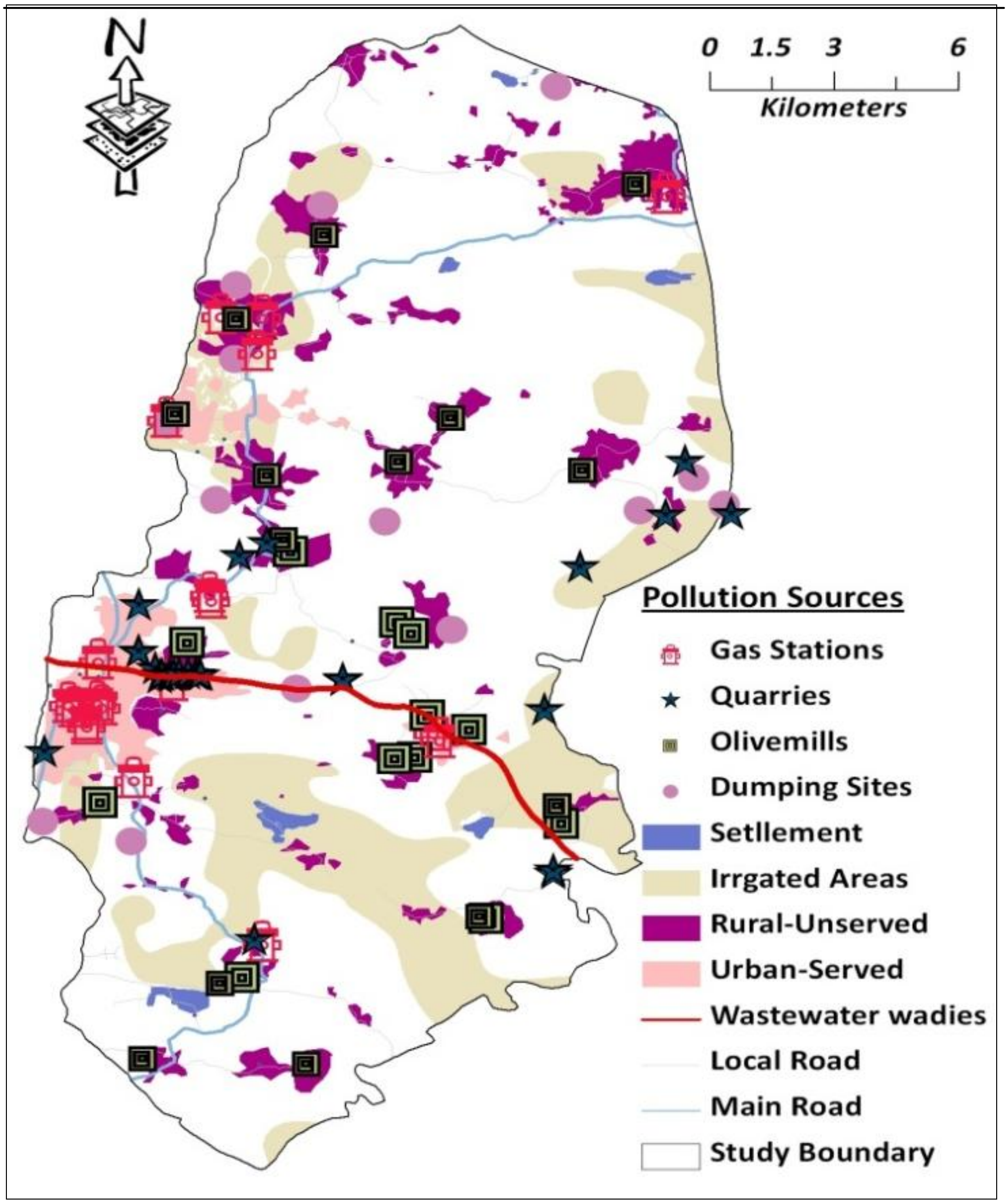


Figure (7.1): The distribution of pollution sources in the study area

7.2 Wellhead Protection Zone

Wellhead protection zone is the area around the well where the land use activities have potential impact on the water quality. It is good way to protect groundwater from pollution and improve its quality (Bates and

Evans, 1996). This is achieved by the delineation of the protection area for groundwater wells and developing preventive guidelines and actions to ensure better management for wells from contamination.

A management plan is a priority plan that is given for groundwater wells taking into account a variety of factors such as the travel time of the contaminant, the number of persons affected, the load of contamination within zones and the contaminant concentration at the wells relative to the maximum contaminant level.

The wellhead protection areas are defined as the areas surrounding the well through which contaminants are reasonable likely to move toward the well **(DWGB, 2007)**. Three zones were delineated that make up a wellhead protection area are based on how long it would take a contaminant to travel through the aquifer and reach the well.

7.2 Delineation of Protection Zones for Selected Groundwater Wells in the Study Area

The wellhead protection zone was delineated for selected groundwater wells in the study area using the outcomes from MODPATH backward tracking analysis. The data was processed and analyzed by GIS tools for better visualization.

The figures below (Figure 7.2 and 7.3) depict the delineation of protection zones for Anabta Municipality and Attil Cooperative Society wells.

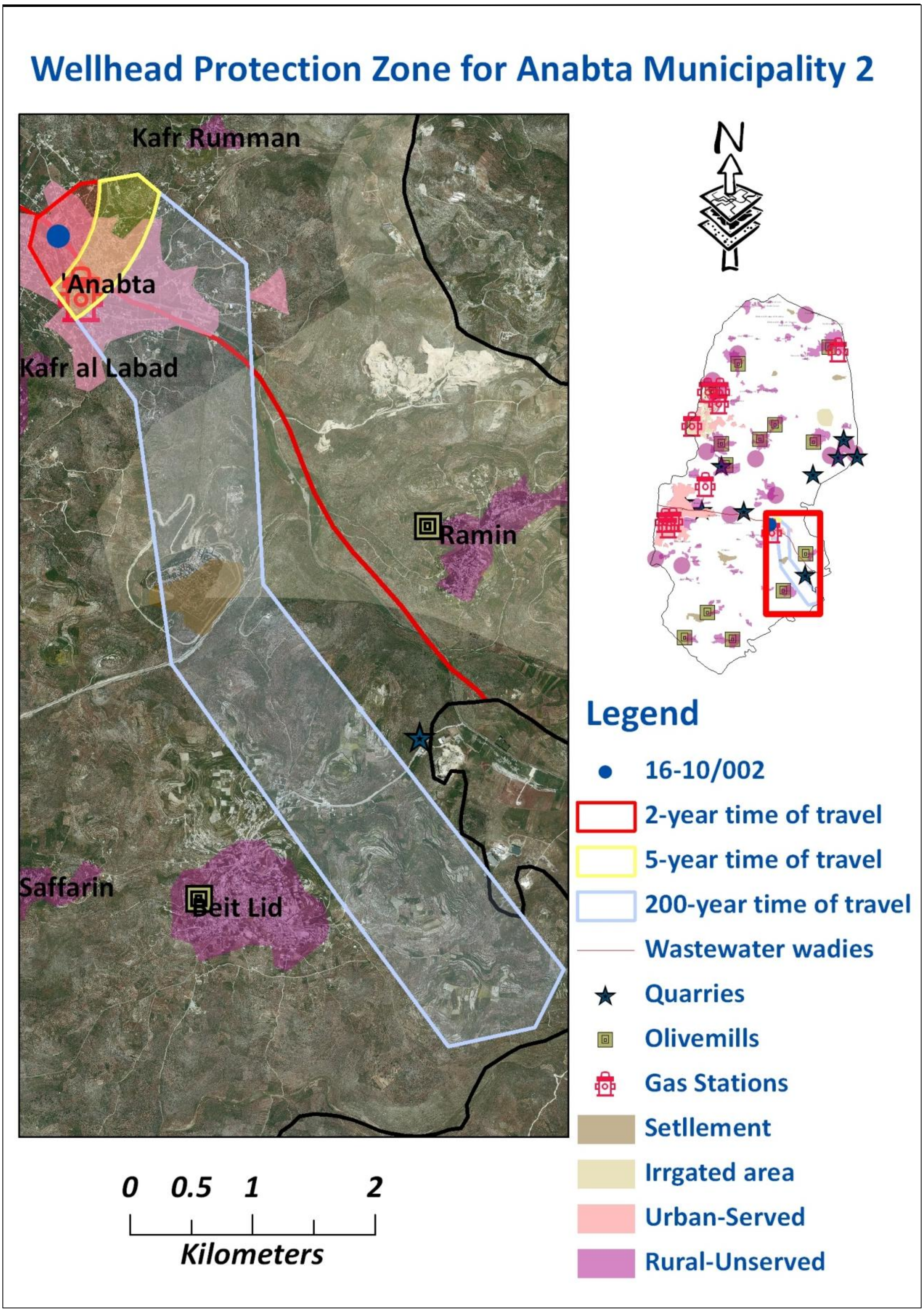


Figure (7.2): The wellhead protection zones for Anabta Municipality well

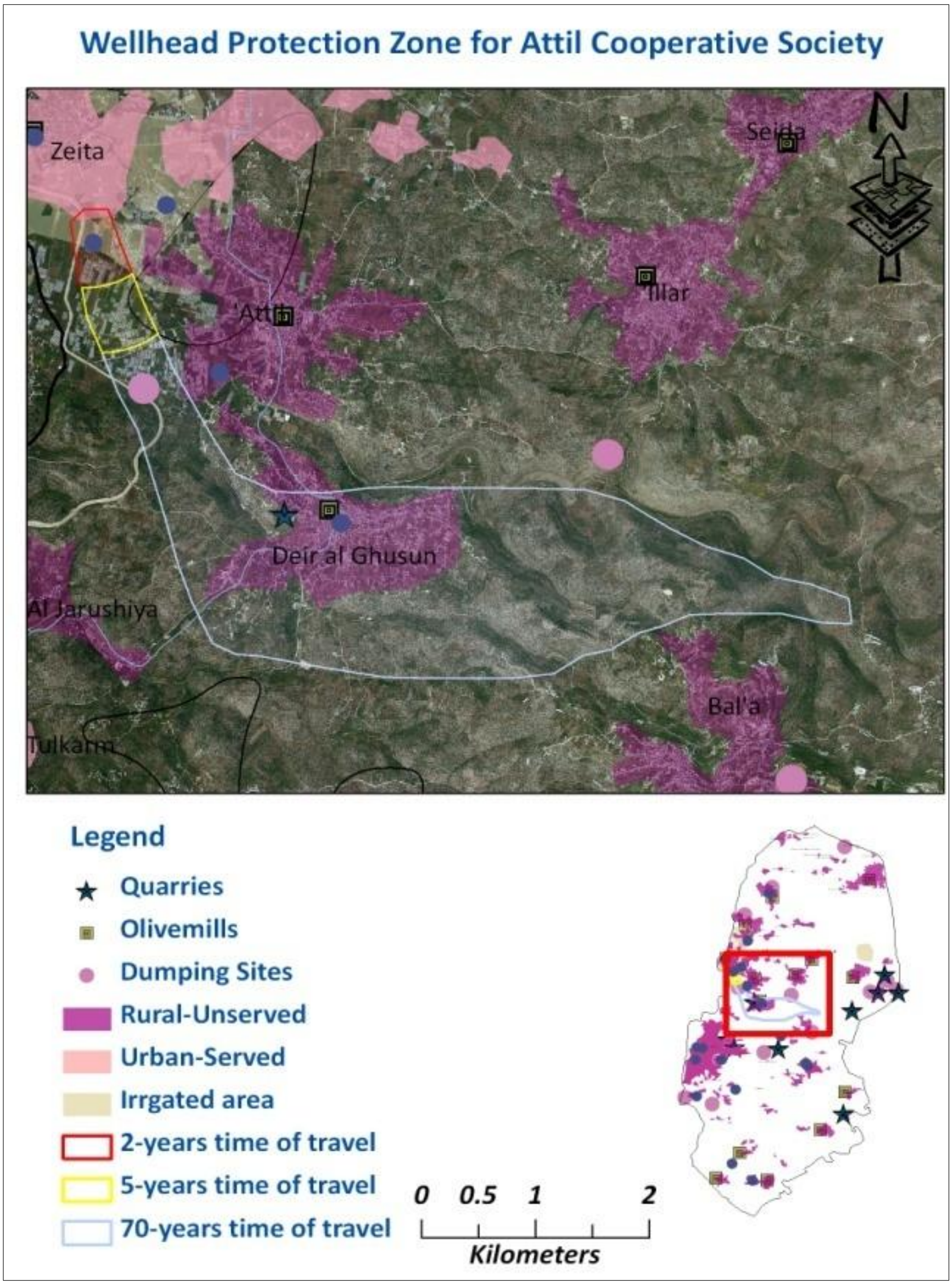


Figure (7.3): The wellhead protection zones for Attil Cooperative Society well

7.3 Groundwater Protection Strategies for Selected Groundwater Wells in the Study Area

Wellhead protection involves integrated water resource planning and preventative actions intended to solve an on-going problem or to avoid the occurrence of a potential problem from contaminants (Tarazi, 2009).

Efforts should be implemented to achieve and maintain compliance with regulatory requirements and to implement best management practices designed to protect groundwater. In order to apply the management options specific actions should be carried out within each zone (Tarazi, 2009).

The first protection zone must be totally a fence and the land use activities should be prevented. In the second and third zones all development activities such as agricultural, industrial and social activities were implemented under the condition that they comply with the laws, which applied in environmentally sound practices.

There are many actions within each zone that should be considered to protect groundwater wells in the study area as summarized in the following strategic points:

1. The majority of groundwater wells in the study area are located in or near un-served communities, so the construction of a wastewater sewage network and treatment plant is imperative.

2. The authorities do not own or control all the land within the wellhead protection areas for many groundwater wells. Groundwater monitoring activities can be carried out in these areas

3. Public education and workshops in coordination with all stakeholders to become more willing to change their behavior when they realize their activities could adversely affect the sources of drinking water.

4. Fertilizer and pesticide applications must be controlled in irrigated areas and restricted or limited in the critical zones around wells. In addition, public education and workshops on safe pesticide and fertilizer use must be implemented by the Ministry of Agriculture.

5. Reducing the risk resulting from the wastewater generated from the industrial sector such as quarries and olive mills. This can be achieved by forcing the industrial sector to treat their wastewater before disposing it.

6. Minimizing the number of pollution sources generated from the random solid waste disposal by establishing main isolated dumping site and outside the wellhead protection area.

7.4 Discussion

The results from this chapter call on all public authorities such as Palestinian Water Authority, Palestinian Ministry of Health and Palestinian Ministry of Agriculture and Municipalities to meet their responsibility and take immediate actions to prevent and control groundwater contamination. This is achieved through a good management plan and developing land use regulation and monitoring program.

The public participation is extremely an important part in developing management plans of wellhead protection. This is achieved through public information via advertisements and brochures and through public consultations which encourage the stakeholders to be more active and powerful as members of the decision making.

Field visits were carried out to the village councils and municipalities in Tulkarem District and the locations of the groundwater wells. The objectives for these visits were to identify the status of groundwater wells, and to verify the pollution sources of groundwater wells and its impact on society, health, and environment. Through the visit, the Municipality of Anabta and Attil assured that the Anabta Municipality 1 (16-19/001) and Muhammad Nemer Barakat (15-19/041) wells were closed because the contaminant concentration for these wells is above the MCL. So without a management plan the quality of water in the aquifer will eventually become degraded.

Wastewater disposing from the un-served communities and industrial sectors had highly risky areas because the majority of the protection zones for groundwater wells in the study intersect with these contamination sources, so to reduce this pollution sewage networks and treatment plant to treat the generated wastewater before disposing into the wadis must be established.

It can be concluded that the contamination sources should be controlled in each zone of groundwater protection and give priority of land use planning and regulations for critical zone around groundwater wells.

To further enhance comprehensive groundwater protection and management, selection of new location for domestic wells should be preceded by delineation of well head protection zone, identification and consultation of development plans to identify the impact of future land use and any need for land use controls within zones to protect well from contamination.

Chapter Eight
Conclusions and Recommendations

8.1 Conclusions

The following are the main conclusions:

1. The highest nitrate concentrations are mainly encountered in the wells and springs that are located in Jenin, Tubas, Tulkarm and Nablus districts. The biological indicators (T. Coliform and F. Coliform) are present in wells and springs in the West Bank aquifers in areas with cesspits such as the communities of Nablus, Tulkarem, Ramallah, and Jenin which are un-served with sewage networks. The highest chloride concentrations are encountered in Jericho wells.

2. In light of the analysis carried out in this thesis, the contributing areas for the majority of contaminated groundwater wells in Tulkarem District intersect with contamination source (cesspits). This confirms that the cesspits considered as one of the main sources of pollution for most groundwater wells in the study area.

3. Delineation of protection zones for groundwater wells in the study area is an effective management plan to minimize the risk of groundwater contamination. The best integrated management plan approach for wellhead protection zones can be implemented through

discussions between regulators and stakeholders taking into account public participation and awareness.

4. The results and observations from this thesis call on all the decision makers and individuals to take immediate actions to prevent contamination of groundwater resources.

8.2 Recommendations

The recommendations listed herein support the future studies and address the following issues regarding the management of groundwater from contamination:

1. Construction of sewerage networks and wastewater treatment plants that cover all communities that use cesspits as well as rehabilitation and sustainable maintenance of the existing wastewater distribution networks.
2. Identification of areas with heavy contamination loading in the West Bank and the implementation of protection plans to minimize the risk of groundwater contamination under the current and future challenges.
3. There is a strong need to establish a regular groundwater quality monitoring system for all domestic sources.

4. Set up management policies and regulations of land use activities for wellhead protection zones especially the critical zones around the groundwater sources. Developing preventive guidelines and operational controls necessary to ensure better management for groundwater resources which can be part of the Palestinian Water Authorities regulations.
5. It is important to carry out an economic analysis to assess the potential impacts of the proposed management plan options on the local economy.

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APPENDICES

Appendix A: The wellhead protection zones for groundwater wells in the study area.

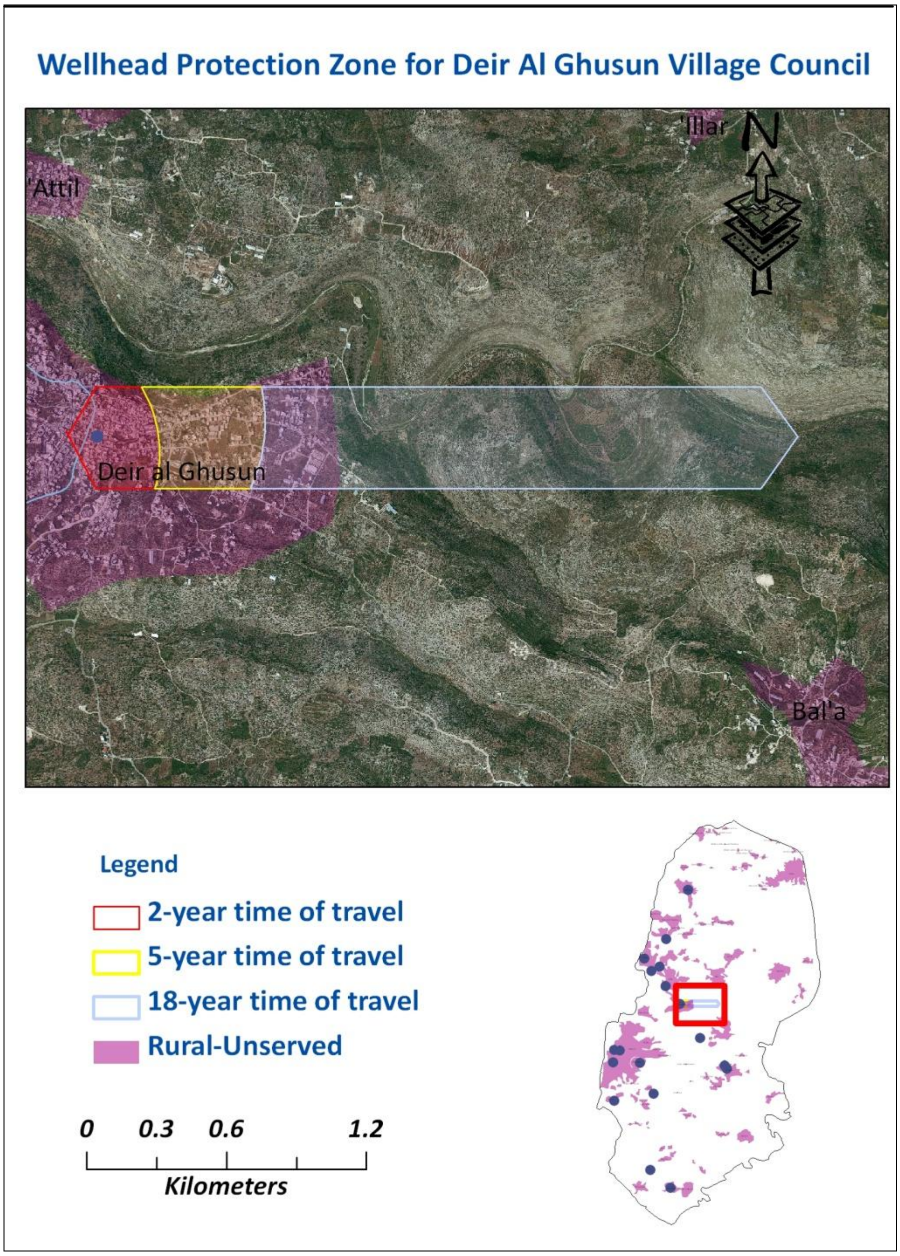


Figure A.1: The wellhead protection zone for Deir al Ghusun Village Council well

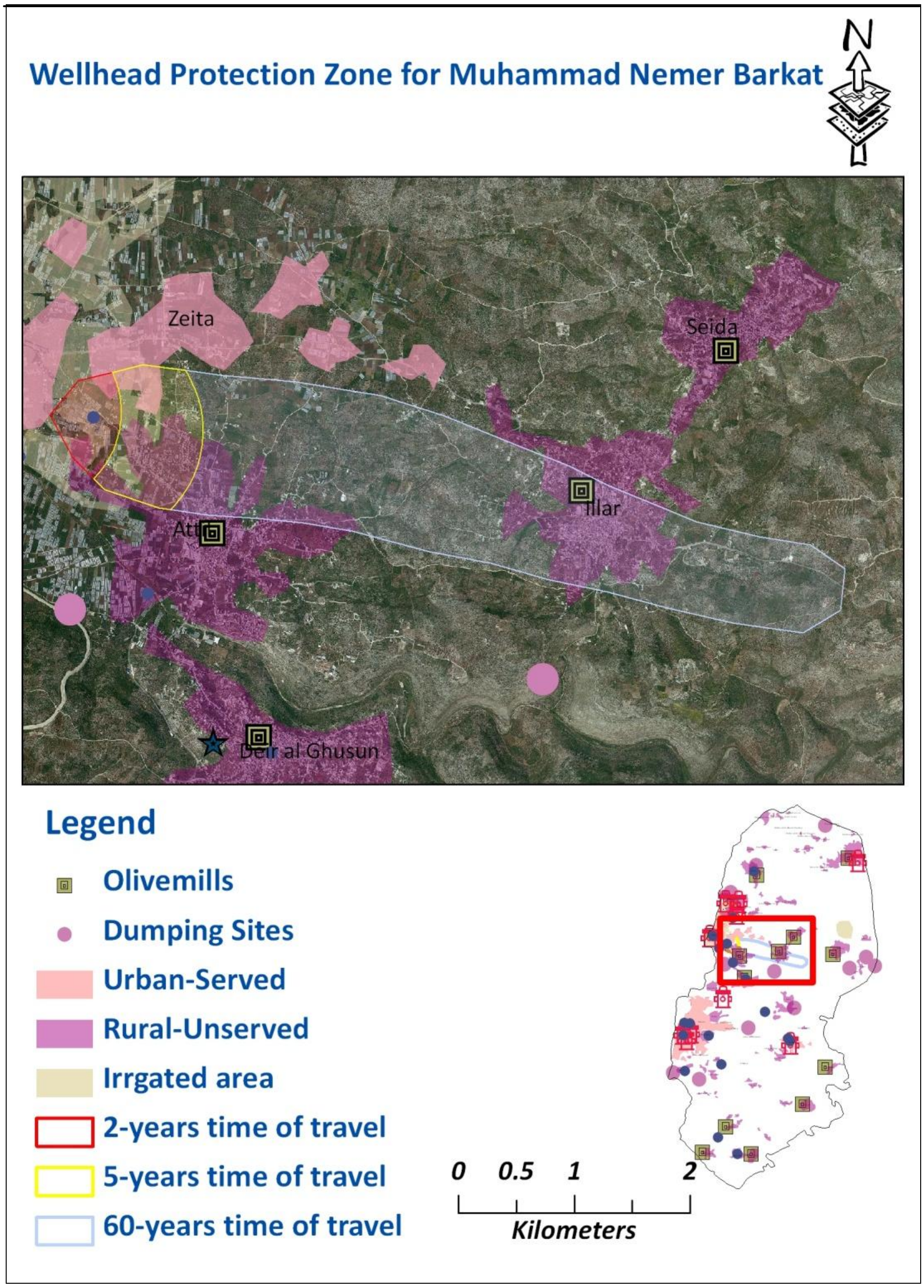


Figure A.2: The wellhead protection zone for Muhammad Nemer Barkat well

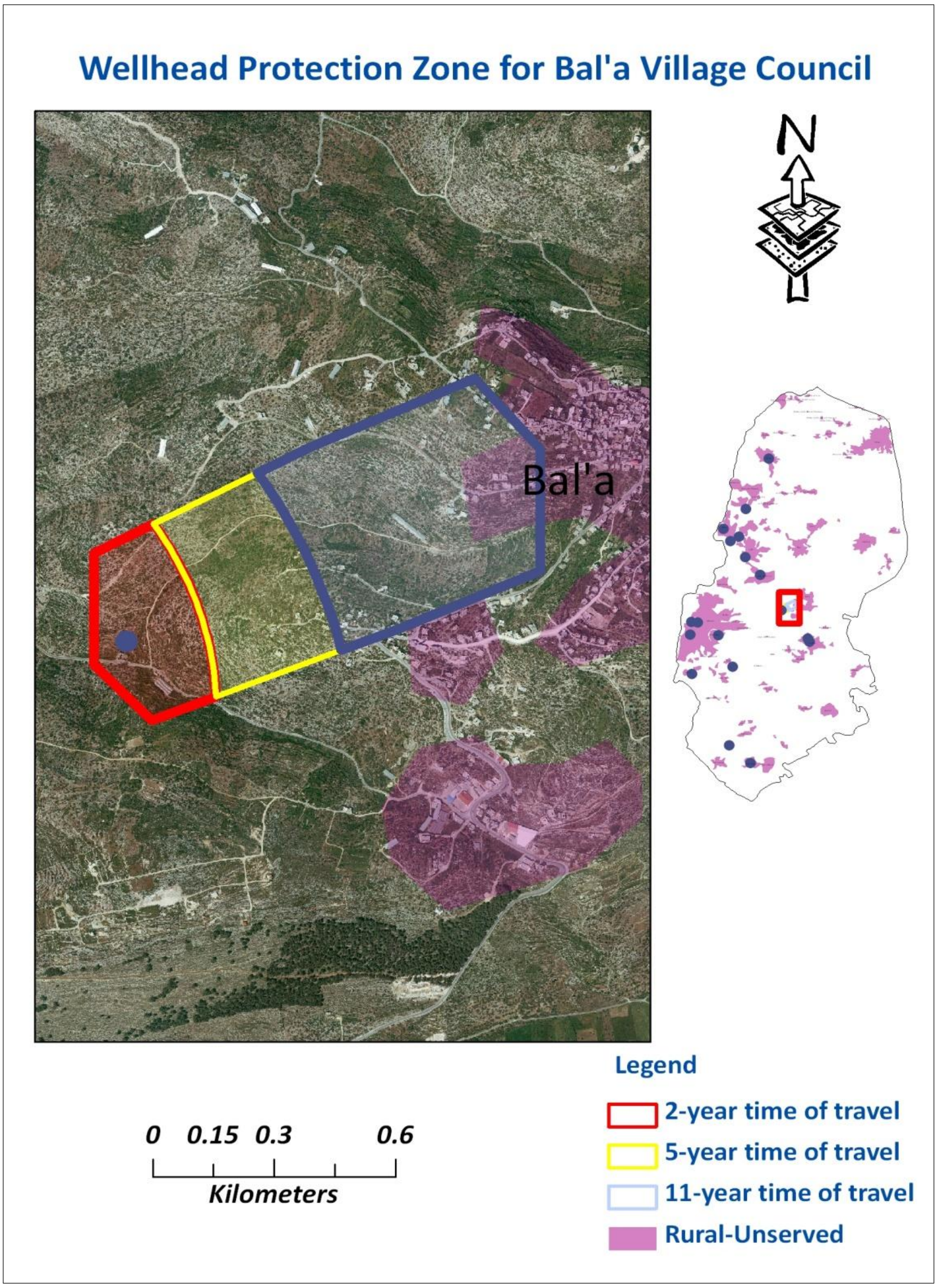
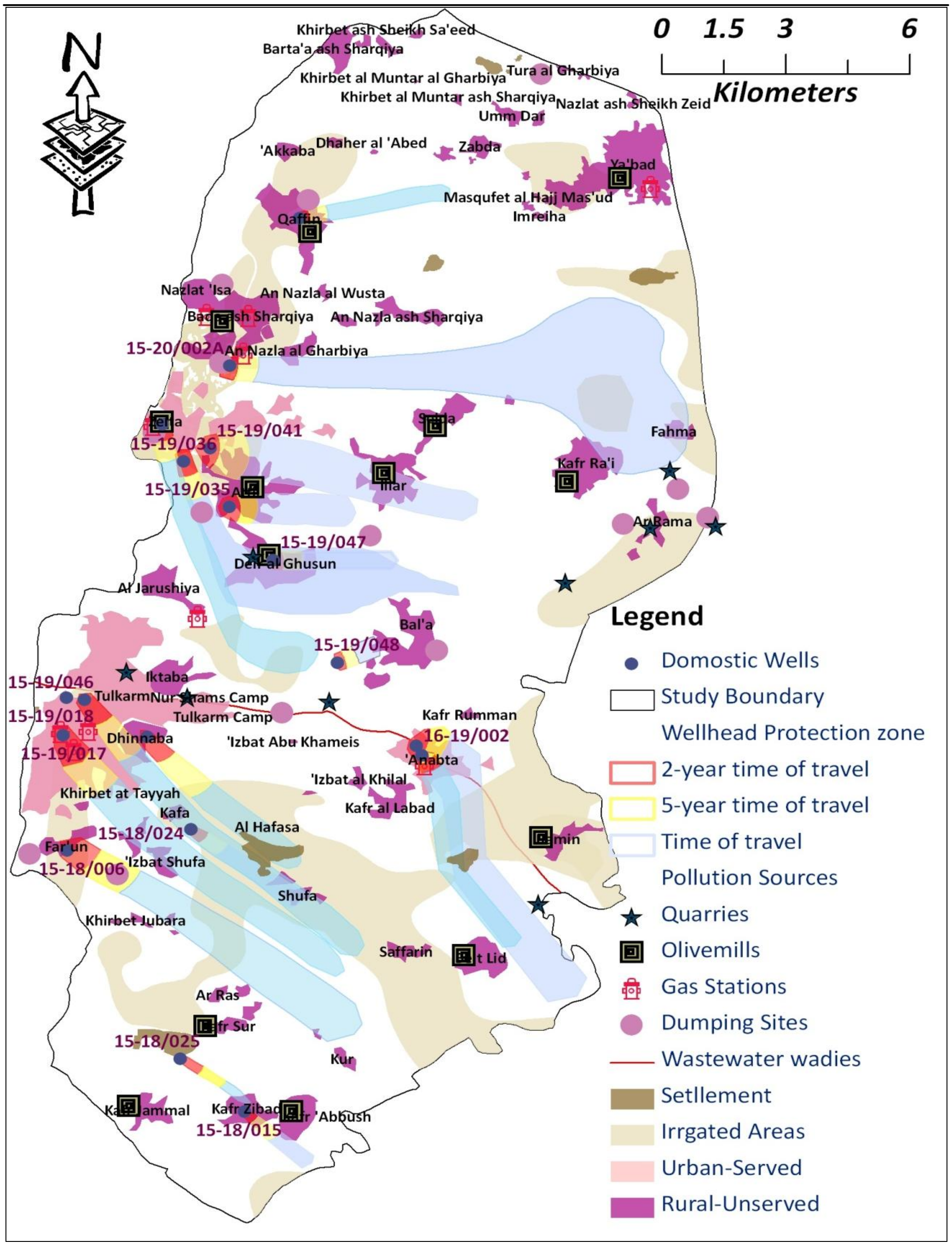


Figure A.3: The wellhead protection zone for Bala Village Council well

Appendix B: The GIS map of wellhead protection zones for 17 groundwater wells in the study area.



جامعة النجاح الوطنية

كلية الدراسات العليا

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الملخص

تعتبر المياه الجوفيه المصدر الرئيسة للمياه بالنسبة للفلسطينين. نوعية هذه المياه قد تستنزف مع مرور الوقت بسبب الأثار المتراكمه لعدة سنوات من الممارسات. أحد المصادر الرئيسية لتلوث المياه الجوفية هي الحفر الامتصاصية المستخدمة على نطاق واسع في الضفة الغربية.

ركز البحث على تحديد وتقييم الاثار البيئية المحتملة من الحفر الامتصاصية على أبار المياه الجوفيه في محافظة طولكرم وذلك بتطوير نموذج رياضي بواسطة MODPATH لتمثيل ودراسة طرق انتقال الملوثات من هذه الحفر الامتصاصية واحتمالية تقاطعها مع المناطق المغذية لآبار المياه الجوفية.

أكدت نتائج هذا البحث ان الحفر الامتصاصية هي من المصادر المحتملة للتلوث آبار المياه الجوفية في منطقة الدراسة. وقد تم تحديد مناطق الحماية للابارالجوفية في منطقة الدراسة عن طريق تصميم ورسم خرائط لثلاث مناطق لكل من الأبار المختاره في منطقة الدراسة واللتي تعتبر ركيزه لخطة وإداره فعالة للحد من مخاطر تلوث المياه الجوفية. وبشكل عام فقد جاءت توصيات هذا البحث لتدعو جميع السلطات ذات العلاقة باتخاذ اجراءات فورية لمنع تلوث المياه الجوفية ومراقبة نوعيتها من خلال التحكم بمصادر التلوث.