An-Najah National University

Faculty of Graduate Studies

Pollutants Tracking from Surface to Groundwater, the Case of Upper Faria Catchment

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Dedication

I dedicate my thesis to my parents, my brothers, and my sisters

with all respect

Malak

Acknowledgements

Foremost, I thank Allah for the strength and guidance given to me and for the wisdom and the physical ability that enabled me to write this thesis.

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Further thanks to my friends and those who have assisted me with my research, especially my friend Noor.

الإقرار

أنا الموقع أدناه مقدم الرساله التي تحمل عنوان

Pollutants Tracking from Surface to Groundwater, the Case of Upper Faria Catchment

أقر أن ما اشتملت عليه هذه الرساله إنما هو نتاج جهدي الخاص باستثناء ما تمت الإشاره إليه حيثما ورد وإن هذه الرساله ككل أو أي جزء منها لم يقدم من قبل لنيل أية درجة أو لقب علمي أو بحثي لدى أي مؤسسة تعليمية أو بحثية أخرى.

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Student's name: **اسم الطالبة: ملك عبد الهادي عيسى**

Signature: **التوقيع:**

Date: **التاريخ: 2016/6/29**

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Abstract

Groundwater is considered the main source of water in Palestine. It has a major influence in both environmental and socio-economic conditions of the Palestinians. The risk of groundwater contamination as a result of human induced pollutants, including wastewater, dumping sites and agricultural practices needs be assessed all the time. Pumping from agricultural and domestic wells are means of transport of pollutants into groundwater; mainly wastewater and agricultural wastes such as pesticides and fertilizers.

The upper part of the unconfined aquifer of Al-Faria catchment, located in the northeastern area of the West Bank, is selected in this thesis to study the fate and transport of pollutants from the surface to groundwater. The aquifer of Al-Faria is part of the Eastern Mountain Aquifer of the West Bank and plays a major source for supplying water, through groundwater wells and springs, to both domestic and agricultural demands within the area.

The research studied the transport of pollutants from surface through the unsaturated zones to the groundwater which may cause contamination. A conceptual model was developed and formulated into a numerical steady state flow model (MODFLOW) which simulates the flow dynamics. The software platform, called GMS, was used to connect the numerical flow simulation (MODFLOW) with MODPATH to track pollutants for Al-Faria aquifer.

The sources of groundwater contamination and the path-lines of transport of these pollutants were established; the potential contaminated wells and springs were also made apparent. The travel time needed to transport these pollutants into the wells and springs were calculated (forward tracking). The main pollutants as well as the risk of contamination were identified. Consequently, protection zones for selected wells were delineated (Backward tracking).

The results confirm that the wastewater and agricultural wastes are the main sources of pollution for several groundwater wells and springs in the study area. Delineation of protection zones for each water resource is a powerful tool and would be the first step of effective management plan to minimize the risk of groundwater contamination. Palestinian Water Authority (PWA) shall consider the severity of the problem and take crucial decisions and plan to control and prevent the pollution of the groundwater resources. It is recommended to apply and model the fate and transport of the pollutants into the groundwater as a control tool for monitoring and analyzing the current and future situations for different scenarios of groundwater reservation and pollution control in Palestine.

Chapter One

Introduction

1.1 General Background

Groundwater is a vital resource to many communities because sometimes it is the only safe source for drinking water (EMSC, 2000). It is an essential resource all over the world. Therefore, groundwater contamination is sensitive issue of this a major source of potable water (Chin, 2013).

When groundwater compared to surface water, groundwater has many advantages: it is of higher quality, better protected from chemical and microbial pollutants, less exposure to seasonal and perennial fluctuations, and more uniformly distributed over large areas than surface water (Taylor, 2011). Groundwater plays primary role in many areas particularly for limited precipitation regions (Wheater, Mathias, & Li, 2010). Some effective protection policies should be taken to prevent the groundwater deteriorations.

Cesspits, leaking underground storage tanks, land application of wastewater, irrigation and irrigation return flow, solid waste disposal sites, waste disposal injection wells, and hazardous chemicals in agriculture are considered as the most common sources of groundwater contamination (Chin, 2013).

The hydrologic cycle has no beginning or end as the water in nature is continuously kept in cyclic motion. precipitation may take place in liquid form as rain and also in solid form as hail, snow, dew, frost etc. While precipitation is taking place, a part of it may evaporate and reach back the atmosphere. Some more precipitation is intercepted by the trees and vegetation and the rest of it only would reach the ground. The intercepted precipitation eventually evaporates into the atmosphere. The precipitation reaching the ground surface is called throughfall. Considerable portion of the thoroughfall gets infiltrated into the ground and that in excess of infiltration would be detained temporarily into the ground before it becomes overland flow and subsequently surface runoff. The precipitation falling directly over the streams is called the channel precipitation and it readily becomes runoff without any delay. The precipitation falling on water bodies like ponds and lakes may be disposed of either as surface runoff to streams if the water bodies overflow or as evaporation or as infiltration. The evaporation would be taking place from stream surfaces. The infiltrated water may be distributed in different ways. First, it supplies moisture to vegetation and after utilizing it for the sustenance of their life, the vegetation sends this moisture back into the atmosphere through the leaves by process known as transpiration. Secondly, the infiltrated water may percolate deep and become groundwater supply to surface streams known as groundwater runoff, or it may become groundwater supply to oceans. The groundwater runoff is sometimes referred to as the baseflow or interflow. The total streamflow which sum of the surface runoff and the groundwater runoff ultimately joins the oceans wherefrom it again evaporates into the atmosphere thus completing the hydrologic cycle. The entire cycle repeats when the atmospheric moisture precipitates on the ground after cloud formation. Thus the hydrologic cycle consists of various complicated processes such as precipitation, interception, evaporation and transpiration, infiltration, percolation, storage and runoff (Reddy, 2005).

Vadose zone is the unsaturated region between the ground surface and the water table and contains the soils that overly the groundwater (Chin, 2013). It acts as filter to preserve groundwater quality. When the water table is close to ground surface, capillary rise process will occur then the water from groundwater table will be driven toward the root zone and soil surface through the capillary fringe (Genuchten & Šimunek, 2006). Figure 1.1 clarifies the water fluxes and shows various hydrologic components in the vadose zone.

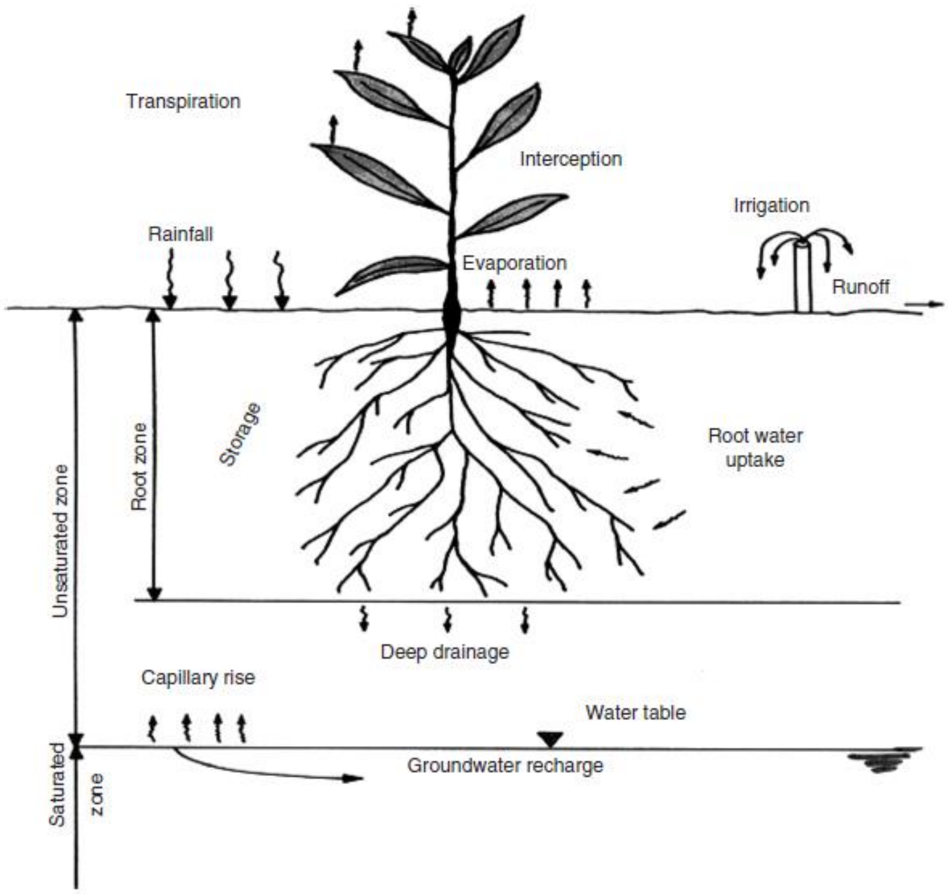

Figure 1.1: Water fluxes and various hydrologic components in the vadose zone (Genuchten & Šimunek, 2006).

Vadose zone, zone of aeration and partially saturated zone are other names for the unsaturated zone (Nimmo, 2005); (Nielsen, 1986) which has several critical hydrologic functions such as storage medium and buffer zone (Nimmo, 2005). Since it absorbs water infiltrating from rainfall and it begins to store as groundwater when it reaches the water table at a rate equal to difference between infiltration and evapotranspiration. Unsaturated zone plays crucial role in transmission process (Nielsen, 1986).

In this study it is to simulate the movements of pollutants from the surface water into the groundwater. The conceptual and numerical steady state flow model was developed to simulate the flow dynamics using MODFLOW.

MODPATH also was used to track pollutants. The sources of groundwater contamination and the path-lines of transport of these pollutants were established; the potential contaminated wells and springs were also made apparent. The travel time needed to transport these pollutants into the wells and springs were calculated (forward tracking). The main pollutants as well as the risk of contamination were identified. Consequently, protection zones for selected wells were delineated (Backward tracking). Upper Part of Al-Faria catchment is selected as a case study.

Groundwater contamination may be point or non-point source. An example of point source pollution is one specific underground storage tank leaking. Failure of subsurface sewage disposal systems in a rural subdivision is an example of non-point pollution (EMSC, 2000).

Generally, in addition to failing or improperly sited septic tanks and percolating pits, a variety of human activities impact water quality. Pollution sources can range from industry, landfills, pesticides, fertilizers, livestock wastes, storm water runoff from agricultural and urban sources, and household wastes (NESC, 2002).

Septic system effluent containing nitrates can pose a health hazard to infants, in particular. Nitrates have been shown to cause methemoglobinemia, known as “Blue Baby Syndrome.” Many health officials recommend testing well water in the vicinity of septic systems more frequently when children or pregnant women are present (NESC, 2002).

Septic tanks and drain fields are used for the treatment and disposal of domestic wastewater. Before wastewater is filtered by the soil it may contain bacteria, viruses, nitrogen and phosphorus. When septic systems fail, are poorly designed, or are concentrated in a small area there is a potential for groundwater contamination. Septic tanks are most likely to contaminate groundwater when there is a high density of homes, a thin layer of soil over permeable bedrock, an extremely permeable soil, such as gravel or when there is a high water table. A combination of any of these may lead to earlier or more severe contamination (EMSC, 2000).

Pesticide use and management by manufacturers, distributors, farmers, and the general public provide multiple sources and opportunities for contamination by pesticides of groundwater resources. The desired result of pesticides is successful application, followed by rapid breakdown into components such as carbon dioxide and water. This occurs in most cases, but the decomposition process and time varies with the types of pesticides used. The fate of a pesticide can be affected by several factors, some of which are a result of the pesticide itself while others vary with the application process. Soil and plant characteristics along with climatic conditions can affect pesticides following application. The pesticides volatility, solubility, half –life and chemical composition are factors that influence pesticide decomposition. Leaching of pesticides is common when pesticides move into and through the soil as opposed to movement over the surface through runoff. Pesticides can leach through the soil and into groundwater from storage, mixing, equipment cleaning, and disposal areas. Under certain conditions, some pesticides can leach into groundwater from normal pesticide application. Soil permeability is an important factor that influences pesticide leaching. The more permeable the soil, the greater potential there is for pesticide leaching to occur (EMSC, 2000).

Al-Faria catchment is significant catchment in the West Bank, many communities in it depends on it as major source of agricultural products, and therefore it is important to study the transport of contaminants from surface through the unsaturated zones to the groundwater system. Most of communities in Al-Faria catchment do not have sewage systems which mean there are a lot of cesspits (PCBS, 2013) which is the source of groundwater pollution.

Groundwater modeling in Al-Faria catchment was done by several studies, among which is Gahanem, 1999. These studies need to be updated as many developments occurred in the catchment since then. A new assumption for boundary conditions is developed to simulate groundwater flow model that simulates the flow dynamics and pollutants transport of Al Faria aquifer and generating numerical flow and transport models (MODFLOW and MODPATH).

Identify of contaminants sources for wells and springs, tracking pollutants, and defining a protection zone for each water source are the major expected outcomes in addition to the flow direction and pollutants behavior for the upper part of the Quaternary of Al-Faria catchment which was selected based on geological map.

1.2 Research Objective

Groundwater is very essential source of water in Al-Faria and it plays important roles in supplying water for West Bank. It is used for domestic uses and irrigation (EQA, 2004). Groundwater quality in the catchment are deteriorating due to the effluent of untreated wastewater from urban areas and the seepage from rural cesspits in addition to uncontrolled agricultural practices (Shadeed, Haddad, & Sawalha, 2015). The situation needs an assessment and significant protection and it is important to improve understanding of the groundwater flow and tracking pollutants from surface to groundwater and to detect any potential deterioration of groundwater quality. This research is to know if the groundwater resources are contaminated and to model the path lines of pollutants. Curial decisions are considered for re-management and some policies should be forced to prevent worse situation.

Improve understanding of water flow and transport pollutants will help other researchers for developing integrated work of conceptual modeling, groundwater modeling using MODFLOW and tracking pollutants using MODPOATH as to assess and find the potential contaminated resources.

The major objectives are to model the transport of contaminants from surface water through the unsaturated zones to the groundwater system in upper part of Al-Faria catchment; these are summarized as:

- To simulate the flow dynamics and pollutants tracking of the aquifer.
- Defining the sources of contamination for polluted wells and springs.
- Identifying the main pollutants as well as the risk of contamination to all other water sources.
- Defining a protection zone for water sources

1.3 Research Needs and Motivations

Groundwater is the main source of domestic and agricultural uses in the upper part of Al-Faria catchment and it is important to study any possible contamination and to define protection zones to rescue the groundwater from deterioration.

Many researches involved modeling for surface water for Al-Faria catchment but did not study the transport of contaminants from surfacewater through the unsaturated zones to the groundwater. From this point stems the study importance. Strong decision based on scientific evidence will help decision makes to develop and adopt the proper management strategies to protect groundwater in the catchment.

The study presents start point in this field to be developed later on to scale it in other regions.

1.4 Research Challenges

The main research challenges are:

- Insufficient geological data.
- The variation, even horizontally or vertically, in the hydraulic conductivity so the assumptions are formulated.
- Conceptual modeling process needs a lot of data from many sources and it also needs analyzing these data to be ready as inputs of numerical model.
- Calibration process needs intensive measured data which is well spatially distributed.

1.5 Methodology

The conceptual model was developed and it was converted into numerical steady state flow model (MODFLOW) which simulates the flow dynamics. The software platform, called GMS, was used to connect the numerical flow simulation (MODFLOW) with MODPATH to track pollutants for Al Faria aquifer (Figure 1.2).

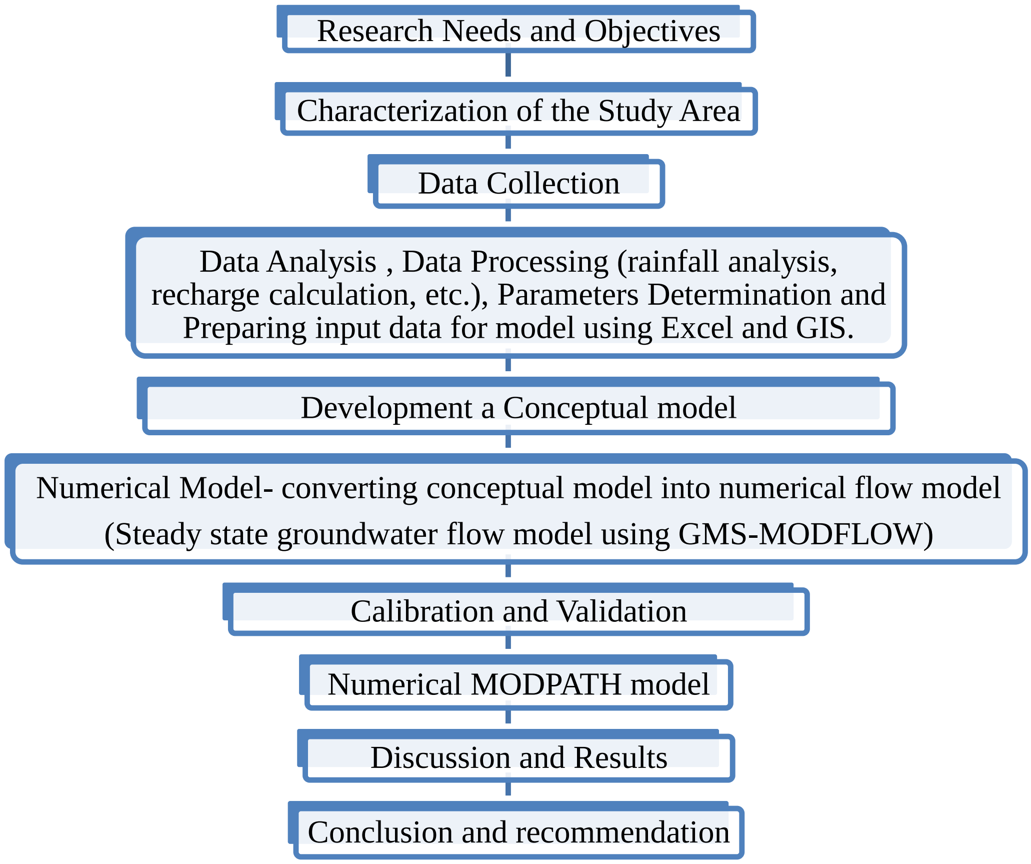

Figure 1.2: Methodology Flow chart for the study

1.6 Thesis Outline

This thesis consists of six chapters. Chapter 1 includes general introduction and Chapter 2 contains a brief description of the study area while Chapter 3 covers the literature review. Conceptual model of Quaternary is described in chapter 4. Development of the MODFLOW and MODPATH for the study area are described in chapters 5 and 6 respectively. Conclusions and recommendations are provided in Chapter 7.

Chapter Two

Description of the Study Area

2.1 Location and Topography

Al Faria catchment, overlying three districts which are Nablus, Tubas and Jericho, is located in the northeastern part of the West Bank. The present Study area is part of Faria catchment; it is located within Nablus and Tubas with an area of about 34.5 km^2 (Figure 2.1).

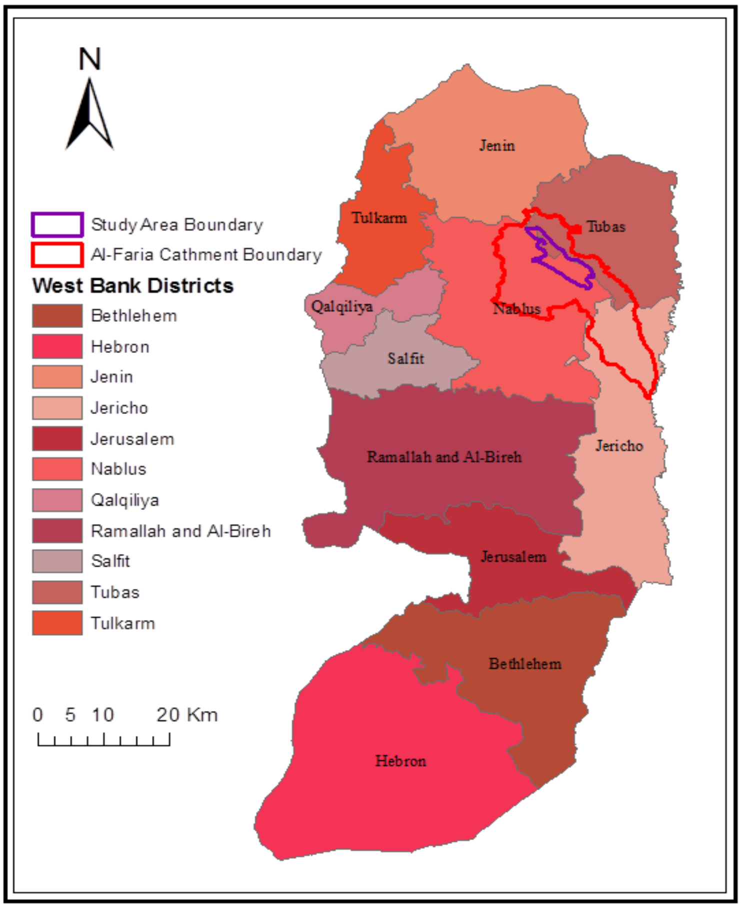

Figure 2.1: Location of study area within the West Bank

In the study area the elevation starts from nearly 375 above mean see level to about 100 below mean see level. These variations in topography of the study area affect the surface water flow direction and the rainfall distribution and accordingly the recharge distribution will be affected. (Figure 2.2). The study area boundary was selected based on geological map (i.e. part of quaternary out covers formation). The upper part of quaternary was selected.

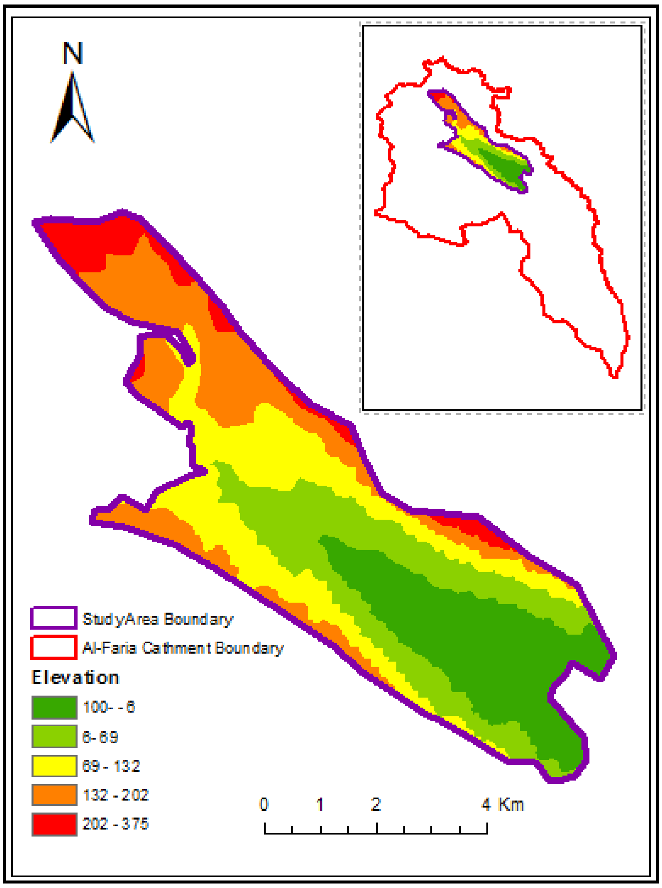

Figure 2.2: Topography throughout the study area

2.2 Land Use

The agriculture is the main economic activity in this area. A new land use map of Al-Faria catchment has been developed using new Aerial photo (HEC, 2015). The produced land use map of the study area is shown in Figure 2.3.

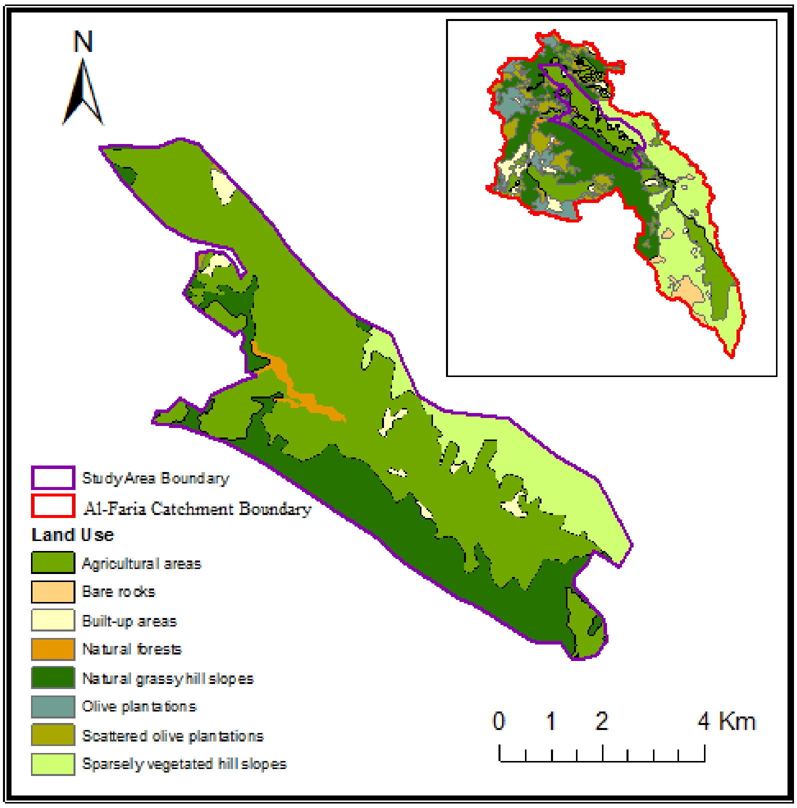

Figure 2.3: Land use map of the study area

Landuse of Al-Faria catchment is classified into eight classes, from which the study area contains six classes: natural grassed hill slopes, sparsely vegetated hill slopes, agricultural areas, scattered olive plantations, built up areas and natural forests. Figure 2.4 explained the percentage of each land use class in the present study area. The agricultural areas form 58.30% of the total study area. This is an indicator of the potential for agricultural pollutants such as pesticides and fertilizer which may transport into groundwater.

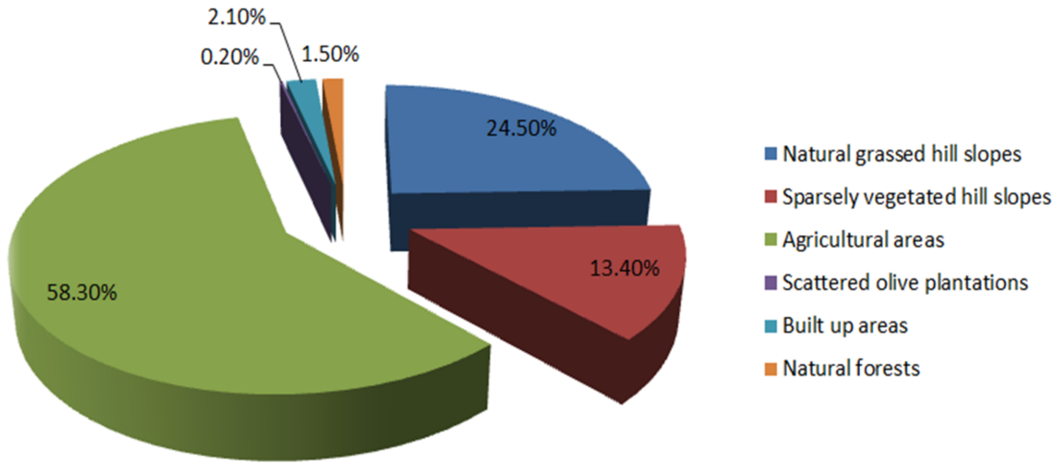

Figure 2.4: Land Use Classification of the study area

2.3 Aquifer System

Groundwater aquifer system of Al-Faria catchment contains many different rock formations ranging from the Triassic to Quaternary consisting of Limestone, Dolomite and marl. Al-Faria catchment overlies the Eastern aquifer (92.7%) as illustrated in figure 2.5 and a small part located in the Northeastern aquifer (7.3%). The present study area is located within the Eastern aquifer (figure 2.5).

The springs drain the shallow unconfined aquifer and the majority of Palestinian wells in Al-Faria catchment pump from only the shallow unconfined aquifer (EQA, 2004).

According to the present model, the model represents steady state unconfined aquifer layer (quaternary) with quaternary average thinness of 80 m.

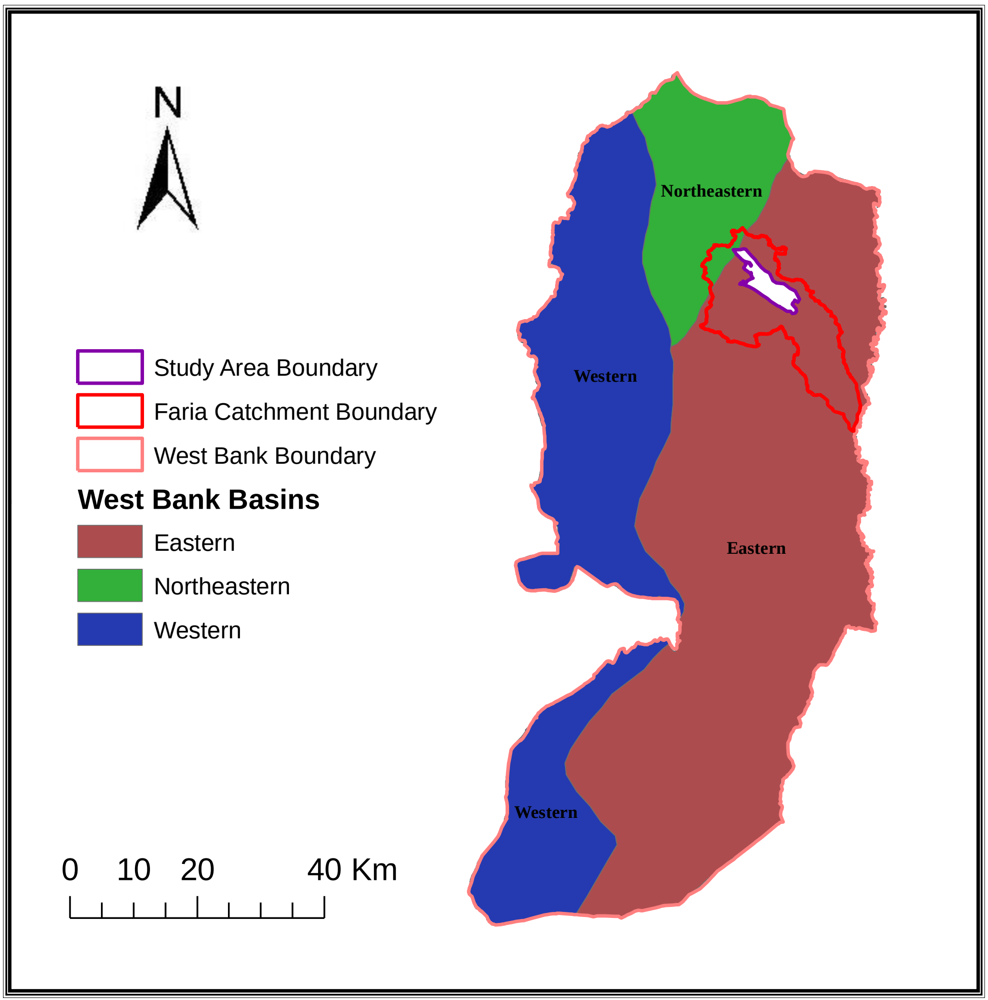

Figure 2.5: Groundwater Aquifer Basins in the West Bank

2.4 Structural Geology

Al-Faria catchment consists of a complicated structural system with anticline drifting from northeast to southwest. Perpendicular to this anticline there are faults and joints which affect the surface water drainage area that trend north-south. Many large faults and joints exist parallel to Jordan Rift Valley because of previous tectonic activity. East-West trends of these faults are common throughout this area (EQA, 2004). Table 2.1 is the geological column in the study area while figure 2.6 shows the major geologic structures in the study area.

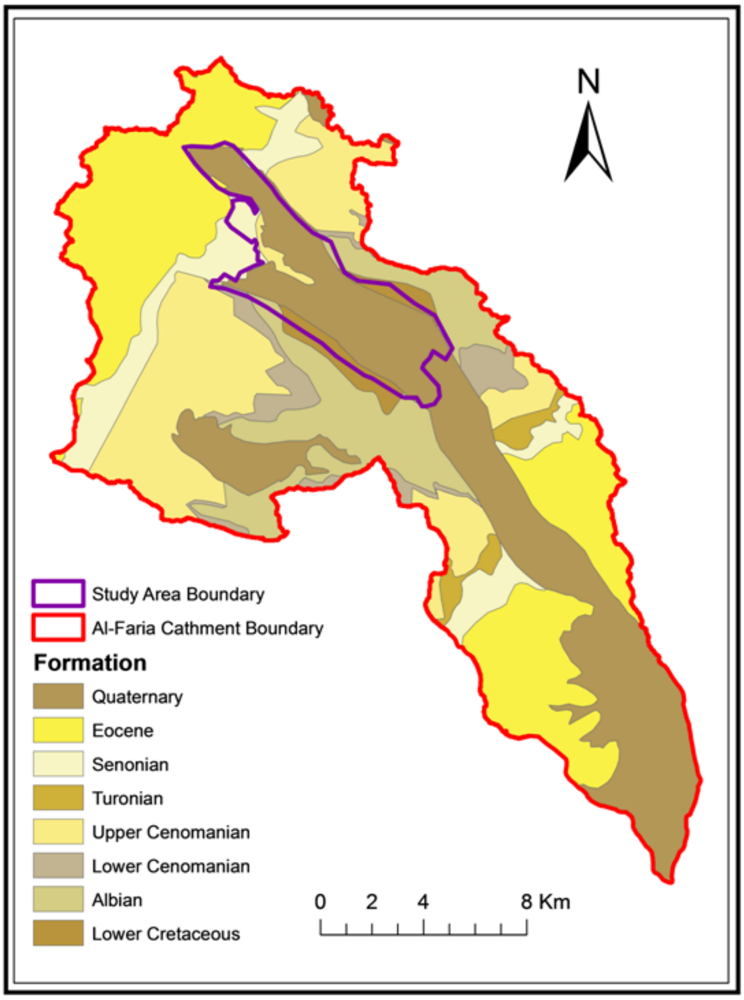

Figure 2.6: Geological formation of the study area

Table 2.1: Geological column in Al-Faria (SUSMAQ, 2004)

Period		Age		Lithology	Palestinian Formation Terminology		Israeli Formation Terminology			Symbol Israeli Map	Hydrostra-tigraphy	Typical Thickness (m)
Quaternary		Pleistocene\Holocene					Costal Basin				Aquifer	0–150
Tertiary	Neogene	Pliocene\Oligocene		Marl, Chalk, Clay and Limestone	Beida	BE	Saqiye Gr.				Aquitard	
Tertiary	Paleogene	Eocene		Marl, clay, chalk, limestone, chert	Jenin subseries	J	Shfela Group	Avedat Group	Zora: Maresha Mbr.		Aquitard	200–250
Tertiary	Paleogene	Eocene		Marl, clay, chalk, limestone, chert	Jenin subseries	J	Shfela Group	Avedat Group	Zora: Adulam Mbr.		Aquitard	200–250
Tertiary	Paleogene	Paleocene		Marl, clay, chalk, limestone, chert	Abu Dis	AD	Shfela Group	Mt.Scopus Group	Taqiya	PA	Aquitard	200–250
Cretaceous	Upper	Senonian		Marl, clay, chalk, limestone, chert	Abu Dis	AD	Shfela Group	Mt.Scopus Group	Ghareb	MA	Aquitard	200–250
Cretaceous	Upper	Senonian		Marl, clay, chalk, limestone, chert	Abu Dis	AD	Shfela Group	Mt.Scopus Group	Mishash	CA	Aquitard	200–250
Cretaceous	Upper	Senonian		Marl, clay, chalk, limestone, chert	Abu Dis	AD	Shfela Group	Mt.Scopus Group	Menuha	SC	Aquitard	200–250
Cretaceous	Upper	Turonian		Limestone, dolostone, marl,chalk chert	Jerusalem	J	Judea Group / Undeferentiated Talme Yafe Group	Daliya Marl	Bi'na	T	Aquifer	200–250
Cretaceous	Upper	Upper	Cenomanian	Limestone, dolostone, marl,chalk chert	Bethlehem Upper	BLU	Judea Group / Undeferentiated Talme Yafe Group	Negba Fm.	Weradim	C3	Aquifer	200–250
Cretaceous	Upper	Upper	Cenomanian	Limestone, dolostone, marl,chalk chert	Bethlehem Lower	BLL	Judea Group / Undeferentiated Talme Yafe Group	Negba Fm.	Kefar Sha'ul	C2	Aquifer	200–250
Cretaceous	Upper	Lower	Cenomanian	Limestone, dolostone, marl,chalk chert	Hebron	HB	Judea Group / Undeferentiated Talme Yafe Group	Negba Fm.	Amminadav	C2	Aquifer	200–250
Cretaceous	Upper	Lower	Cenomanian	Limestone, dolostone, marl,chalk chert	Yatta Upper	YU	Judea Group / Undeferentiated Talme Yafe Group	Negba Fm.	Moza	C2	Aquitard	100–150
Cretaceous	Upper	Lower	Cenomanian	Limestone, dolostone, marl,chalk chert	Yatta Lower	YL	Judea Group / Undeferentiated Talme Yafe Group	Negba Fm.	Beit Meir	C2	Aquitard	100–150
Cretaceous	Lower	Albian		Limestone, dolostone, marl,chalk chert	Upper Beit Kahil	BK4 BK3	Judea Group / Undeferentiated Talme Yafe Group	Yagur Fm.	Kesalon	C1	Aquifer	300–400
Cretaceous	Lower	Albian		Limestone, dolostone, marl,chalk chert	Upper Beit Kahil	BK4 BK3	Judea Group / Undeferentiated Talme Yafe Group	Yagur Fm.	Soreq	C1	Aquifer	300–400
Cretaceous	Lower	Albian		Limestone, dolostone, marl,chalk chert	Lower Beit Kahil	BK2 BK1	Judea Group / Undeferentiated Talme Yafe Group	Yagur Fm.	Giv'at Ye'arim	C1	Aquifer	300–400
Cretaceous	Lower	Albian		Limestone	Lower Beit Kahil	BK2 BK1	Judea Group / Undeferentiated Talme Yafe Group	Yagur Fm.	Kefira	LC	Aquifer	300–400
Cretaceous	Lower	Albian		Marl and shale interbedded with limestone	Kobar: Qatana	Q	Yakhini	Qatana		LC	Aquitard	
Cretaceous	Lower	Albian		Marl and shale interbedded with limestone	Kobar: Ein Qinya	EQ	Yakhini	Ein Qinya		LC	Aquitard	
Cretaceous	Lower	Albian		Marl and shale interbedded with limestone	Kobar: Tammun	T	Yakhini	Tammun		LC	Aquitard	

2.5 Climate and Rainfall

The dominant climate of the study area is the Mediterranean, semi-arid climate, characterized by hot summer with no rain and mild rainy winter starting from October to April or May (EQA, 2004).

The high variability of topographic conditions within the region leads to variability in climate throughout the region.

The annual average rainfall in Al-Faria catchment varies between 150 to 660 mm while the annual rainfall in the study area ranges from 350 to 500 mm. The rainfall map is illustrated in Figure 2.7 and 90% of the total annual rainfall events mainly occur in autumn and winter. Rainfall values within the region change significantly due to the topography. The annual rainfall of Al-Faria Catchment was clarified in Table 2.2.

Table 2.2: Annual Rainfall of Al-Fara Catchment (EQA, 2004).

Station Name	Average Annual Rainfall (mm)	Years of Record
Talluza	630.5	1964-2002
Nablus	642.6	1947-2002
Tubas	415.2	1968-2002
Bait Dajan	379.1	1953-2002
Tammoun	322.3	1967-2002
Al-Faria	198.6	1953-1989

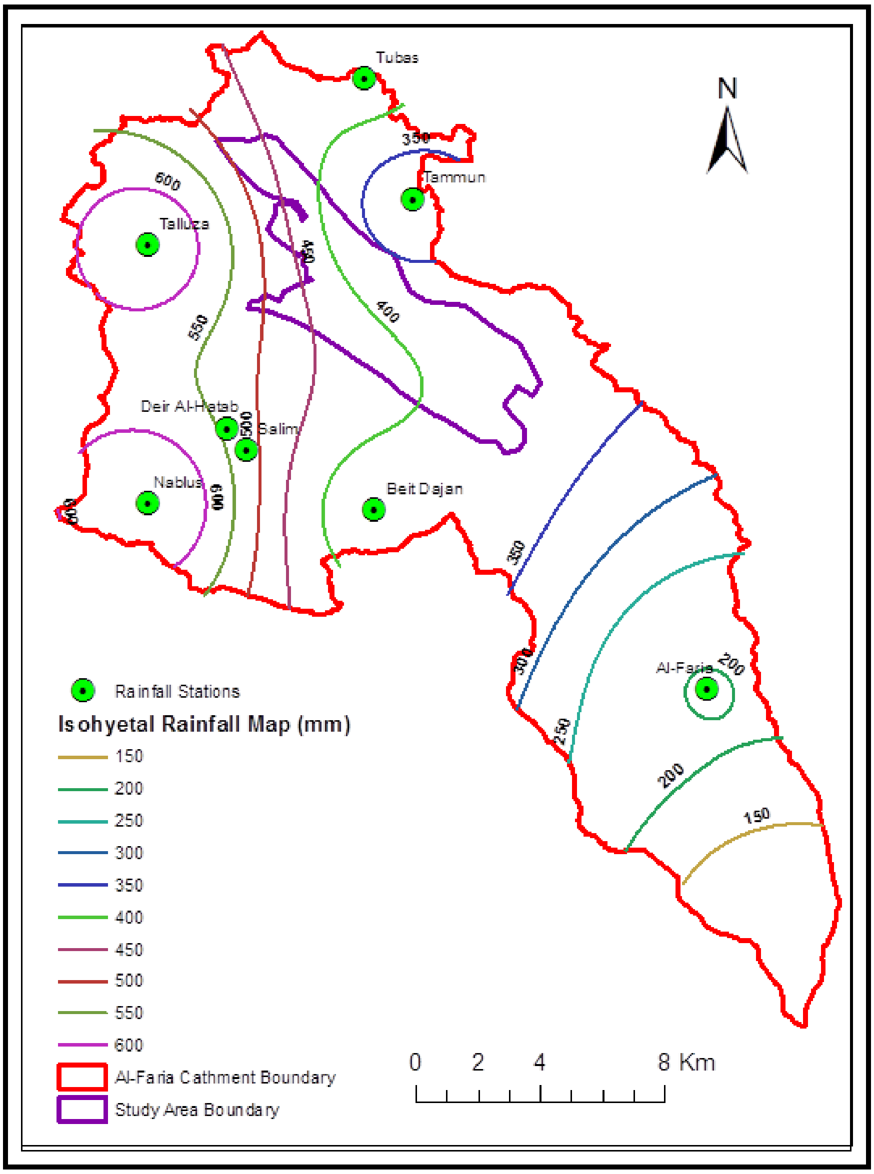

Figure 2.7: Isohyetal rainfall map of the study area

2.6 Soil

In Al-Faria catchment there are six soil classes while the study area overlaps only three kinds of soil which are (Figure 2.8): Grumusols (49%), Brown Rendzianas and Pale Rendzinas (40.1%), and Terra Rossas, Brown Rendzianas and Pale Rendzinas (10.9%).

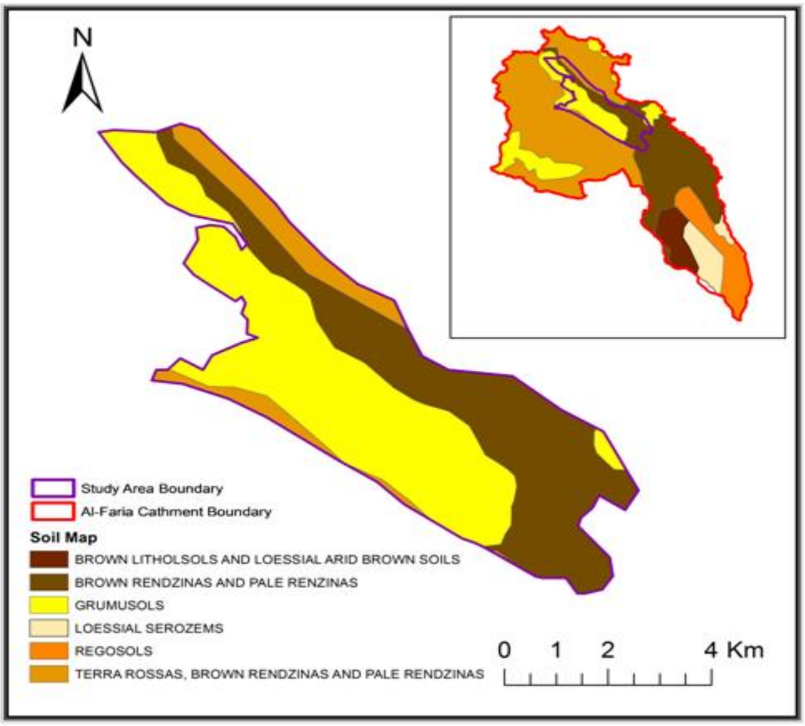

Figure 2.8: Soil map of the study area

2.7 Water Resources

Water resources are either surfacewater or groundwater in Al-Faria catchment. There are no storage structures in the catchment to store the excess water; therefore, most surface runoff in the catchment is usually lost in water. Al-Faria catchment groundwater aquifer system includes several rock formations from the Triassic (Lower Cretaceous) to recent age. The existing formations mainly composed of limestone, dolomite and marl. Groundwater aquifers are usually utilized through springs and wells, which are mostly, located in the catchment upper and middle parts (Shadeed, 2008).

2.7.1 Groundwater Wells and Springs

The present study considers the unconfined wells within the study area boundaries since the modeling works for quaternary layer. The study area contains 16 agricultural wells and 4 fresh water springs one of them was dried (Figure 2.9). Springs are considered as the only natural groundwater drainage outlets in that region.

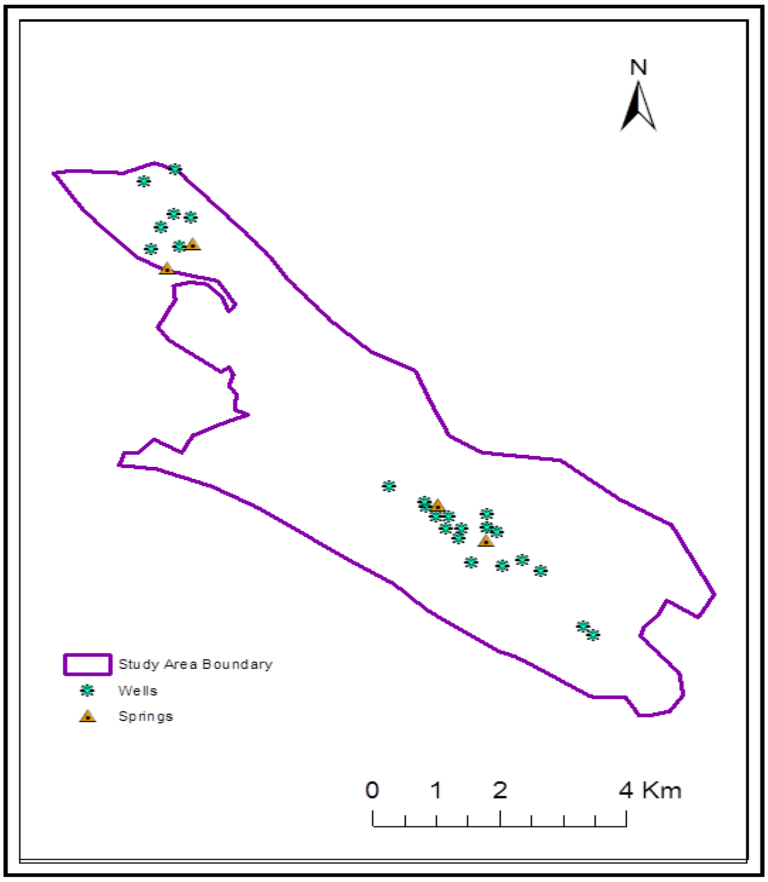

Figure 2.9: Location map for wells and springs in the study area

2.7.2 Surface Water

Compared to other catchments in the West Bank, the surface runoff of Faria catchment is considered high. The runoff decreases from west to east with decreasing rainfall through the catchment. The untreated industrial and domestic wastewater effluents of Nablus city discharges to Al-Badan stream while untreated domestic wastewater of Al-Faria Refugee camp discharges to Al-Faria stream. Therefore, the stream flow of the Faria catchment is a mix of (Shadeed, 2008):

- Winter storms generated runoff. It contains urban runoff from the eastern side of the city of Nablus and other built up areas in the catchment.
- Nablus eastern part and of Al-Faria Refugee camp untreated wastewater.
- Springs fresh water which provides the catchment main stream with base flow to prevent it from drying up during hot summers.

2.8 Groundwater Quality of the Study Area

Groundwater quality in the catchment are deteriorating due to the effluent of untreated wastewater from urban areas and the seepage from rural cesspits in addition to uncontrolled agricultural practices (Shadeed, Haddad, & Sawalha, 2015). Sewage pollution is the largest and most common problem as well as intensive use of pesticides and fertilizers which has led to chemicals being leached into freshwater supplies in many places. Nitrate pollution from excess fertilizer use is now one of the most serious water quality problems. Nitrates is dangerous to human health, leading to brain damage and even death in some infants (UNEP, 2000).

Shadeed, Haddad, & Sawalha made an assessment of groundwater quality in the Faria Catchment in 2015. They were found that the overall groundwater quality of the study area is suitable for drinking purposes in terms of chemistry except for nitrate where the concentration exceeds the maximum desirable limit in some samples. In addition, detected FC values in the tested wells and springs were unacceptable and make it unsafe for drinking purposes.

Chapter Three

Literature Review

3.1 Sources of Contaminants

The most common sources of groundwater contamination are cesspits, leaking underground storage tanks, land application of wastewater, Irrigation and irrigation return flow, solid-waste disposal sites and landfills, Waste-disposal injection wells, Hazardous chemicals in agriculture. In general, the most frequently reported contaminants in ground water are Petroleum products, Volatile organic compounds, Nitrates, Pesticides, and Metals (Chin, 2013).

In the study area the dominant sources are cesspits, irrigation return flow and hazardous chemicals used in agriculture. Most of people who lives in Palestinian rural areas depend on cesspits which leads to a serious problem since the cesspits discharge pathogenic microorganisms, syntheticorganic chemicals, nutrients (such as Nitrogen and Phosphate), and other contaminants directly into the groundwater especially if drinking water sources are too close to the septic tanks. To avoid it, the unsaturated soil should exist between the leach bed and the water table then the effluent from the septic tank will not enter the groundwater directly (Chin, 2013).

The risk of contamination depends on several factors, including (NESC, 2002):

- the well pumping rate.
- the aquifer slope.

- the distance between the soil absorption trench and well location.
- the composition of the soil.

According to Irrigation and Irrigation Return Flow, using water with high dissolved solids to irrigate an area leads to subsequent salt and contaminant buildup in soils. This is because portion of the irrigation water will return to the atmosphere by evapotranspiration and the salts will be accumulated in soil. To avoid this and to maintain the salt content in soil within acceptable range and sustain crop growth and fertility of soils, excess irrigation water must be applied if precipitation is not sufficient to control salt buildup in soils (Chin, 2013).

3.2 Selecting Appropriate Techniques for Quantifying Groundwater Recharge

There are several techniques to quantify recharge, while selecting the appropriate techniques depends on many factors such as hydrologic zone (Table 3.1). Space and time scales, range, and reliability of recharge estimates are the important consideration when choosing the technique.

The reliability of recharge estimates depends on the techniques since the potential recharge comes from those that are based on surface-water and unsaturated-zone data while the actual recharge results come from techniques of providing groundwater data.

To increase reliability of recharge, more than one approach is preferred to be used (Scanlon et al., 2002).

Schematic representation of the recharge into a subsurface reservoir is shown in Figure 3.1.

Table 3.1: Appropriate techniques for estimating recharge in regions with arid, semiarid, and humid climates (Scanlon et al., 2002).

Hydrologic zone	Technique	
	Arid and semiarid climates	Humid climate
Surface water	Channel water budget	Channel water budget
	Seepage meters	Seepage meters
	Heat tracers	Baseflow discharge
	Isotopic tracers	Isotopic tracers
	Watershed modeling	Watershed modeling
Unsaturated zone	Lysimeters	Lysimeters
	Zero-flux plane	Zero-flux plane
	Darcy's law	Darcy's law
	Tracers [historical (Cl^{36}, H^3) environmental (Cl)]	Tracers (applied)
	Numerical modeling	Numerical modeling
Saturated zone	-	Water-table fluctuations
	-	Darcy's law
	Tracers [historical (CFCs, H^3/He^3), environmental (Cl, C^{14})]	Tracers [historical (CFCs, H^3/He^3)]
	Numerical modeling	Numerical modeling

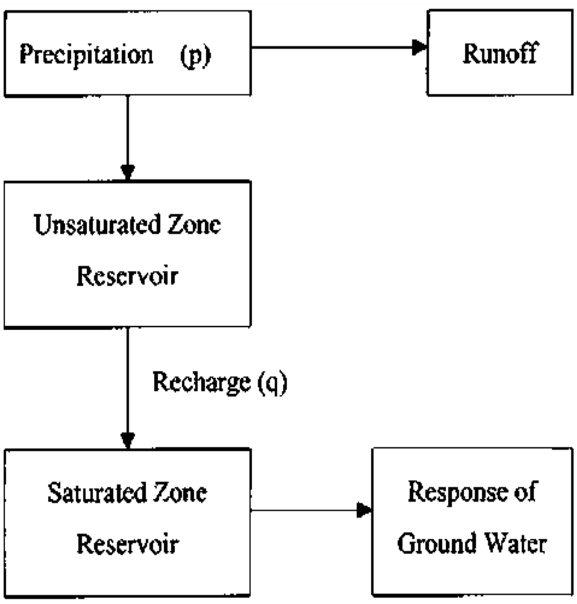

Figure 3.1: Schematic of the recharge into a subsurface reservoir (Liu & Gau, 2000)

3.3 Previous Studies

The aquifer of Al-Faria catchment is mainly divided into two aquifer systems; phreatic (upper) and confined (lower) aquifers. The saturated thickness of the phreatic aquifer, which consists of Pleistocene, Neogene and Eocene sub aquifers, is about 82.9m. The Pleistocene sub-aquifer has wide range of transmissivity within small areas; it ranges between 126 m^2/d and 10000 m^2/d. This variety refers to the fracturing caused by complex structures in the area that was formed during the formation of the Jordan Rift Valley (Ghanem, 1999).

The Eocene aquifer is an important source of water supply to local communities in Jenin district and parts of Nablus district. The aquifer is heavily utilized specifically for agricultural activities. The Simulation/ optimization model was developed in Kharamh (2007) study using the U.S. Geological Survery’s MODFLOW and GWM. Based on the calibrated steady-state groundwater flow model, the annual discharge from the Eocene aquifer outside the West Bank is about 55 million cubic meters. His simulation model was then utilized in the development of the GWM model (optimization) to find out the optimal pumping rates that the aquifer can sustain without depleting the aquifer. The outcome from the GWM model shows that 23 MCM can be safely pumped out from the Eocene aquifer through the existing wells (Kharmah, 2007).

Modeling could be used to assess the current situation or to evaluate and expect certain results from different scenarios. Assessment of water quality for Faria stream indicates that untreated Waste water discharged at upstream is the main source for pollution as results of the measured quality parameters explained (Alawneh, 2013)

Modeling the Western Aquifer Basin (WAB), which falls in the middle-to-Late-Cretaceous Judea Group, was performed by Abusaada (2011) to evaluate the impact of a combination of different rainfalls and pumping scenarios. WAB consists of two main sub-aquifers; upper and lower. These separated by a lower permeability layer (i.e. Yatta formation). Three-layer model was used to simulate WAB using MODFLOW-2000. The model calibration periods were during 1951-2000 whereas the validation period was during 2000-2007 in monthly time steps. The aquifer's physical properties, flow dynamics, and aquifer water balance were obtained from the model. Water balance results display that an average of 62% of the natural recharge directly replenishes the upper sub-aquifer and 11% of the total aquifer outflow flows from the lower towards the upper sub-aquifer. To evaluate the impact of a combination of different rainfalls and pumping scenarios, the transient model for WAB was also developed and extended to the year of 2034/2035 (Abusaada, 2011).

Generally, the modeling could be used for assessment of certain situations. The work of Hamarshi (2012) 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 Tulkarm District. A well head 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 (Hamarshi, 2012).

In this study MODFLOW was used to simulate Al-Faria Quaternary and to study the flow dynamics using steady state flow model. The model was connected to MODPATH to track pollutants so as to assess the situation of aquifer by finding the potentially polluted wells and springs.

3.4 Introduction of the groundwater modeling

A model is a device that represents an approximation of a field situation. Groundwater model can be implemented physically or mathematically; the first one simulates groundwater flow directly such as laboratory sand tanks. The second simulates groundwater flow indirectly using governing equation to represent the physical processes that occur in the system. Mathematical models can be solved analytically or numerically and both of them may involve a computer (Sinha, 2011). In the present study, steady state groundwater flow model using MODFLOW and MODPATH were used to delineate the capture zone. MODFLOW is a three-dimensional finite-difference groundwater model used for groundwater flow simulation. It simulates confined, unconfined, or combined aquifer and to simulate steady state or transient flow system. (Harbaugh, 2005) while MODPATH it is a post processing program which is a useful tool to understand flow patterns in the simulated groundwater flow system using MODFLOW. It is used for delineating capture zone for source and drawing flow pathlines of contaminants simulated with MODFLOW (Pollock, 1994).

3.4.1 Types of modeling application

There are three types of modeling applications, which are (Anderson & Woessner, 1992):

1- Predictive: used to predict the consequences of a proposed action; it requires calibration.

2- Interpretive: used as a framework for studying system dynamics and/or organizing field data, it does not necessarily require calibration.

3- Generic: used to analyze flow in hypothetical systems. It may be useful to help frame regulatory guidelines for specific region; it does not necessarily require calibration.

3.4.2 Modeling Protocol

Steps in a protocol for model application were summarized in the following schematic diagram (figure 3.2) (Anderson & Woessner, 1992).

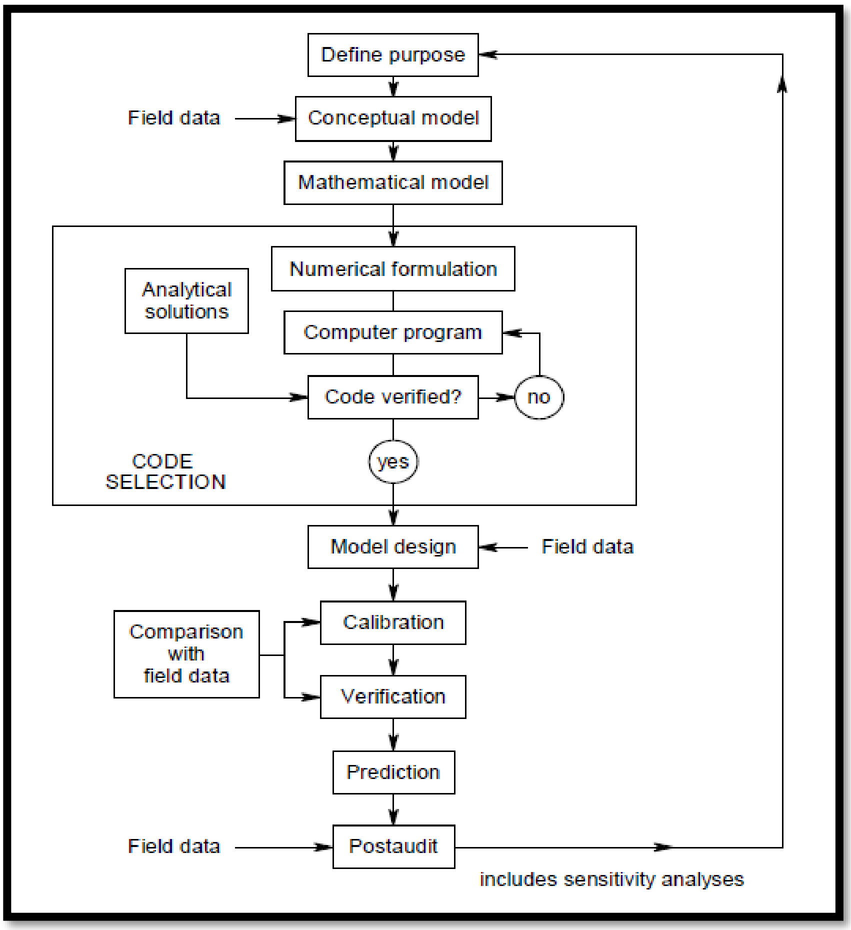

Figure 3.2: Modeling Protocol Steps

Brief description of modeling steps are illustrated in the following points (Anderson & Woessner, 1992):

1- Define Purpose

The first step of modeling process is establishing the purpose of the model to determine the type and level of modeling effort needed. The model might be steady state or transient, one-, two-, or three-dimensional, analytical or numerical, and whether the solution involves a particle tracking or full solute transport analysis. Answers to the following questions will help in selecting the magnitude of the modeling effort:

- Is the model to be constructed for prediction, system interpretation, or a generic modeling exercise?
- What do you want to learn from the model? What questions do you want the model to answer?
- Is a modeling exercise the best way to answer the question(s)?
- Can an analytical model provide the answer or must a numerical model be constructed?

The purpose will determine what governing equation will be solved and what code will be selected.

2- Develop a Conceptual Model

The second step is to develop a conceptual model of the system. It is a pictorial representation of the groundwater flow system, frequently in the form of a block diagram or a cross section. Moreover, the conceptual model will act as useful tool to determine the dimensions of the numerical model and the design of the grid.

3- Select the Governing Equation and Computer Code

A computer code solves algebraic equations which are formed by partial differential equations such as governing equations, boundary conditions, and initial conditions forming a mathematical model.

Techniques such as finite difference and finite element form mathematical models in a way that can be solved easily by software. Both the governing equation and the code should be verified systematically.

There are many flow codes used such as MODFLOW, PLASM, and AQUIFEM-1. The compassion between these flows codes are clarified in table 3.2.

Table 3.2: Groundwater Flow Codes

Name	Type	Solution technique
MODFLOW	3D finite difference	SIP (strongly implicit procedures); SSOR (slice successive over-relaxation)
PLASM	2D finite difference	LADIP (iterative alternating direction implicit procedure)
AQUIFEM-1	2D finite elements; Linear triangular elements	Direct solution using Grout's method

4- Model Design

The conceptual model includes designing the grid, selecting time steps, setting boundaries and initial conditions, and prior selection of values for aquifer parameters and hydrologic stresses.

5- Calibration

The objective of calibration is to check the reliability of the model by adjusting the values until reaching reasonable results that represent the actual situation. After that, the results could be taken. The calibration can be implemented using an automated parameter estimation code or by trial and error adjustment of parameters.

6- Calibration Sensitivity Analysis

Uncertainties when defining the exact spatial and temporal distribution of parameter values, boundary conditions and stresses in the problem domain are possible and this affects the calibrated model. The sensitivity analysis is performed in order to establish the effect of uncertainty on the calibrated model.

7- Model Verification

Verification answers the question ‘’ Have we built the model right?’’. It is the process of determining whether the model implementation and its associated data are representing or represent the conceptual description and specifications of the model to establish greater confidence in the model.

8- Prediction

Uncertainty in the calibrated model and inability to estimate accurate values for magnitude and timing of future stresses leads to uncertainty in a predictive simulation. Simulation plays an important role in predication and quantifying the response of the system of future events.

9- Predictive Sensitivity Analysis

Predictive sensitivity analysis plays the role of measuring the effect of uncertainty in parameter values on the prediction by simulating ranges in estimated stresses and to check the impact on the model's prediction.

10- Presentation of Modeling Design and Results

Obtaining effective communication of the modeling effort comes from introducing a clear presentation of the model design and results.

11- Post-audit

A post-audit is implemented after accomplishing the modeling study. It is checked by collecting new field data to determine whether the prediction was correct and in case of accurate model prediction results. The model is validated for that particular site since each model is unique. Note that the validation answers the question "Have we built the right model?”.

12- Model Redesign

Typically, the post audit will lead to new insights into system behavior which may lead to changes in conceptual model or changes in model parameter.

3.4.3 Conceptual Model

The main purposes of constructing a conceptual model are to simplify the field problem and to organize the associated field data so that the system can be analyzed more readily.

As the conceptual model is close to the field situation then the numerical model will be more accurate. It should be simplified to a large extent yet entails enough complexity so that it sufficiently reproduces system behavior Developing the conceptual model implemented through many steps. To build the conceptual model define the study area and identify the boundaries of the model. ‘’Numerical models requires boundary conditions, such as the head or flux must be specified along the boundaries of the system. Whenever possible the natural hydro-geologic boundaries of the system should be used as the boundaries of the model. The valid and complete conceptual model is essential for making accurate predictions. The data requirements for a groundwater flow model are summarized in table 3.3.

The main three steps for building the conceptual model are: defining hydrostratigraphic units, preparing a water budget and defining the flow system.

Table 3.3: Data Requirements for Groundwater Flow Model (Moore, 1979)

Data Requirements for Groundwater Flow Model	
Physical framework	Hydrologic framework
1. Geological map and cross sections showing the areal and vertical extent and boundaries of the system. 2. Topographic map showing surface water bodies and divides. 3. Contour maps showing the elevation of the base of aquifers and confining beds. 4. Isopach maps showing the thickness of aquifers and confining beds. 5. Maps showing the extent and thickness of stream and lake sediments.	1. Water table and potentiometric maps for all aquifers. 2. Hydrographs of groundwater head and surface water levels and discharge rates. 3. Maps and cross sections showing the hydraulic conductivity and/or transmissivity distribution. 4. Maps and cross sections showing the storage properties of the aquifers and confining beds. 5. Hydraulic conductivity values and their distribution for stream and lake sediments. 6. Spatial and temporal distribution of rates of evapotranspiration, groundwater recharge; surface water-groundwater interaction, groundwater pumping, and natural groundwater discharge.

3.3.4 Boundaries

Governing equation, boundary conditions and initial conditions are the main contents of the mathematical model.

Boundary conditions are defined as mathematical statements specifying the dependent variable (head) or the derivative of the dependent variable (flux) at the boundaries of the problem domain.

The most critical step during model design is the correct selection of the boundary condition and it should be realistic

Groundwater flow system can have either physical or hydraulic boundaries or both of them. The physical presence of an impermeable body of rock or a large body of surface water and the hydrologic conditions represent physical boundaries such as river while hydraulic boundaries are invisible boundaries such as groundwater divides and stream lines.

Hydrologic boundaries are described by the following mathematical conditions (Anderson & Woessner, 1992):

1. Specified head boundaries

Specified head boundaries are used when the head values are given at certain boundaries and it is simulated by setting the head at the relevant boundary nodes equal to known head values. In case of river, the head along the boundary varies spatially while in case of lakes and reservoirs the boundary condition is simulated as constant head condition.

2. Specified flow boundaries

For which the derivative of head (flux) across the boundary is given.

Specified flow conditions are used to describe fluxes to surface water bodies, spring flow, underflow, and seepage to or from bedrock underlying the modeled system.

3. No-flow boundaries

When the flux across the boundary is zero then the boundary is set by defining flux to be zero. Impermeable bedrock, an impermeable fault zone, a groundwater divides, or streamline are simulated as a no-flow boundary.

4. Head-dependent flow boundaries

This is a mixed boundary condition because it relates boundary heads to boundary flows. It is set when flux across the boundary is calculated given a boundary head value. The flux in this case is dependent on the difference between a user-supplied specified head on one side of the boundary and the model calculated head on the other side.

3.4.5 The used software's

Generally during modeling the researcher needs to use one or more software to accomplish the model. In the present study, Creation the required GIS shapefiles is conducted to be able to analysis the data spatially. After preparing shapefiles and doing the needed analysis the output shapefiles were ready for groundwater modeling using MODFLOW and MODPATH. GMS is used throughout the modeling process for its simplicity and multifunctioning. GMS is an all-inclusive platform which provides tools for every phase of groundwater simulation including site characterization, model development, post-processing, calibration, and visualization. GMS package currently includes MODFLOW, MODPATH, MT3D, RT3D, FEMWATER, and SEEP2D.

MODFLOW software is used to solve three-dimensional ground-water flow equation numerically for a porous medium using a finite-difference method. Whereas MODPATH is post-processing program mainly used for particle tracking and it is designed to work with the U.S. Geological Survey's finite-difference groundwater flow model, commonly known as MODFLOW (Zheng, Hill, & Hsieh, 2001).

Steady state or transient simulations output are used in MODPATH to compute paths for imaginary particles that move through the simulated groundwater system and to track the travel time for particles that move through the system.

3.4.6 Steady State versus Transient Modeling

Groundwater flow models can be steady state or transient. The main difference between these kinds of flow models is the relationship between the flow magnitude and direction with time.

When the magnitude and direction of flow in certain domains are constant with time, it is steady state flow. On contrary, when the magnitude and direction of flow changes with time, it is transient flow. That is to say, in a steady state flow system, the hydraulic head does not change with time, while it changes during transient flow. However, movement of groundwater also exists in a steady state system only that the amount of water of the certain area is kept the same. The amount of water that flows into the system equals the amount of water that flows out of the system. The groundwater flow equation is simplified by the steady state flow conditions. In steady state flow, the storage term disappears in the groundwater flow equation as time is no longer an independent variable since the amount of water within certain domains is the same. There is no change in hydraulic head and there is no change in the amount of water stored in the domain. The simplified equations demonstrating the transient and groundwater flow are shown as follows (ESO, 2016):

Transient Flow:

$$\frac{\partial(\mathrm{pwqw})}{\partial \mathrm{x}}+\frac{\partial(\mathrm{pwqw})}{\partial \mathrm{y}}+\frac{\partial(\mathrm{pwqw})}{\partial \mathrm{z}}=\frac{\partial(\mathrm{pw\varphi Sw})}{\partial \mathrm{t}}$$

Where:

Pw= density of water

Qw= Darcy flux of water

φ= porosity

Sw= saturation

Steady State Flow:

$$\frac{\partial(\mathrm{pwqw})}{\partial \mathrm{x}}+\frac{\partial(\mathrm{pwqw})}{\partial \mathrm{y}}+\frac{\partial(\mathrm{pwqw})}{\partial \mathrm{z}}=0$$

Where:

Pw= density of water

qw= Darcy flux of water

Chapter Four

Conceptual Model

4.1 Model Boundary and Boundary Conditions

The specification of appropriate boundary and initial conditions is an essential part of conceptualizing and modeling groundwater system and is also the part most subject to serious error by groundwater hydrologists.

Quantitative modeling of groundwater system entails the solution of a boundary value problem. The flow of groundwater is described in the general case by partial differential equations. A groundwater problems defined by establishing the appropriate boundary-value problem; solving the problem involves solving the governing partial differential equation in the flow domain while at the same time satisfying the specified boundary and initial conditions (Franke, Thomas , & Bennett , 1987).

4.1.1 Model Boundary

Boundary of Groundwater molding for the study area is illustrated in figure 4.1. The exact boundary is defined geologically by quaternary (unconfined aquifer).

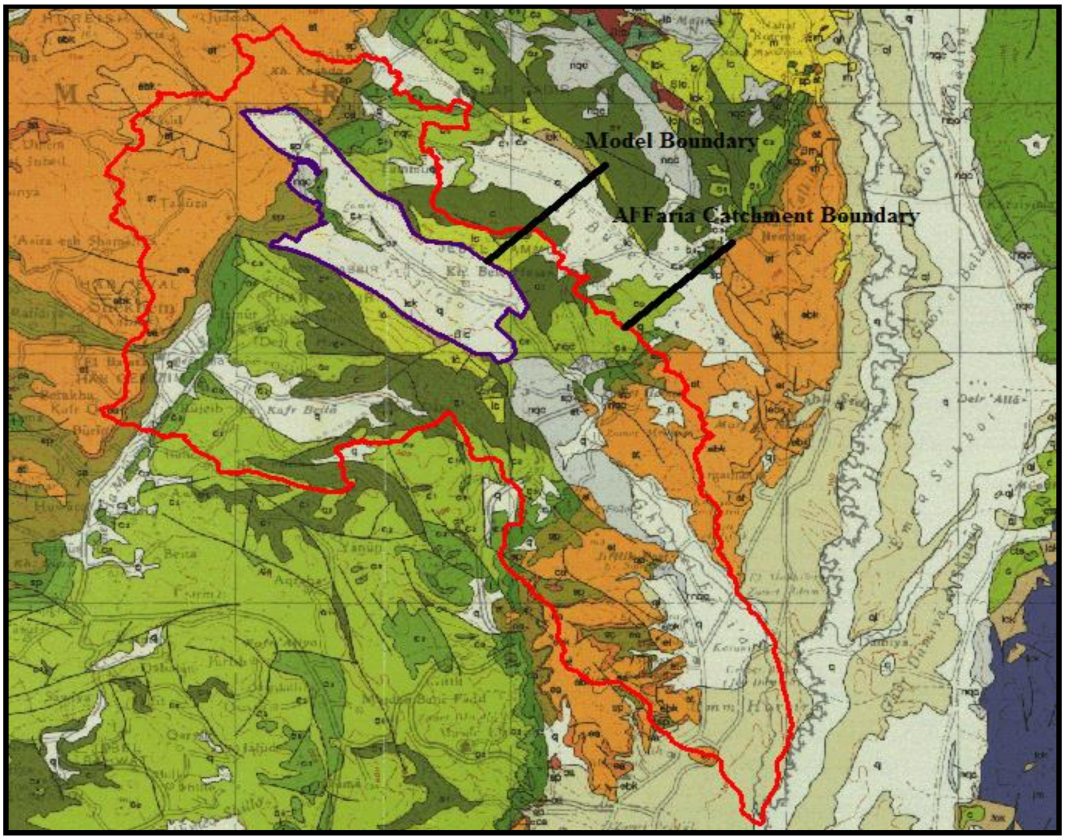

Figure 4.1: Boundary of groundwater molding

4.1.2 Boundary conditions

The boundary conditions depend on the structure geology of the study area. Figure 4.2 describes the geological cross section that was applied.

Two boundary conditions are found in the present model:

A. No flow boundary.

B. Specified flow boundary for connected points between Quaternary with Eocene, upper aquifer and lower aquifer (Figure 4.3).

Only the quaternary layer is used in the model.

4.2 Aquifer Geometry

Lithology of different wells in the study area, cross section (Figure 4.2), the Geological Map and quaternary thickness were used to estimate the bottom elevation of the aquifer while DEM (Figure 2.2) is used to estimate the top elevation. The final simulated geometry result is represented by Figure 4.2. The geometry in Figure 4.3 represents the whole geometry and the relationships between quaternary with other layers before starting groundwater modeling.

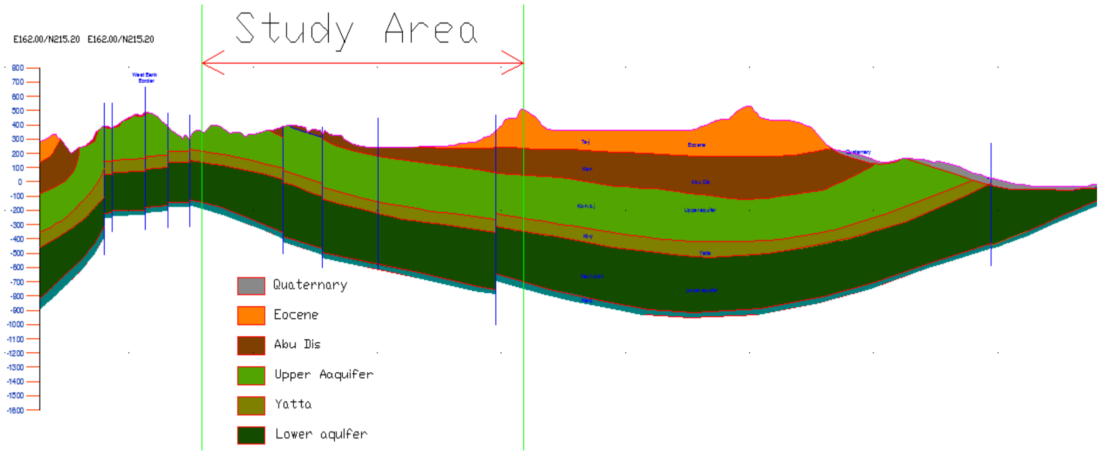

Figure 4.2: A hydrogeological cross section for study area (SUSMAQ, 2004)

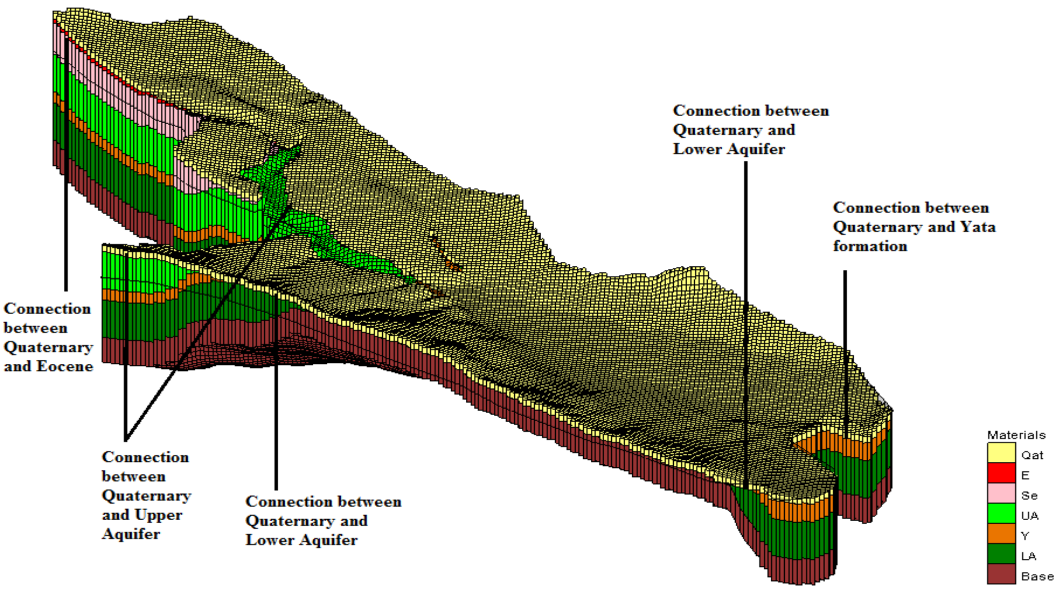

Figure 4.3: Final simulated geometry result of intended layer and relation with the other layers

4.3 Rainfall Analysis

The conceptual model was prepared for years from 2005-2014 after that 2011 was selected to represent the model. The selection of year 2011 depends on the availability of modeling related data on that year.

Rainfall station (called A) was assumed to represent the rainfall value at the study area. The rainfall value at the ungauged station A was estimated from the existing surrounded stations. Figure 4.4.

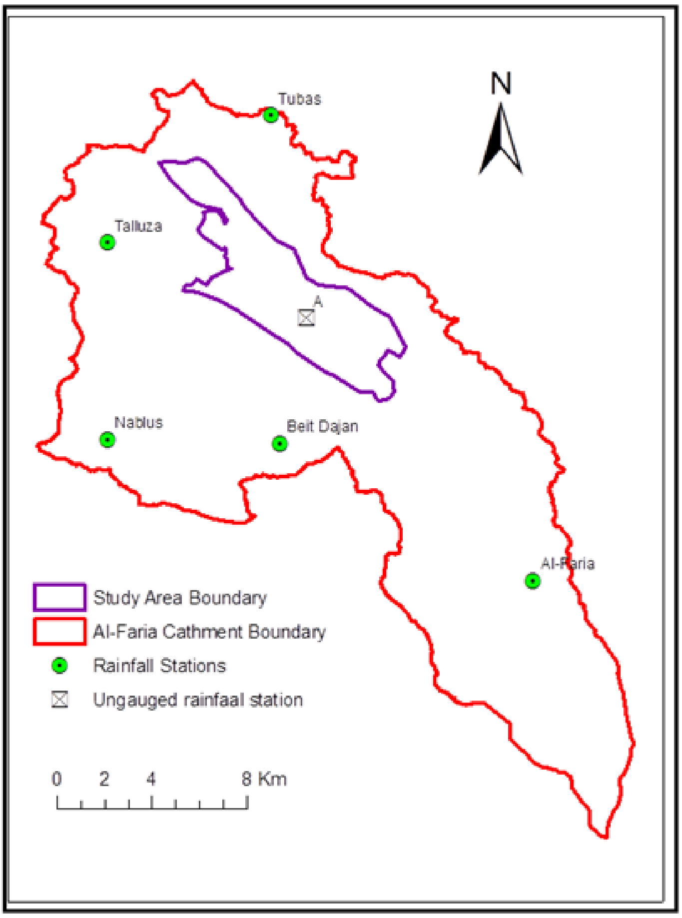

Figure 4.4: Gauged and un-gauged rainfall Station location within study area boundary

Six rainfall stations exist in Al-Faria catchment; these are Talluza, Nablus, Tubas, BeitDajan, Tammoun and Al-Jiftlik stations. The location of each rainfall stations is shown in Figure 4.4. Tammoun station is excluded from the rainfall analysis for many reasons: the lack of rainfall data at this station and that it is very close to Tubas station. The density of stations is concentrated in the upper part of Al-Faria catchment. While estimating the missing data if two stations are so close that will affect the estimation process and lead into doubtful results.

For the incomplete and missing rainfall data the Normal Ratio method was used. IDM was used to interpolate points and estimate rainfall at ungauged points (in our case point A). Annual rainfall of Al-Faria catchment is shown in Table 2.2.

4.3.1 Estimation of Missing Rainfall Records

To estimate missing data two methods are available; Station – Average Method and Normal – Ratio Method (Reddy, 2005).

Station – Average Method or arithmetic average method has limitation for use, it is commonly used if the average annual rainfall at the adjacent stations are within about 10% of the average annual rainfall at station under consideration. For **m** rain gauges with available measured data for certain storm event in region if the data are missing for storm event at station **X** then, (Reddy, 2005):

$$P_x = \frac{1}{m}\sum_{i=1}^{m} P_i \qquad \text{……………………………………………….....} \quad (4.1)$$

Where $\mathbf{P_1}$, $\mathbf{P_2} \ldots \mathbf{P_m}$ are rainfalls at m adjacent stations.

Al-Faria catchment is not uniform and it has significantly changes in elevations throughout the catchment that leads into significantly changes in rainfall since areas in higher elevations generally receive more rainfall than areas in lower elevations within the catchment (Shadeed, 2008).

Normal – Ratio Method is more reliable because the normal annual rainfall at the station under consideration shared in equation to give indication of previous rainfall measurement at the missing station. The storm rainfall is missing but the normal annual rainfall for the station under consideration is available to support the estimation. In this method the rainfall values at surrounding stations are weighed by the ratio of the normal annual rainfalls.

If the missing precipitation at station **x** is $\mathbf{P_x}$ while $\mathbf{P_1}$, $\mathbf{P_2} \ldots$ $\mathbf{P_m}$ are rainfall measurements at m rainfall stations that surrounds station **x** and $\mathbf{N_1}$, $\mathbf{N_2} \ldots$ $\mathbf{N_m}$ are the normal annual rainfalls at the same previous stations including station **x** ($\mathbf{N_x}$ is the normal annual rainfall at station **X**. A minimum of 3 adjacent stations generally used in the normal-ratio method (Reddy, 2005).

$$P_x = \frac{1}{m}\left[\frac{N_x}{N_1}P_1 + \frac{N_x}{N_2}P_2 + \cdots + \frac{N_x}{N_m}P_m\right] \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (4.2)$$

Use Table 2.2 to obtain normal annual rainfall for Talluza, Nablus, Tubas, BeitDajan, Tammoun and Al-Faria stations.

4.3.2 Estimation of rainfall at ungauged stations

To predict rainfall at ungauged points from surroundings stations such as prediction for ungauged point A within Al-Faria catchment (Figure 4.5), rainfall interpolation is constructed using inverse distance weighting (IDW) method. The rainfall at predictive point is more influenced by nearby and close stations than far ones such that the rainfall at prediction point is inversely proportional to the distance to the measurement points (Reddy, 2005).

$$\widehat{P}=\frac{\sum_{i=1}^{N}\left(\frac{P_i}{d_i^2}\right)}{\sum_{i=1}^{N}\left(\frac{1}{d_i^2}\right)} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (4.3)$$

Where $\mathbf{d_i}$ represents distances from ungauged rainfall point into all measurement points.

The ungauged point A is selected to represent rainfall in part A (study area boundary). Apply equation 4.3 to estimate rainfall at point A. (figure 4.6, Table 4.1 and 4.2).

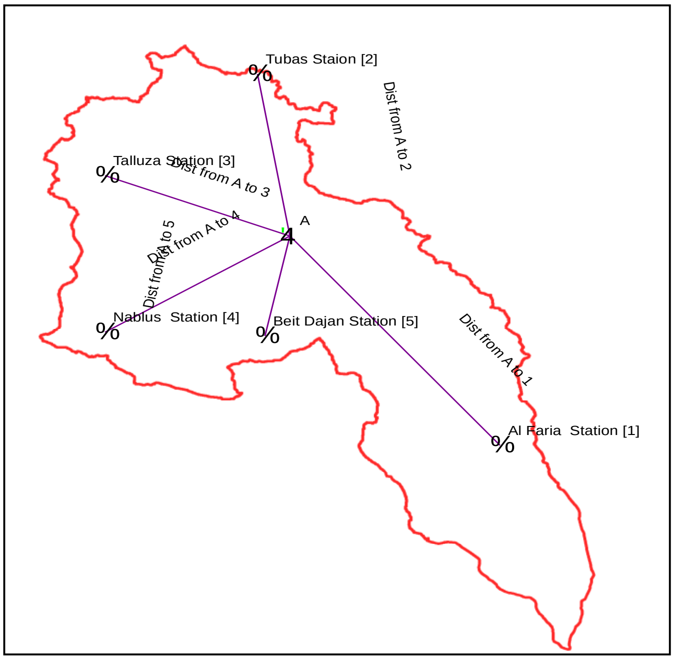

Figure 4.5: Distances from ungauged rainfall point (point A) into all measurement points

Table 4.1: Rainfall data for year 2011 (PA-MET, 2011)

Station/ Month	Monthly rainfall (mm)												annual rainfall (mm)
	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	
Tubas station	0	3.5	0	74	106.5	69.3	117	26	5.5	0	0	0	401.8
Taluza station	0	6.2	0	195.9	99.1	91	101.5	41.6	8.9	0	0	0	544.2
Beit Dajan station	0	3.5	0	63.2	29.7	102.4	65	31.3	7.2	0	0	0	302.3
Nablus station	0	5.3	0	151.1	100	97.2	129.1	57.8	30	0	0	0	570.5
Al-Faria station	0	0.2	6	109.6	84.8	72.5	67	16.1	3.2	0	0	0	359.4
Station A (computed)	0	3.99	0.37	102.18	68	92.05	89.27	34.79	10.09	0	0	0	400.7

Table 4.2: Predicted rainfall data at point A (using IDW).

year	monthly rainfall (mm)									annual rainfall (mm)
month	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	March	April	May.	
2005/2006	0	6	39	91	88	105	11	89	0	428
2006/2007	0	45	8	71	56	103	68	5	10	366
2007/2008	0	0	58	46	124	73	4	0	0	304
2008/2009	4	12	11	110	18	207	55	10	0	426
2009/2010	3	24	66	70	74	168	29	0	3	436
2010/2011	0	4	0	102	68	92	89	35	10	401
2011/2012	0	2	98	25	112	131	68	0	0	437
2012/2013	0	5	54	62	257	27	5	27	0	437
2013/2014	0	4	1	189	1	6	66	0	27	294

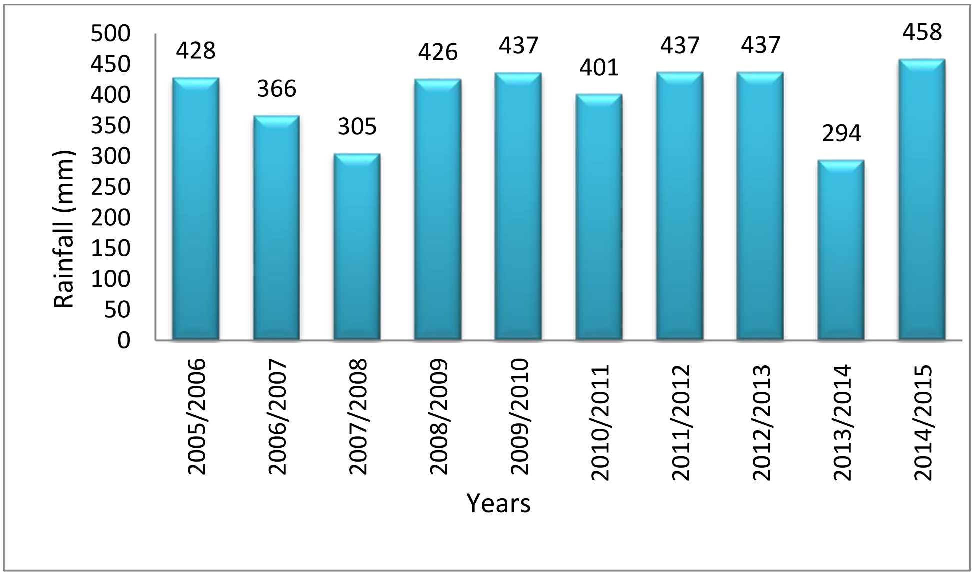

Figure 4.6: Predicted rainfall data at point A (using IDW)

4.4 Recharge Calculations

Recharge describes water movement below the root zone and it is defined as water that reaches an aquifer from any direction either down, up, or laterally (Scanlon et al., 2002).

The main methods of estimating direct recharge from precipitation are direct measurement, empirical methods, water budget methods, Darcian approaches , tracers, plane of zero flux, temperature and electromagnetic method, base flow separation, remote sensing, and inverse groundwater modeling (Jyrkama & Sykes, 2006).

Water budget and groundwater model are used to find recharge for the present study.

To develop a conceptual model of recharge in the system, collecting existing data on potential controls on recharge should be involved. Some of these data are climate, hydrology, geomorphology, and geology.

Recharge calculation applied for two reasons firstly for water balance (m^3/year) and secondly for modeling process (m/day) to find recharge values in each recharge zones. The recharge is divided into six parts:

1- Recharge from rainfall (**R_{Rain}**).
2- Recharge from wastewater that comes from Nablus municipality, Azmut, Deir Al Hatab, Salim, Beitdajan, Rujeib, Kafrqalil and Beitfurik (**$R_{Sew-Nab}$**).
3- Recharge from water network leakage (**$R_{Wat-Net}$**).
4- Recharge from surface runoff (recharge from storm water) (**$R_{Run-off}$**).
5- Return flow from agriculture (**$R_{Agr-Ret}$**).
6- Recharge from Cesspits (**R_{Cess}**).

Calculation method and assumptions of each recharge item are described in the followings sections. Evapotranspiration has been neglected in groundwater recharge calculation since water table is more than two meters below ground surface.

4.4.1 Recharge from rainfall (R_{Rain})

Recharge estimation depends on the transient quantities of precipitation (wet verses dry years) besides other meteorological and geologic factors, empirical equations were developed by Guttman to estimate recharge depending on rainfall quantities. The three linear equations of Guttman are (Menachem & Haim, 2007):

$$R = \begin{cases} 0.45(\mathrm{P} - 0.18) & , \ \mathrm{P} < 0.6\ \mathrm{m} \\ 0.88(\mathrm{P} - 0.41) & , \ 0.6\ \mathrm{m} < \mathrm{P} < 0.1\ \mathrm{m} \\ 0.97(\mathrm{P} - 0.463) & , \ \mathrm{P} > 0.1\ \mathrm{m} \end{cases} \quad \ldots\ldots \ (4.4)$$

Where

R: yearly recharge

P: yearly precipitation (in meters).

From isohyetal rainfall map for annual precipitation, the study area is divided into three zones depending on rainfall values. Station A is located in zone 3; Rainfall values at zone 3 is the same as rainfall at Station A. This means it is the reference value to find values for other zones based on it as clarified in the following equation and by Figure 4.7.

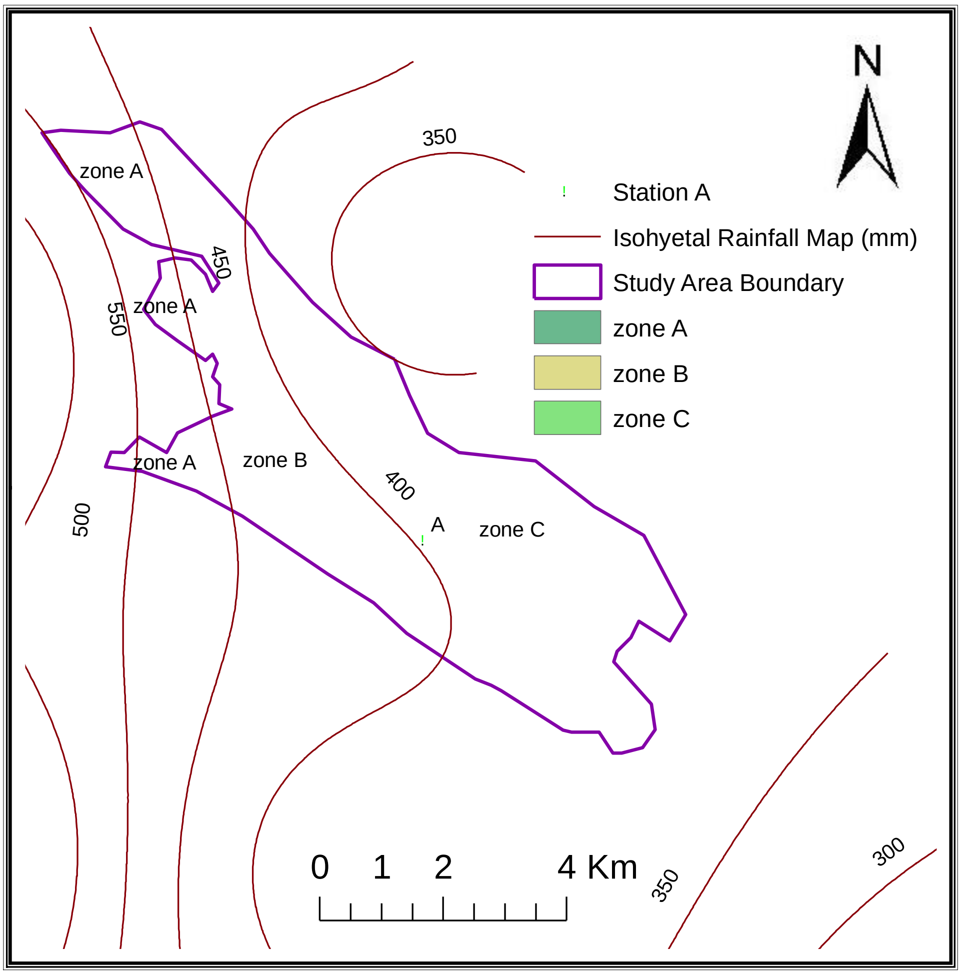

Figure 4.7: Rainfall Recharge Zones

Annual rainfall for zone 3 = (400+350)/2=375 mm (reference value).

$$\text{Rainfall in zone k} = \frac{\text{rainfall in zone C (reference zone)}}{\text{annual rainfall in zone C}} \times \text{annual rainfall in zone k}$$

Recharge from rainfall:

$$R_{Rain}\ (\text{m/day}) = \frac{\text{Rainfall in zone k}\ (\frac{mm}{year})}{1000\ (\frac{mm}{m}) \times 365 (\frac{day}{year})} \quad \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots \ (4.5)$$

The obtained results show rainfall in each isohyetal zone. Annual Rainfall (mm/year) for zones A, B and C are 475, 425 and 375 respectively. Rainfall results are shown in Table 4.3.

Table 4.3: The computed rainfall values for zones A, B and C.

Year	Rainfall (mm)		
	A	B	C (reference zone)
2005/2006	542	485	428
2006/2007	464	415	366
2007/2008	386	345	305
2008/2009	539	483	426
2009/2010	553	495	437
2010/2011	508	454	401
2011/2012	553	495	437
2012/2013	554	496	437
2013/2014	372	333	294
2014/2015	581	520	458

After converting point rainfall data into aerial data the recharge (**R_{Rain}**) values for the various zones in different years was estimated using the above Guttman empirical equation (equation 4.4).

The final recharge zone values from rainfall are computed in m/d and m^3/year in tables 4.4 and 4.5 respectively. Figures 4.8 describe the relationship between recharge and rainfall.

Table 4.4: Recharge from rainfall m/day

R **Rain** (m/day)			
Year	A	B	C
2005/2006	0.000447	0.000376	0.000306
2006/2007	0.000350	0.000290	0.000229
2007/2008	0.000254	0.000204	0.000153
2008/2009	0.000443	0.000373	0.000303
2009/2010	0.000460	0.000388	0.000316
20010/2011	0.000404	0.000338	0.000272
2011/2012	0.000460	0.000388	0.000316
2012/2013	0.000461	0.000389	0.000317
2013/2014	0.000236	0.000188	0.000140
2014/2015	0.000494	0.000419	0.000343

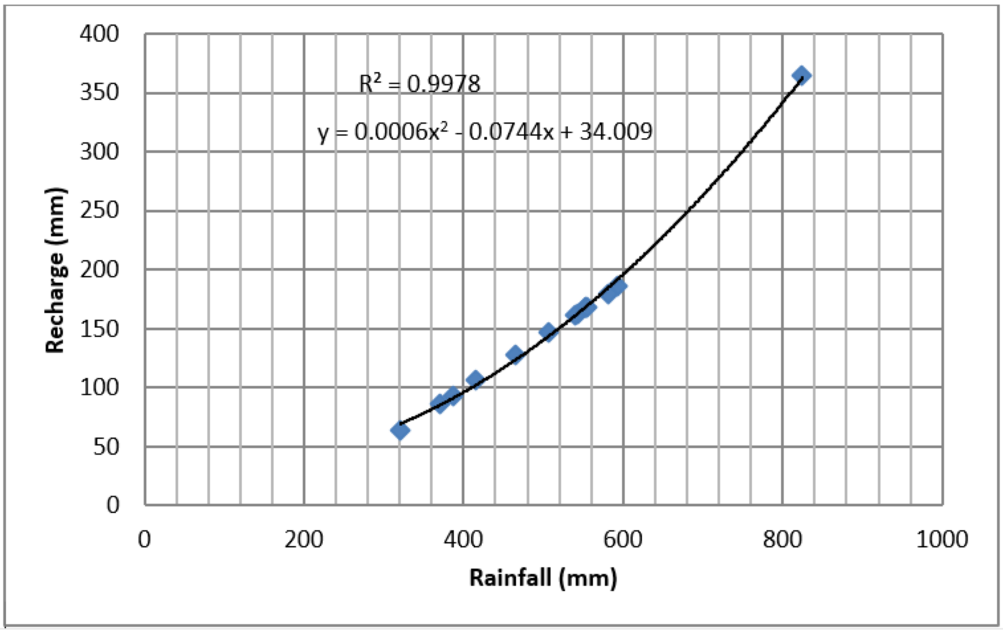

Figure 4.8: Recharge- rainfall relationship using Guttman

Table 4.5: Recharge from rainfall m^3/year

Zones	A	B	C	
Areas (m^2)	3,944,055	11,300,930	19,229,251	
R_{Rain}(m^3/yr)				
year	A	B	C	Total
2005/2006	643173	1552544	2147715	4343432
2006/2007	503565	1194633	1610354	3308551
2007/2008	365081	839603	1077319	2282003
2008/2009	637777	1538712	2126947	4303437
2009/2010	661832	1600381	2219536	4481750
2010/2011	581350	1394049	1909753	3885152
2011/2012	662057	1600958	2220402	4483416
2012/2013	663856	1605568	2227324	4496748
2013/2014	340352	776204	982134	2098691
2014/2015	711066	1726601	2409041	4846708

4.4.2 Recharge from Wastewater flow ($R_{Sew\text{-}Nab}$)

To estimate recharge from wastewater discharge effluent in to wadi Al-Faria ($R_{Sew\text{-}Nab}$), the following was implemented:

A. Identify the communities that discharge its wastewater into the wadi streams. These are Nablus municipality, Azmut, Deir Al Hatab, Salim, Beitdajan, Rujeib, Kafrqalil and Beitfurik.

B. Find water consumption for the mentioned communities from 2005-2014. The water consumption in each community is estimated by PWA.

C. Find number of population from 2005-2014 and filling the missing data by 1.03% growth rate. The Population in each community is approximated by PCBS (Palestinian Central Bureau of Statistics).

D. Find the generated wastewater quantities in each community from 2005-2014. It was found by assuming wastewater generation factor at 80% for urban areas and 75% for rural.

E. Sumup wastewater quantities for all considerable regions in each period (2005-2014); to get $Q_{\textbf{Sew-Nab}}$ apply equation 4.6

$$Q_{\text{Sew-Nab}}\ (m^3/day) = WC\ (L/c.d) \times P\ (c) \times F_{\text{Sew-Nab}} \times \frac{1\ m^3}{1000\ liter} \quad \text{……...…..(4.6)}$$

WC (L/c.d): Water consumption (liter/capita. day)

P: population (capita)

$F_{\text{Sew-Nab}}$: wastewater generation factor

F. Assuming recharge coefficient (**$RC_{\text{Sew-Nab}}$**) at 1%. In other words, 1% of $Q_{\text{Sew-Nab}}$ percolates deeply into groundwater, accordingly Table 4.6 is produced.

G. Find wadi area within the study area boundary (part A) using GIS. Sewage wadi area was found at about 9000 m^2. Then apply equations 4.7 and 4.8 to find the total recharge for each year from wastewater discharge into the wadi.

Recharge from Wastewater flow in wadi (**$R_{\text{Sew-Nab}}$**):

$$R_{\text{Sew-Nab}}\ (m/day) = \frac{Q_{\text{Sew-Nab}}\ (m^3/day) \times RC_{\text{Sew-Nab}}}{A_{\text{Sew-Nab}}\ (m^2)} \quad \text{………..…................... (4.7)}$$

$$R_{\text{Sew-Nab}}\ (m^3/year) = Q_{\text{Sew-Nab}}\ (m^3/day) \times RC_{\text{Sew-Nab}} \times 365 \frac{day}{year} \quad \text{………..... (4.8)}$$

Where

$A_{\text{Sew-Nab}}$ (m^2): wadi area within the study area boundary (part A)

The results for **$R_{\text{Sew-Nab}}$** calculation are listed in Table 4.6.

Table 4.6: Recharge from Wastewater Flow in Wadi

Year	$Q_{Sew\text{-}Nab}$ (m^3/day)	$R_{Sew\text{-}Nab}$	
		(m/day)	(m^3/year)
2005	7634	0.00848	27864
2006	8016	0.00891	29257
2007	8416	0.00935	30720
2008	8837	0.00982	32256
2009	9279	0.01031	33869
2010	9743	0.01083	35562
2011	10230	0.01137	37341
2012	10742	0.01194	39208
2013	11279	0.01253	41168
2014	11843	0.01316	43226

4.4.3 Recharge from water networks ($\mathbf{R_{Wat\text{-}Net}}$)

To estimate recharge from water networks ($\mathbf{R_{Wat\text{-}Net}}$), the following was applied:

A. Find communities that are located within the study area boundary (part A). The communities are Ein Shibli, Beit Hasan, Shihda and Hamalan, An Nassariya, Kirbet Tall al Ghar, Al'aqrabaniya, Wadi Al-Faria, Ras Al-Faria and Al-Faria Camp. Distribution of these communities is shown in Figure 4.9.

B. The Populations in each community are approximated.

C. Water consumptions for these communities from year 2005 to 2014 are assumed to be 70l/c.d.

D. Availability of water networks in each community are clarified in table 4.7 which summarizes the availability of water network in study area communities based on PCBS in 2013.

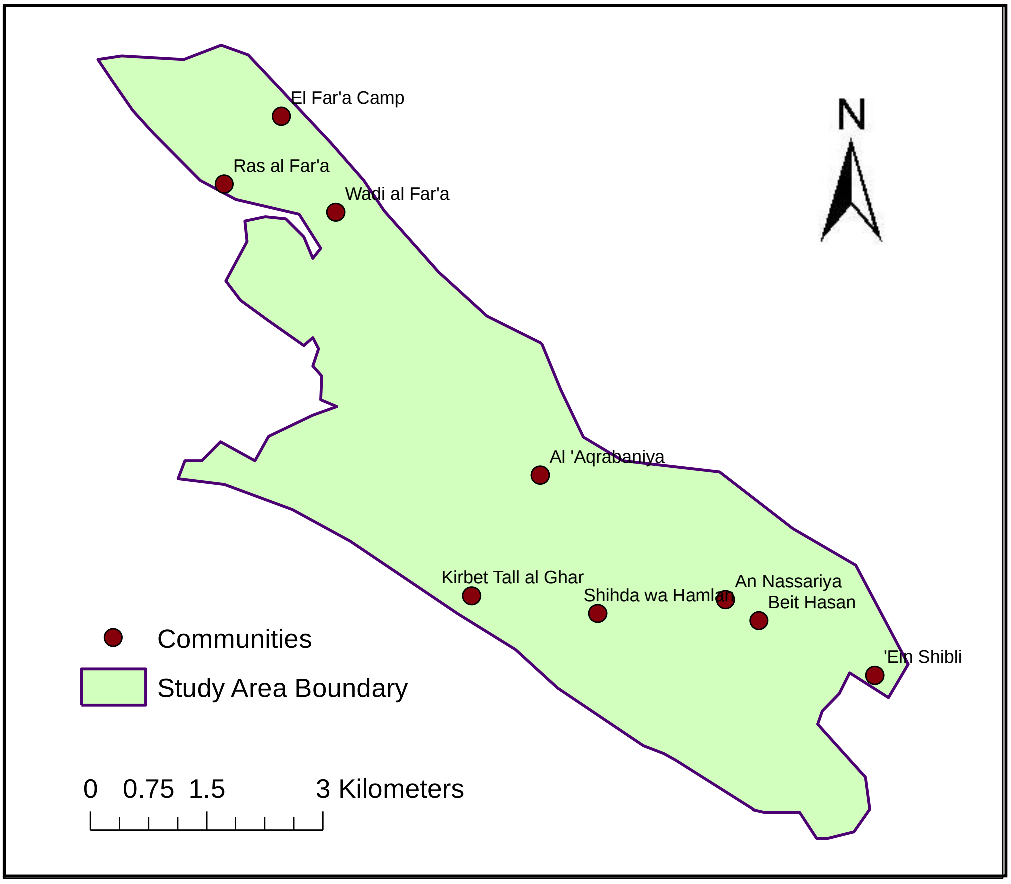

Figure 4.9: Communities in study area boundary (part A).

E. Get water that releases from networks in each community from 2005 to 2014; and the water that releases from networks in each community. Sum-up all water that releases from networks for all considered communities in each year to obtain $Q_{\textbf{Wat-Net}}$. Assume network loss coefficient ($F_{\textbf{Wat-Net}}$) at about 35%. Apply Equation 4.9 to get $Q_{\textbf{Wat-Net}}$.

$$Q_{Wat\text{-}Net}\ (m^3/day) = WC\ (L/c.d) \times P\ (c) \times \frac{F_{Wat-Net}}{(1-F_{Wat-Net})} \times \frac{1\ m^3}{1000\ liter} \quad \text{........(4.9)}$$

Where

WC (l/c.d): Water consumption (liter/capita .day)

P: population (capita)

$F_{\textbf{Wat-Net}}$: network loss coefficient

Table 4.7: Availability of water networks (PCBS, 2013)

Community	water network
'EinShibli	available
BeitHasan	available
Shihdawa Hamlan	no data
An Nassariya	available
Kirbet Tall al Ghar	no data
Al 'Aqrabaniya	available
Wadi al Far'a	available
Ras al Far'a	available
El Far'a Camp	available

F. Assume recharge coefficient from water network losses ($RC_{\textbf{Wat-Net}}$) about 25%.

G. Land use shapefile for Faria catchment is available and GIS is used to find the built up areas (part A). Assume built up area growth rate is 1.005.

$$R_{\text{Wat-Net}}\ (\text{m/day}) = \frac{Q_{\text{Wat-Net}}\ (\text{m}^3/\text{day}) \times RC_{\text{Wat-Net}}}{A_{\text{Wat-Net}}\ (\text{m}^2)} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ (4.10)$$

$$R_{\text{Wat-Net}}\ (\text{m}^3/\text{year}) = Q_{\text{Wat-Net}}\ (\text{m}^3/\text{day}) \times RC_{\text{Wat-Net}} \times 365 \frac{\text{day}}{\text{year}} \ldots\ldots\ldots (4.11)$$

Where

$A_{\textbf{Wat-Net}}$ (m^2): built up area within the study area boundary (part A).

After applying all the previous steps recharge from network losses was computed from year 2005 to 2014 as shown in table 4.8.

Table 4.8: Recharge from water networks

Year	$Q_{Wat-Net}$ m^3/day	Urban Area m^2	$R_{Wat-Net}$	
			m/day	m^3/year
2005	465	737253	0.000158	42397.77
2006	479	740939	0.000161	43669.7
2007	493	744644	0.000165	44979.79
2008	508	748367	0.00017	46329.19
2009	523	752109	0.000174	47719.06
2010	539	755870	0.000178	49150.63
2011	555	759649	0.000183	50625.15
2012	571	763447	0.000187	52143.91
2013	589	767264	0.000192	53708.22
2014	606	771101	0.000197	55319.47

4.4.4 Recharge from storm water ($R_{Run\ off}$)

To estimate recharge from runoff many processes were achieved:

A. Delineate sub catchments that contribute in runoff generation at study area boundary then find centroids for these sub catchments.

B. Find distances from each centroid to all rainfall stations (Tubas, Talluza, Beit Dagan, Nablus and Faria stations) to estimate the rainfall values at centroid using IDW method of each sub catchment (Figure 4.10).

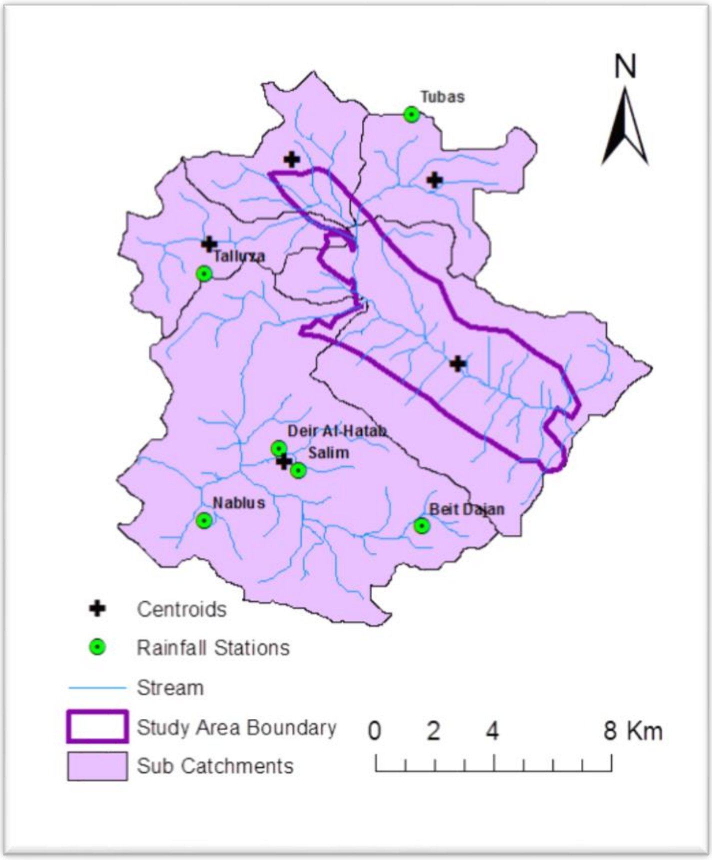

Figure 4.10: Recharge from runoff surface water

$$\widehat{P}=\frac{\sum_{i=1}^{N}\left(\frac{P_i}{d_i^2}\right)}{\sum_{i=1}^{N}\left(\frac{1}{d_i^2}\right)} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4.12)$$

Where $\mathbf{d_i}$ represents distances from ungauged rainfall point (in these case, centroids into all measurement points) and $\mathbf{P_i}$ is the precipitation. centroids and $\mathbf{d_i}$ were found using GIS. Rainfalls in each subcatchment are defined.

C. Shadeed (2005) reported that the runoff coefficient for Faria catchment ranges from 4.5% to 15% of the annual rainfall. In this study the runoff coefficient was assumed at 2.5% since the actual runoff coefficient was decreased due to the interception processes.

The runoff values are calculated using the following equation

Runoff volume ij= runoff coefficient×A_j×rainfall $_{ij}$ (i: year, j: subcatchment ID) ……………………..……………..………… (4.13)

D. To estimate recharge from runoff (**$R_{Run\text{-}off}$**). Assume recharge coefficient (**$RC_{Run\text{-}off}$**) from runoff is 15%.

Total recharge runoff at year i (m^3/yr) = $RC_{Run\text{-}off}$× ∑ Runoff volume ij

E. After calculating the Total wadi area (**$A_{T\text{-}W}$**) and wadi area within study area boundary (**$A_{B\text{-}W}$**), Recharge from runoff (**$R_{Run\text{-}off}$**) was estimated.

$$R_{Run\text{-}off}\ (m^3/yr) = \frac{\text{Total Recharge runoff at year i}(m^3/yr)\times A_{B-W}\ (m^2)}{A_{T-W}\ (m^2)} \quad \text{…..…. (4.14)}$$

$$R_{Run\text{-}off}\ (m/day) = \frac{\text{Recharge runoff}\ (m^3/yr)}{A_{B-W}\ (m^2)\times 365\frac{day}{yr}} \quad \text{………………………….……… (4.15)}$$

Recharge from run off (**$R_{Run\text{-}off}$**) is shown in table 4.9.

Table 4.9: Recharge from runoff water

Year	total runoff	total recharge	Recharge to area (m^3/yr) $R_{Run\text{-}off}$	Recharge to area (m/d) $R_{Run\text{-}off}$
2005/2006	2,823,715.2	423,557.3	110,429.9	0.000851001
2006/2007	2,168,742.4	325,311.4	84,815.2	0.000653607
2007/2008	1,687,686.5	253,153.0	66,002.1	0.000508629
2008/2009	2,524,660.7	378,699.1	98,734.5	0.000760873
2009/2010	2,565,768.2	384,865.2	100,342.1	0.000773262
2010/2011	2,319,595.0	347,939.3	90,714.8	0.000699071
2011/2012	2,647,131.6	397,069.7	103,524.1	0.000797783
2012/2013	2,583,583.9	387,537.6	101,038.8	0.000778631
2013/2014	1,715,168.2	257,275.2	67,076.8	0.000516911
2014/2015	2,646,918.6	397,037.8	103,515.7	0.000797718

4.4.5 Recharge from agricultural return flow ($R_{Agr-Ret}$)

In agricultural areas recharge occurs from irrigation and irrigation Return Flow. To estimate recharge quantities, consumed water for irrigation were estimated. Irrigation recharge coefficient of 3% ($\mathbf{RC_{Agr-Ret}}$) was assumed. Total agricultural area in Al-Faria was found at 20,110,376 m^2; apply equation 4.16 to find $\mathbf{R_{Agr-Ret}}$; results are tabulated in table 4.10.

$$R_{Agr\text{-}Ret}\,(m/d) = \frac{\text{Consumption (wells,springs) } (m^3/yr) \times RC_{Agr-Ret}}{\text{Agriultural area } (m^2) \times 365 \frac{day}{yr}} \text{.......... (4.16)}$$

Table 4.10: Recharge from Irrigation (PWA, 2011)

		$R_{Agr-Ret}$	
Year	Consumption (m^3/yr) (pumping from wells and springs)	m/day	m^3/year
2005	7,853,188	3.20962×10^{-5}	235596
2006	8,686,026	3.55001×10^{-5}	260581
2007	5,296,789	2.16482×10^{-5}	158904
2008	2,114,701	8.64285×10^{-6}	6 3441
2009	1,328,608	5.43007×10^{-6}	39858
2010	2,023,777	8.27124×10^{-6}	60713
2011	2,782,134	1.13707×10^{-5}	83464
2012	2,424,905	9.91067×10^{-6}	72747
2013	3,021,124	1.23474×10^{-5}	90634
2014	2,823,684	1.15405×10^{-5}	84711

4.4.6 Recharge from Cesspits (R_{Cess})

A. Find freshwater consumption from year 2005 to 2014 (it was computed in section 4.4.3).

B. Find potential produced Wastewater (m^3/day), it was assumed to be 75% of freshwater consumption.

C. Find amount of cesspits wastewater infiltration (m^3/day), it was assumed to be 50% of Potential Produced Waste Water.

Recharge values from cesspits in m/day and m^3/year are computed, (Table 4.11).

Table 4.11: Recharge from cesspits

years	R_{Cess}	
	m/day	m^3/year
2005	0.000438905	118108
2006	0.000449823	121651
2007	0.000461012	125301
2008	0.00047248	129060
2009	0.000484233	132932
2010	0.000496279	136920
2011	0.000508624	141027
2012	0.000521277	145258
2013	0.000534244	149616
2014	0.000547533	154104

The recharge from all components was distributed into different zones. Figure 4.11 shows 4 recharge zones in the study area and Table 4.12 summarizes recharge calculation from all components while Table 4.13 describes the recharge source of each zone.

Dividing the Zones were mainly based on the land use and the source of pollution, the zones are; zone 1, Zone 2-A, zone 2-B, Zone 2-C, Zone 3-A, zone 3-B, Zone 3-C and zone 4.

Table 4.12: Recharge from all components (m/day)

Year	wadi	Urban built-up areas			Agricultural areas			others		
	Zone 1	Zone 2-A	Zone 2-B	Zone 2-C	Zone 3-A	Zone 3-B	Zone 3-C	Zone 4-A	Zone 4-B	Zone 4-C
2005	0.009333	0.001043	0.000973	0.000902	0.000479	0.000408	0.000338	0.000447	0.000376	0.000306
2006	0.00956	0.000961	0.000901	0.000841	0.000385	0.000325	0.000265	0.00035	0.00029	0.000229
2007	0.00986	0.00088	0.00083	0.00078	0.000275	0.000225	0.000175	0.000254	0.000204	0.000153
2008	0.01058	0.001085	0.001015	0.000945	0.000452	0.000382	0.000312	0.000443	0.000373	0.000303
2009	0.011083	0.001118	0.001046	0.000974	0.000465	0.000393	0.000322	0.00046	0.000388	0.000316
2010	0.011525	0.001078	0.001012	0.000947	0.000412	0.000346	0.00028	0.000404	0.000338	0.000272
2011*	0.012165	0.001151	0.001079	0.001008	0.000471	0.000399	0.000328	0.00046	0.000388	0.000316
2012	0.012714	0.00117	0.001098	0.001026	0.000471	0.000399	0.000327	0.000461	0.000389	0.000317
2013	0.013049	0.000962	0.000914	0.000866	0.000249	0.000201	0.000152	0.000236	0.000188	0.00014
2014	0.013956	0.001238	0.001163	0.001087	0.000505	0.00043	0.000355	0.000494	0.000419	0.000343

*year 2011 is the year selected for the study

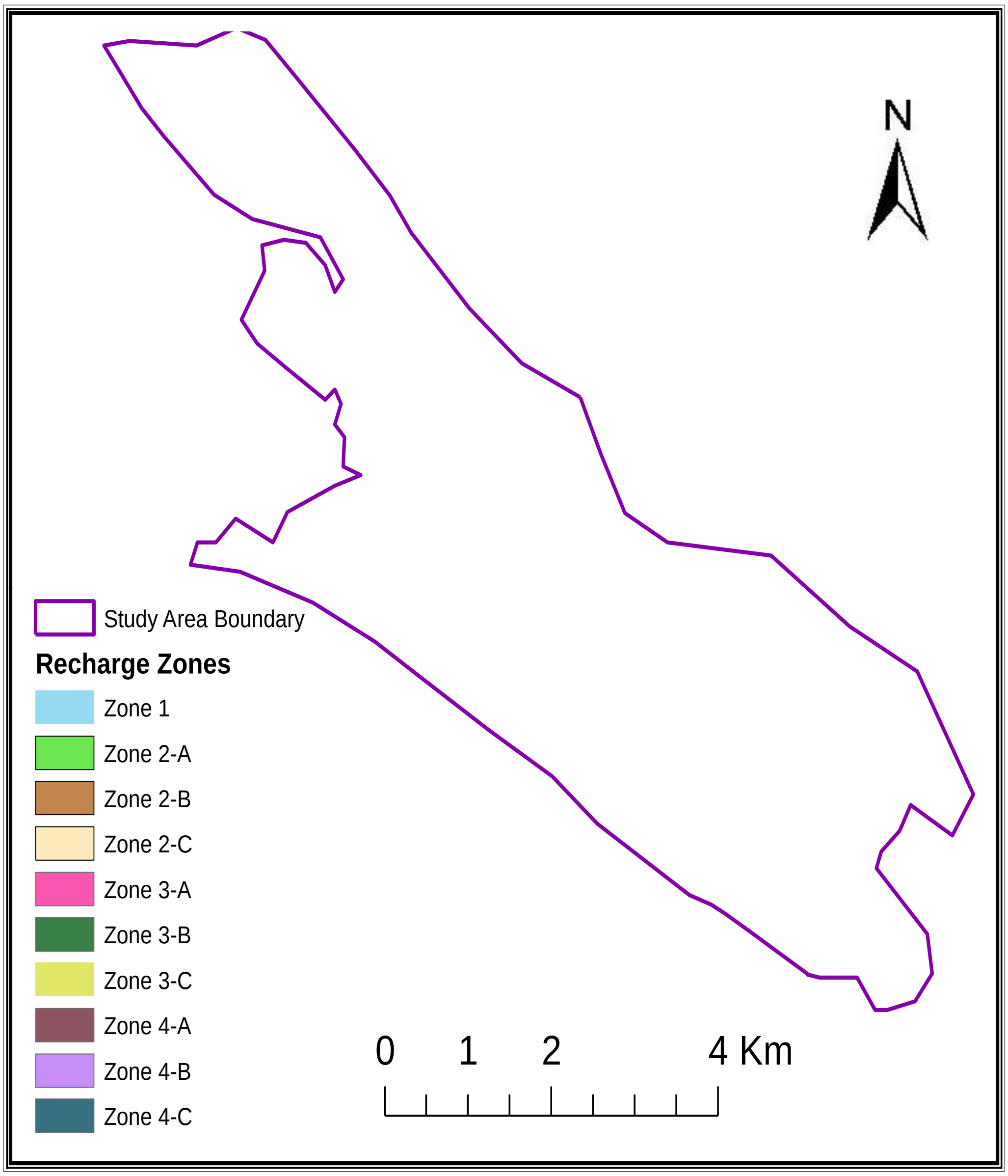

Figure 4.11: Recharge zones and

Table 4.13: Recharge source in each Zone

Land use	Zone code	Recharge source	Description
wadi	Zone 1	$(R_{Sew\text{-}Nab})+(R_{Run\text{-}off})$	recharge comes from Nablus sewage and runoff
Built-up areas	Zone 2-A	$(R_{Wat\text{-}Net})+(R_{Cess})+(R_{Rain\ -A})$	recharge comes from water network, sewage (cesspit) and rainfall for zone A
Built-up areas	Zone 2-B	$(R_{Wat\text{-}Net})+(R_{Cess})+(R_{Rain\ -B})$	recharge comes from water network, sewage (cesspit) and rainfall for zone B
Built-up areas	Zone 2-C	$(R_{Wat\text{-}Net})+(R_{Cess})+(R_{Rain\ -C})$	recharge comes from water network, sewage (cesspit) and rainfall for zone C
Agricultural areas	Zone 3-A	$(R_{Agr\text{-}Ret})+(R_{Rain\ -A})$	recharge comes from irrigation and rainfall for zone A
Agricultural areas	Zone 3-B	$(R_{Agr\text{-}Ret})+(R_{Rain\ -B})$	recharge comes from irrigation and rainfall for zone B
Agricultural areas	Zone 3-C	$(R_{Agr\text{-}Ret})+(R_{Rain\ -C})$	recharge comes from irrigation and rainfall for zone C
Others (not agricultural or built-up areas)	Zone 4-B	$(R_{Rain\ -A})$	recharge comes from rainfall for zone A
Others (not agricultural or built-up areas)	Zone 4-C	$(R_{Rain\ -B})$	recharge comes from rainfall for zone B
Others (not agricultural or built-up areas)	Zone 4-A	$(R_{Rain\ -C})$	recharge comes from rainfall for zone C

4.5 Aquifer Properties

Initial values for hydraulic conductivity are assumed at 0.01-5 m/day for all active cells based on hydraulic properties at different wells (PWA, 2011). It will be adjusted later on by model calibration.

4.6 Pumping

There are 16 pumping wells and 3 springs located within the study area boundaries (Figure 4.12). However, annual pumping rates as well as the spatial distribution of these wells and springs are available. Pumping and discharge from wells and springs in 2011 are listed in Table 4.14.

Table 4.14: Pumping and discharge from wells and springs for year 2011 (PWA, 2011)

ID of wells and springs	Pumping/discharge (as observed) m^3/yr
18-18/002	0
18-18/005	0
18-18/011A	-97090
18-18/011B	-242725
18-18/013	-170090
18-18/014	0
18-18/023	-271925
18-18/026	0
18-18/027	-20075
18-18/030	0
18-18/031	-3650
18-18/031A	-129575
18-18/034	270100
18-18/035	- 146000
18-18/036	-328500
18-18/039	- 474500
El Faria	0
Abu Saleh	0
Miska	-75923

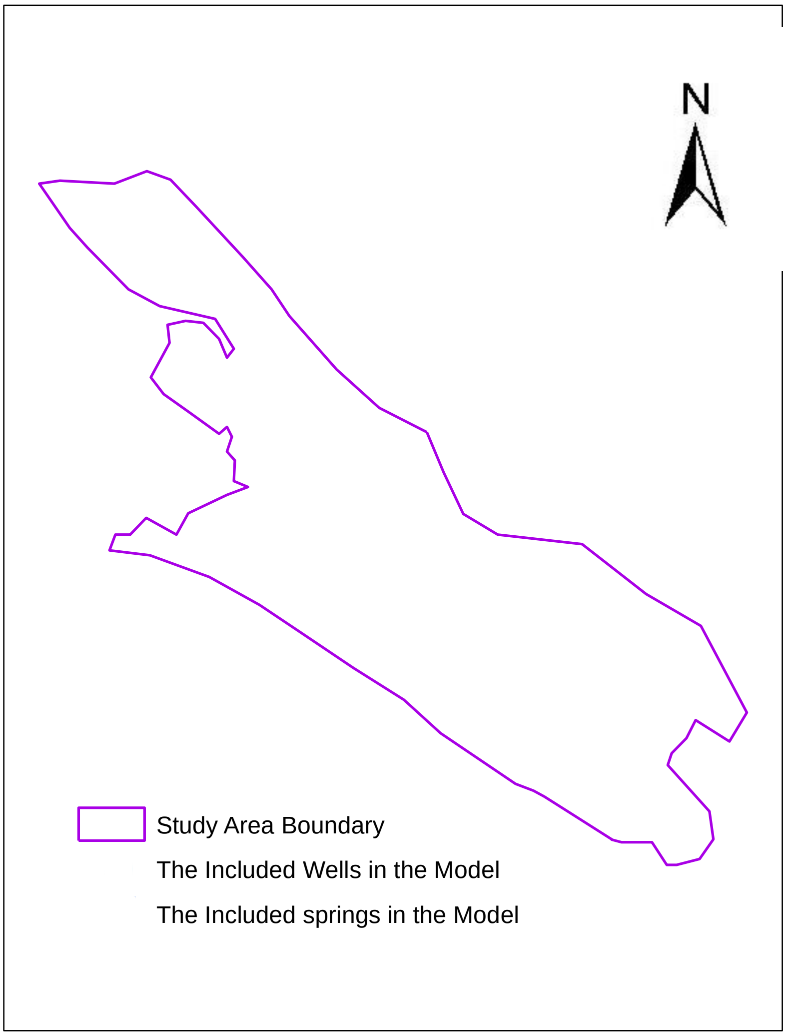

Figure 4.12: The wells and springs that are included in the model

There are many agricultural wells within the aquifer area. All the licensed wells within the study area boundary that pump from Quaternary are agricultural wells (PWA, 2011).

4.7 Observed Water Levels

The water level in the quaternary aquifer (modeled area) was measured and estimated using two wells (well 18-18/016 and well 18-18/030). The water levels of the two observation wells were used for model calibration.

However, the records show many outranges data, these outranges were modified according to the water level trend in the same well.

Figure 4.13 and 4.14 show the historical water level in the two wells in the modeled area.

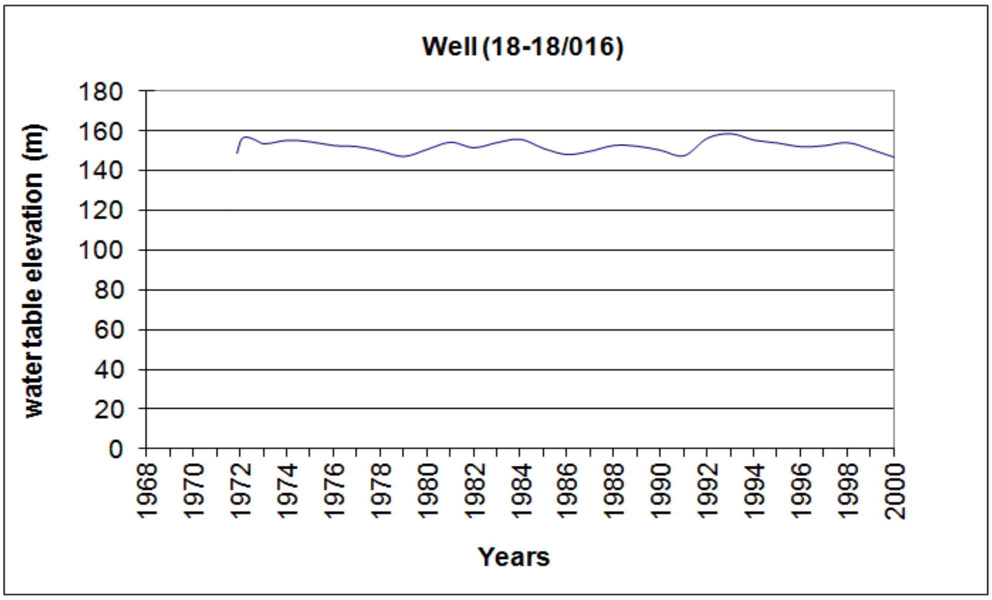

Figure 4.13: Water table for observation well18-18/016

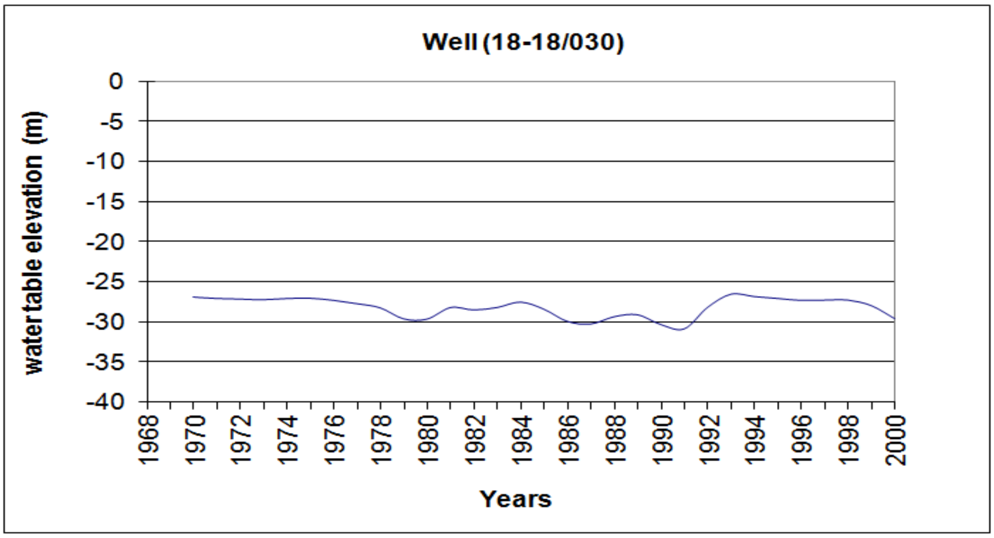

Figure 4.14: Water table for observation well18-18/030

4.8 Starting Head (Initial Heads)

To solve the partial differential equation by MODFLOW, initial water level distribution for the present Quaternary aquifer, interpolating of the two monitoring wells was performed; these initial values were modified by the steady state model. The water level distribution by steady state model was used in the MODPATH model.

4.9 Water Balance

The recharge was found in 2011 (The selection of year 2011 depends on the availability of modeling related data on that year) as inflow from different sources at 4.9 Mm^3/yr. Pumping from wells was 2.7 Mm^3/y while discharge from springs was 0.08 Mm^3/yr. In total the outflow from wells and springs was estimated to be 2.78 Mm^3/yr.

Inflow – outflow = 2.12 Mm^3/yr. This difference is assumed as the inflow or outflow to other aquifers, which is the boundary flow.

Chapter Five

Development of the MODFLOW Model for the Study Area

5.1 Introduction

A conceptual model was carried out and a steady state groundwater flow model for upper part of the quaternary aquifer of Al-Faria catchment was formulated in order to be used and utilized with MODPATH.

The research is compromised from major steps and these are the characterization of the study area, collecting and analyzing data using GIS and Excel, conceptual modeling, numerical groundwater flow model (MODFLOW), particle tracking model MODPATH, assessment the situation and decision making.

5.2 Development of the MODFLOW

5.2.1 General Introduction about MODFLOW

MODFLOW is a three-dimensional finite-difference groundwater model used for groundwater flow simulation. It simulates confined, unconfined, or combined aquifer and to simulate steady state or transient flow system. It is able to simulate flow from external stresses, such as flow to wells, recharge, evapotranspiration, flow to drains, and flow through river beds (Harbaugh, 2005).

The model applied for Faria represents steady state unconfined aquifer layer (quaternary) with quaternary average thickness of 80 m.

5.2.2 MODELING PERIOD

The main objective of this study is to track contaminants applying steady state model, which was compiled in MODPATH. The conceptual model was prepared for years from 2005-2014 and 2011 was selected (The selection of year 2011 depends on the availability of modeling related data on that year). The steady state model represents the status of the unconfined aquifer in 2011. Therefore, pumping and recharge in 2011 are used to produce average water levels distribution.

5.2.3 MODEL GRIDS

The model domain is uniformly discretized into 200 columns by 200 rows forming small grids about 52 m. All cells located outside the model domain are considered inactive cells. As a result, there are 12698 active cells out of 40000 cells as shown in Figure 5.1.

Figure 5.1: Discretization of the Model domain of the study area

5.2.4 Model Calibration

Calibration is the process that is performed to adjust the model parameters. This is done until the model output matches the observed data. Calibration of the hydraulic conductivity is done until potentiometric head at certain locations matches the measured values (Bear, 1979).

There are different methods for calibration including manual (trial and error calibration) and automated calibration. The automated is developed in ordered to minimize the uncertainties associated with user's subjectivity (Anderson & Woessner, 1992).

The model coefficients and constants are usually estimated by solving the model equation for the parameters of interest after supplying observed values of both the dependent and independent variables. The actual travel patterns are conducted to obtain the observed values of variables. The estimation process is a trial and error effort that seeks the parameter values which have the greatest probability or maximum likelihood of being accurate within acceptable tolerance of error (Anderson & Woessner, 1992).

5.2.5 Steady State Calibration

In steady state model, water level, pumping rate, recharge rate, boundary conditions within the model period 2011 are entered. Then, the model domain is divided into several zones according to the geological outcropping, available well logs and the understanding of the flow regime in the aquifer. In each zone, a roughly estimated hydraulic conductivity is given and the model is run to obtain the first simulated heads. The simulated heads in all monitoring wells are then compared with measured values. Accordingly, the hydraulic conductivities in model zones are re-adjusted in order to match the observed values. The hydraulic conductivity values are ranging between 0.1 to 3.4 m/day according to model calibration. The final computed versus observed water heads in monitoring wells are shown in Figure 5.2. The figure presents the two points that were calibrated. Only these two wells provided sufficient information and were observed and calibrated. At this stage, the hydraulic conductivity distribution of ‘’Quaternary of Faria’’ aquifer is achieved.

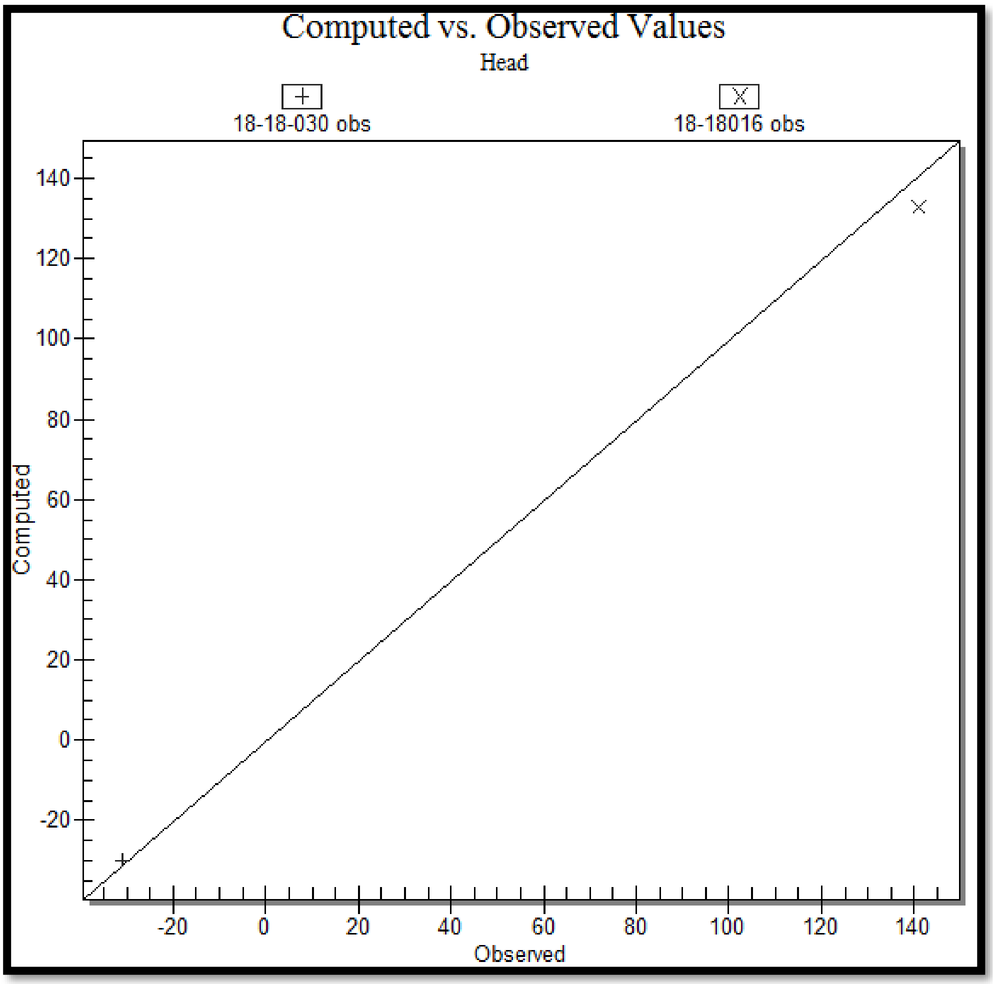

Figure 5.2: Computed verses observed head values, steady state model

5.3 Water levels, Flow direction and Water Budget

1- Water levels

Water levels for the flow model ranges between 35.7 below mean sea level to 176.65 m above mean sea level (Figure 5.3).

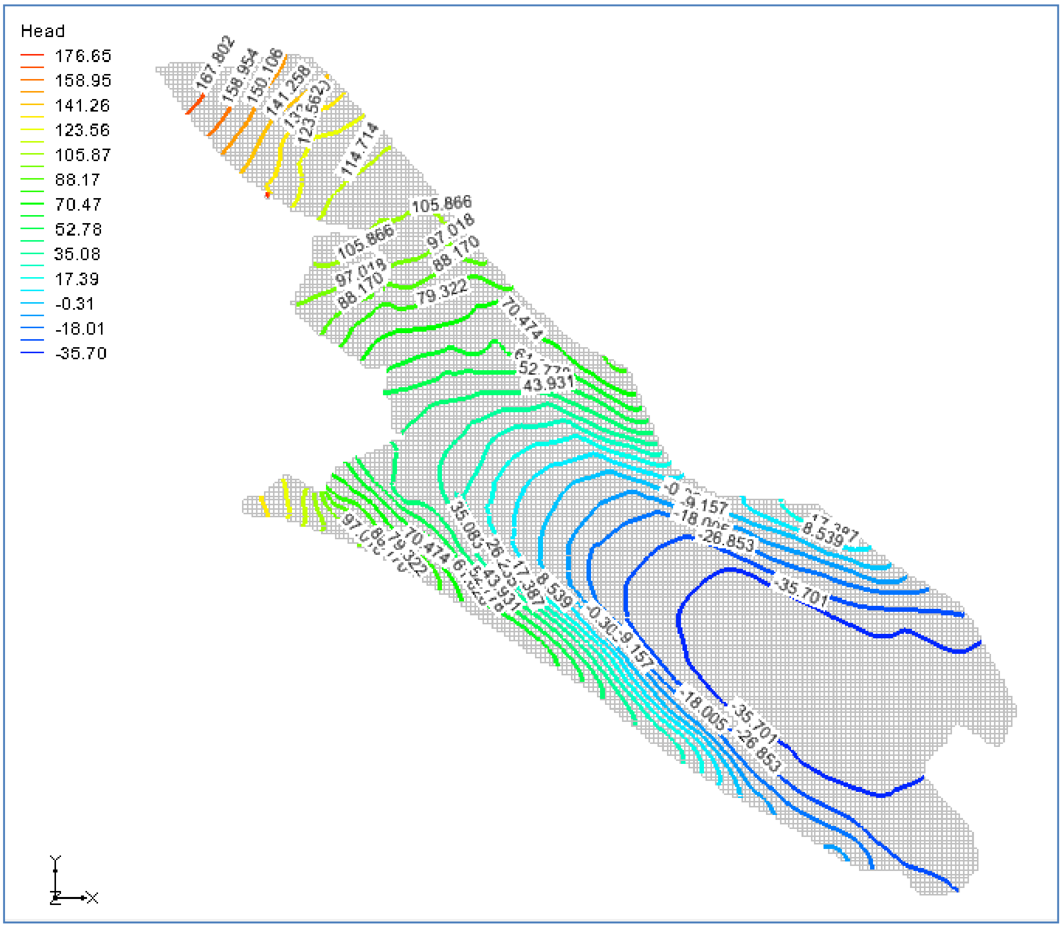

Figure 5.3: Simulated groundwater level in the study area

2- Flow direction

MODPATH was developed to simulate steady state groundwater flow model. The flow values vary from 0 to 800 (m^3/day). Figure 5.4 clarifies the flow direction with magnitudes.

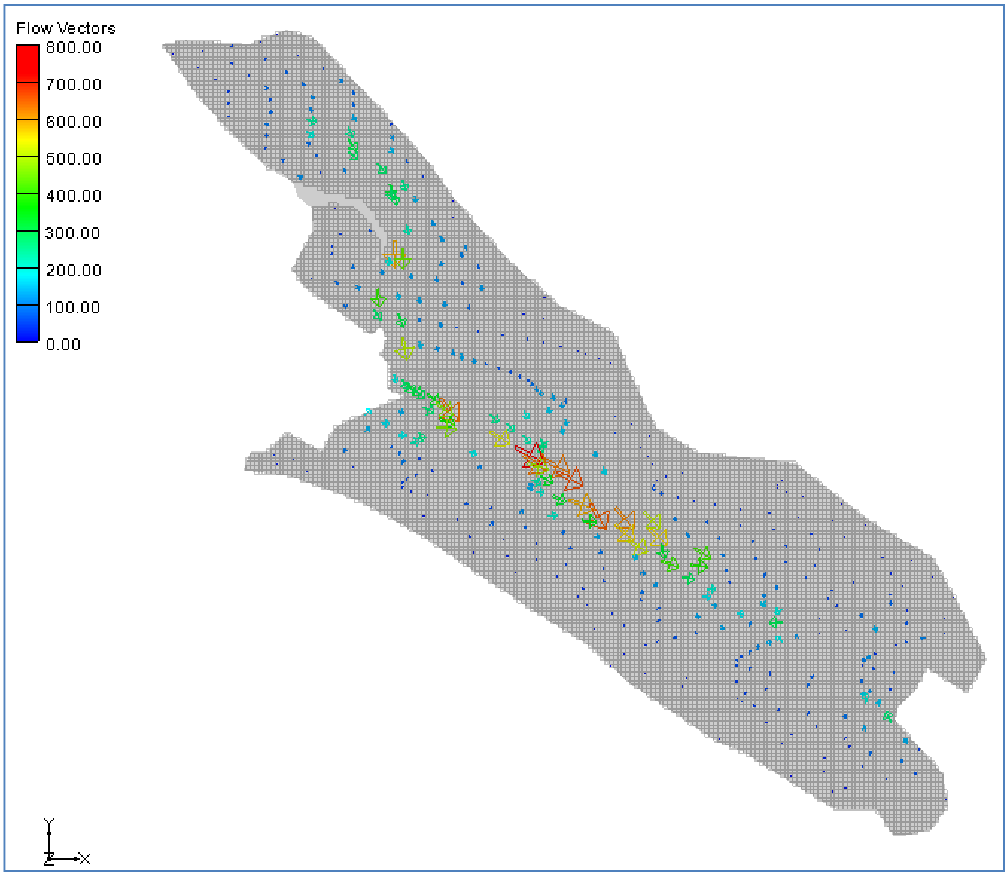

Figure 5.4: Groundwater Flow direction resulted from the model

3- Water Budget

Because it is a steady state model then inflow= outflow;

Model inflow, which is represented by recharge, is about 16252 m^3/day while model outflow, which represents pumping from wells and springs, is about 16251 m^3/day.

Figure 4.1 of the previous chapter indicated that there is contact between Quaternary and the following layers Eocene: Upper aquifer, Lower Aquifer and Yata formation. Figure 5.5 clarifies the flow budget of the model.

Flow Budget

Cells | Zones

Number of selected cells: 0 (data for all cells is displayed below)

	Flow In	Flow Out
Sources/Sinks		
Storage		
Constant heads	0.0	0.0
Drains	0.0	-99.63540649414
Drains (DRT)		
General heads		
Rivers		
Streams		
Streams (SFR2)		
Wells	0.0	-16152.0
Multi-Node Wells		
Recharge	16252.0137707	0.0
Evapotranspiration		
Evapotranspiration (ETS)		
Lake		
Total Source/Sink	**16252.0137707**	**-16251.63540649**
Zone Flow		
Top		
Bottom		
Left	0.0	0.0
Right	0.0	0.0
Back	0.0	0.0
Front	0.0	0.0
Total Zone Flow	**0.0**	**0.0**
TOTAL FLOW	**16252.0137707**	**-16251.63540649**
Summary	**In - Out**	**% difference**
Sources/Sinks	**0.3783642053604**	**0.0023281337015**
Cell To Cell	**0.0**	**0.0**
Total	**0.3783642053604**	**0.0023281337015**

Figure 5.5: Water Flow budget as modeled for the study aquifer

Chapter Six

Development of the MODPATH Model for the Study Area

6.1 General Introduction about MODPATH

MODPATH platform has been applied to MODFLOW; it is a post processing program which is a useful tool to understand flow patterns in the simulated groundwater flow system using MODFLOW. It is used for delineating capture zone for source and drawing flow pathlines of contaminants simulated with MODFLOW (Pollock, 1994).

MODPATH can be used for forward and reverse particle tracking. MODPATH used particle tracking algorithm for even steady state or transient flow model but in the present study MODPATH is implemented for steady state flow model or field.

Main options included in MODPATH analysis; backward tracking from each of several wells or drains (the capture zone analyses) and forward tracking from particle release points.

The particle tracking algorithm used by MODPATH can be implemented for either steady state or transient flow fields but in the present study the steady state flow model is used.

Capture zone, is the area contributing flow to a particular well and within which groundwater will migrate to the pumping well. It can be delineated using groundwater flow models. In the present study, steady state groundwater flow model using MODFLOW and MODPATH were used to delineate the capture zone.

Defining capture zones for water resources can be an efficient tool to get wellhead protection plan. Capture zones (figure 6.1) assist in the protection of groundwater pollution and to show the risk of contamination from any activities that might cause pollution in the area. A pumped well derives water from a capture zone in the groundwater surrounding the well therefore when the activity is close, the risk will increase.

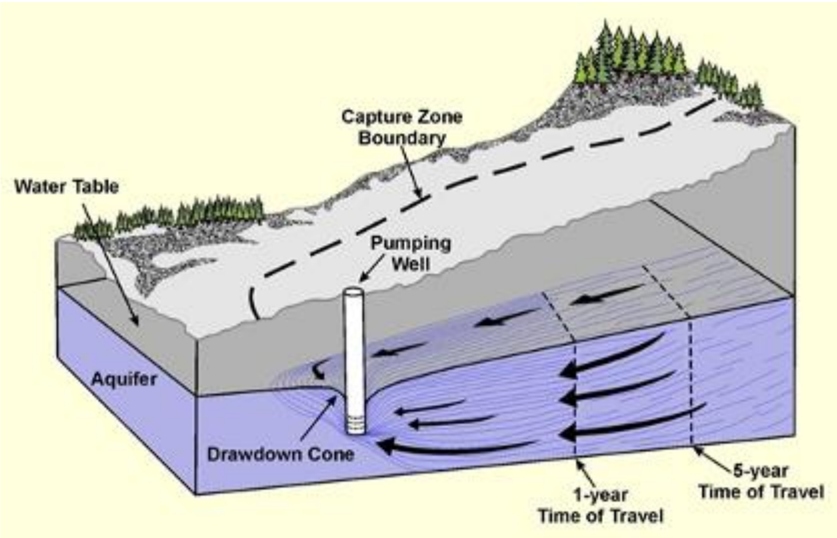

Figure 6.1: Capture Zone

The area in which the velocity vectors (streamlines) intersect the pumped well is the definition of the capture zone while the radial distance from pumped well to the line of zero drawdown is the radius of influence. The capture zone is more limited than the radius of influence or cone of depression that are commonly determined by hydraulic gradient or water level drawdowns (Seaburn, 1989).

6.2 Particle Tracking

MODPATH requires a flow solution before path lines can be computed. MODPATH is used after using MODFLOW which must be run and cell by cell output written to a file. MODPATH also requires MODFLOW head output for any layer that can have a water table within it to be able to compute the velocity components using the cell-by-cell budget information generated by MODFLOW.

For MODPATH to work properly, the contaminants sources should be found and displayed on maps. There are three main contaminants sources: contaminates from wadi Al Faria stream, built up areas (cesspits) and agriculture (pesticides, fertilizers, etc).

The location of each source of contaminates are described in Figure 6.2.

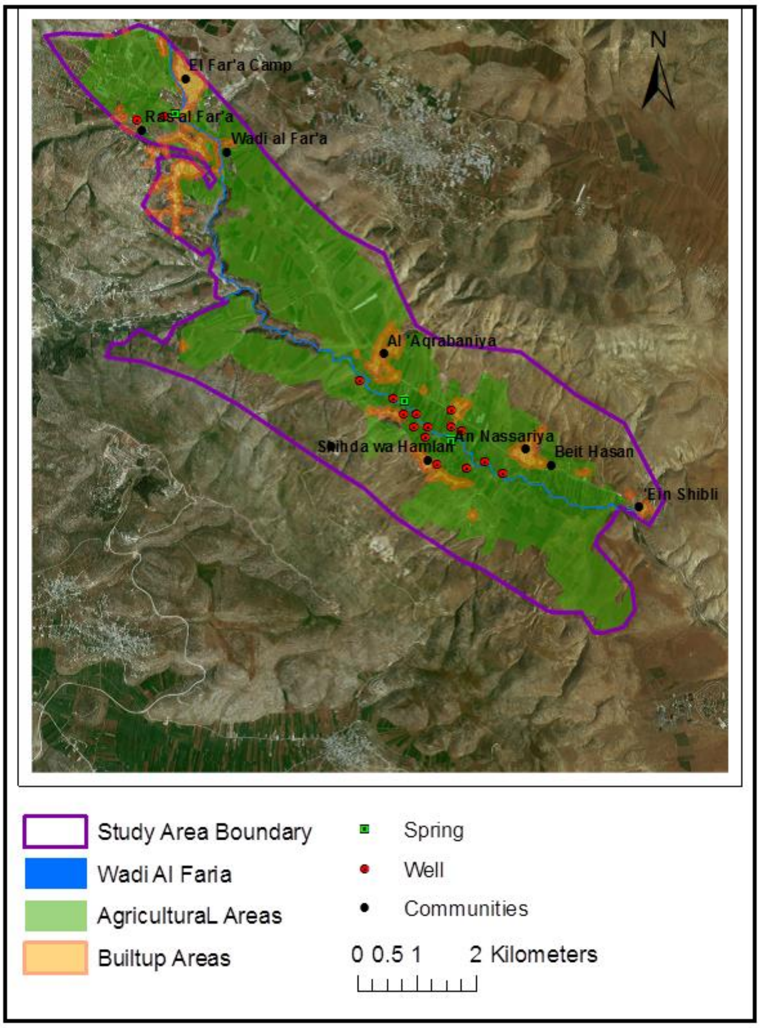

Figure 6.2: Location of each source of contaminants

1- Forward particle tracking

A- Stream

Faria stream that pass through Al-Faria catchment is exposed to pollution from wastewater that discharges from Eastern Nablus and that comes from the neighboring draining lands. Water Quality Modeling for Faria Stream was carried out by Alawneeh, 2013.

The quality parameters are measured and it was found that average Total Kindal Nitrogen (TKN) changed from 233 mg/l at upstream (in the present modeling region) to about 160 mg/l at the downstream. The results point out that the untreated wastewater that discharged at upstream is the major cause for stream pollution (Alawneh, 2013).

Stream particles are tracked using the integrated MODFLOW and MODPATH to study the potentially polluted wells and springs due to this stream. Figures 6.3 and 6.4 clarify the MODPATH results, applied to study area.

General view of all possible path lines of wastewater stream particles (figure 6.3) shows the affected wells. Most of wells that's close to wastewater stream are exposed to pollution.

Path lines of Wastewater stream particles that is reach to well no. 18-18/023 are clarified in figure 6.4.

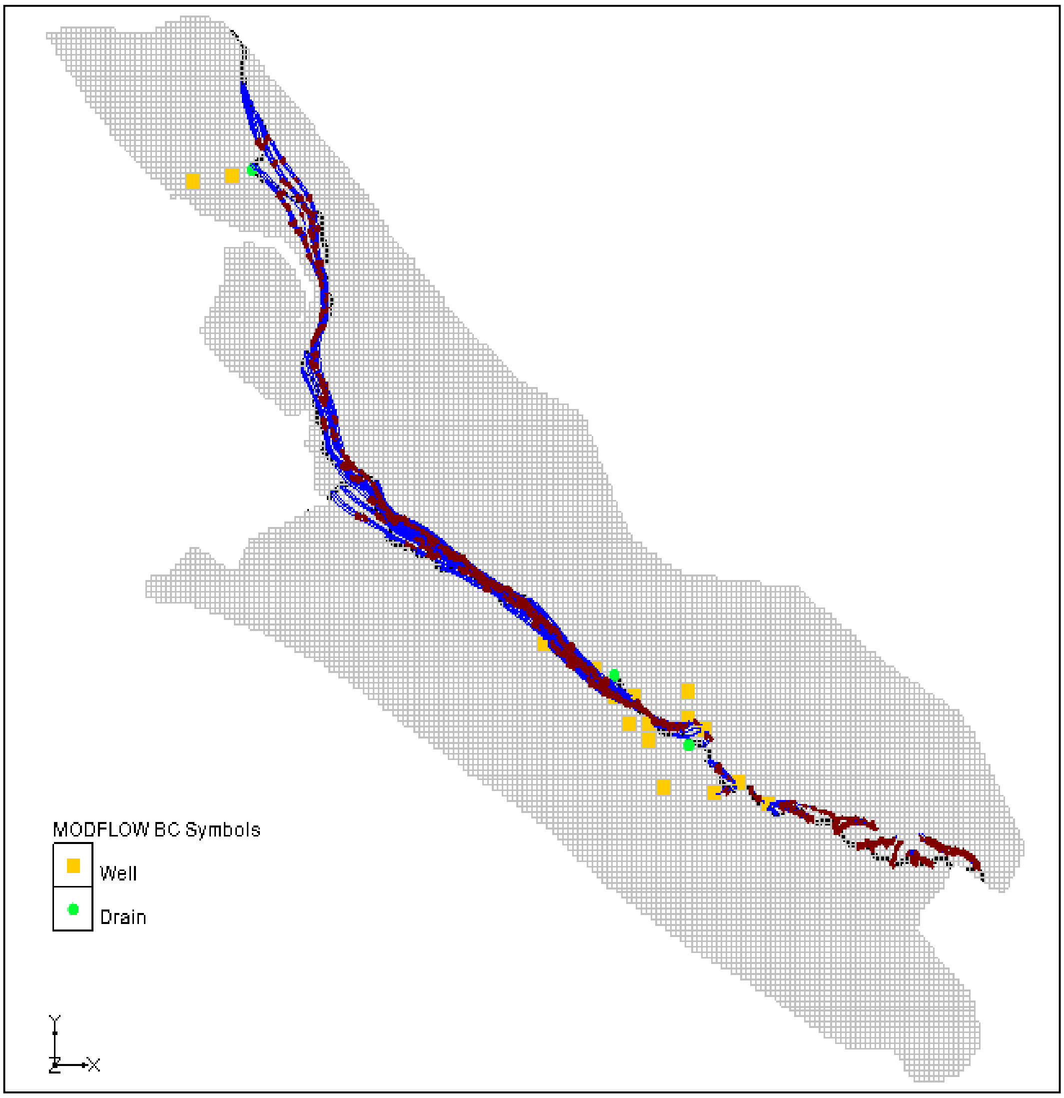

Figure 6.3: Particles path lines of the stream from the upper stream area to wells in the downstream area

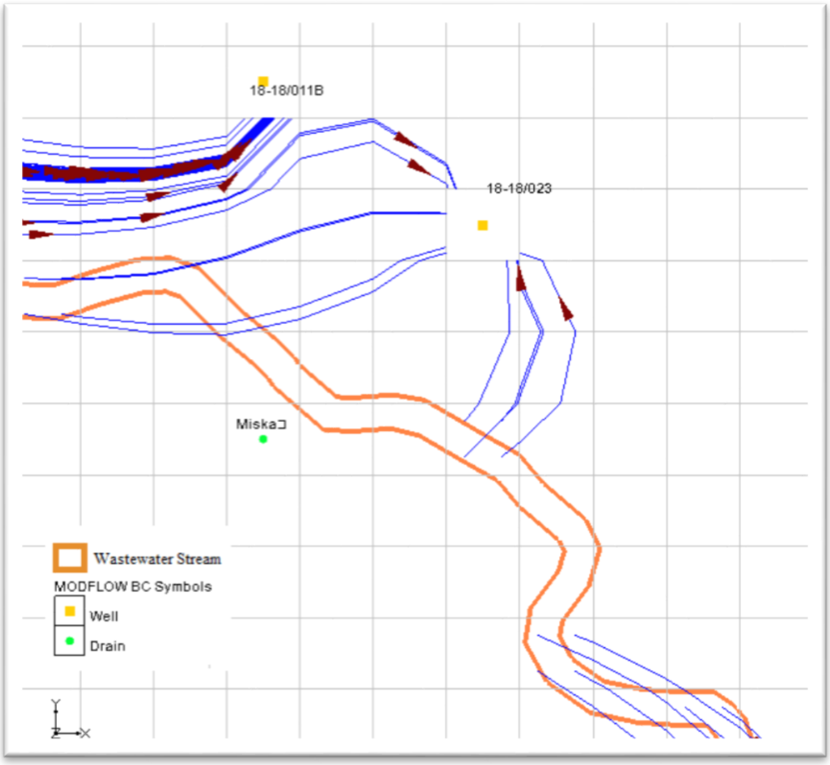

Figure 6.4: Particle tracking of stream to well no. 18-18/023

B- Built-up area

Referring PCBS, 2015 no wastewater networks were found in the built-up areas that are located within the study area. Which means All the houses are using cesspits and that leads to groundwater contamination. These cesspits considered as source of pollutions, therefore, the particles were tracked from cesspits into groundwater wells as shown in figure 6.5 and 6.6.

Built-up areas were allocated and are set as particles to track path lines of sewage flow. The potentially affected water resources were studied using MODPATH.

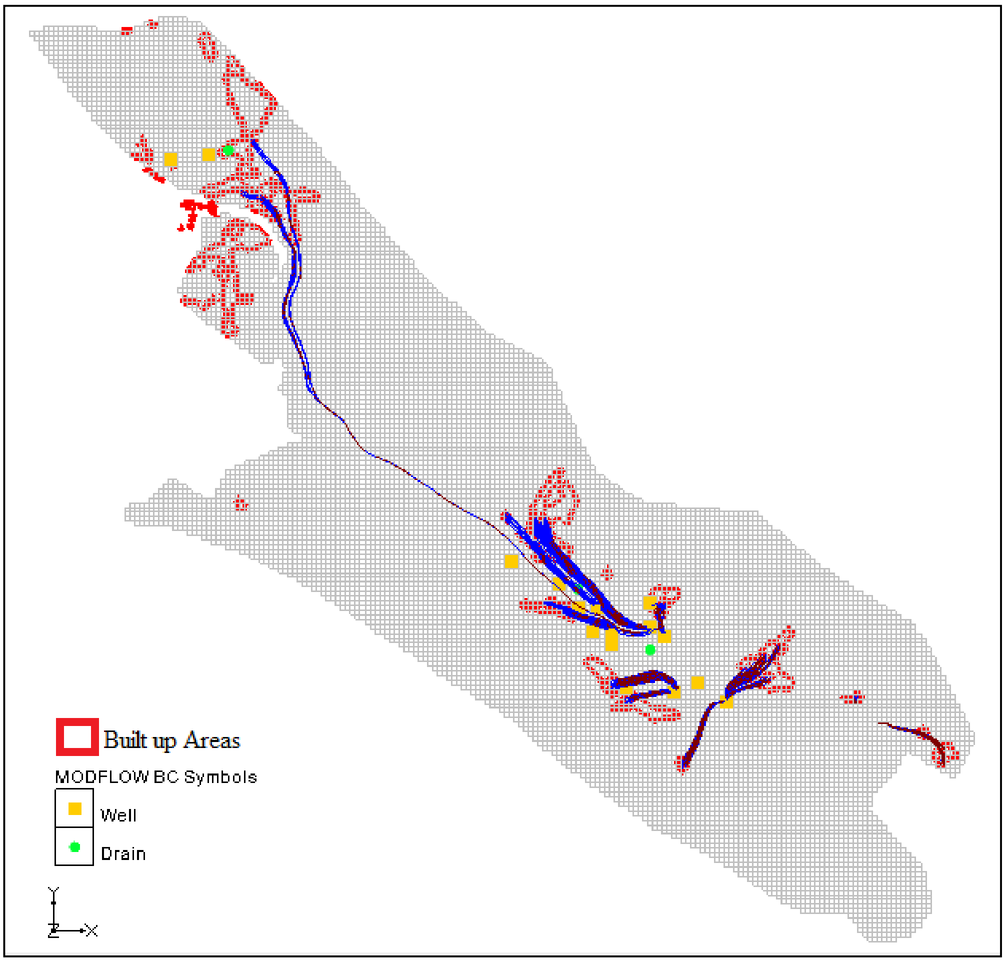

Figure 6.5: General view of particle tracking of the built-up areas toward wells

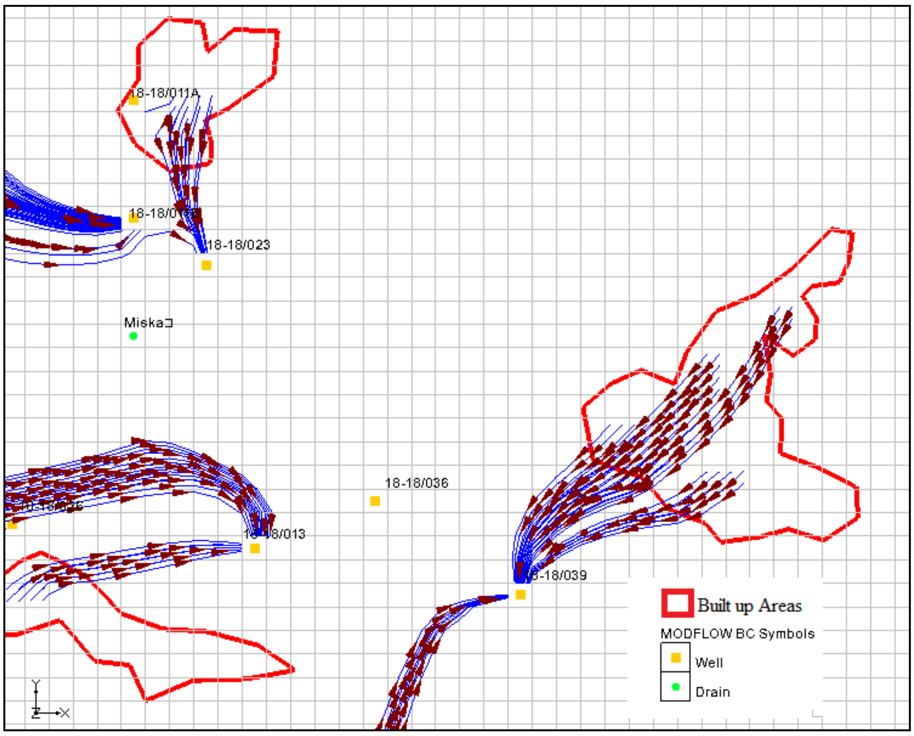

Figure 6.6: Particle tracking of built up areas

c- Agriculture

Faria catchment is agriculturally activated and the agricultural areas occupy a large percentage of the land (Figure 6.2). Farmers used fertilizers and pesticides regularly to increase crop production. The extensive uses of fertilizers, pests and heavy irrigation may cause nitrate and pollutants leaching into the groundwater.

Certain locations were selected within the agricultural areas (figure 6.6 and 6.7) to define particles pathlines to indicate the particles end points. The potentially affected water resources were identified. Figures 6.6 to 6.7 illustrate the MODPATH particle tracking results.

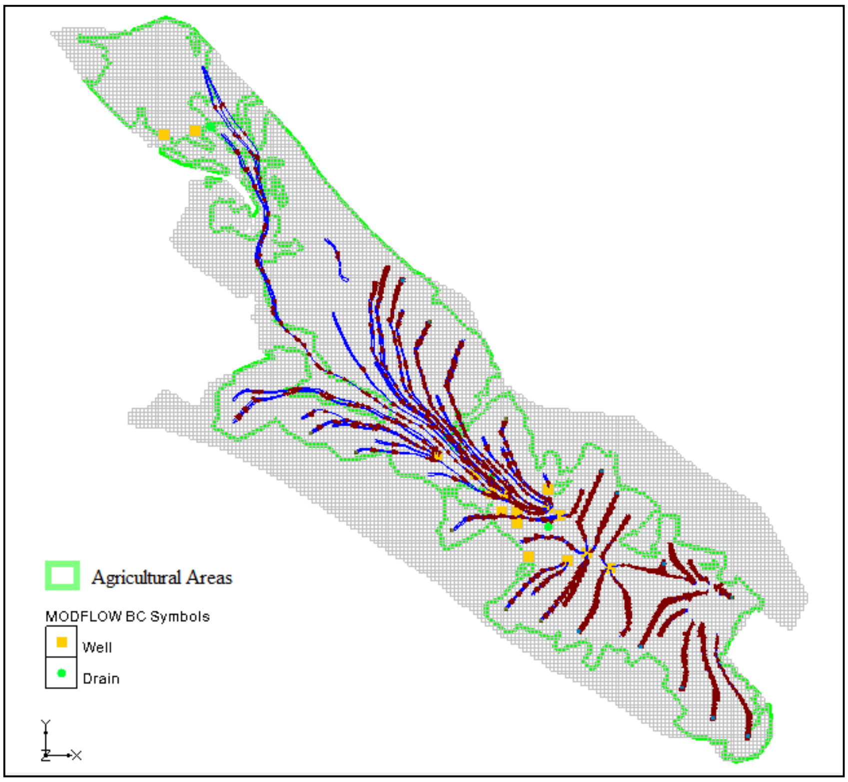

Figure 6.7: General view of particle tracking of the agricultural areas toward wells

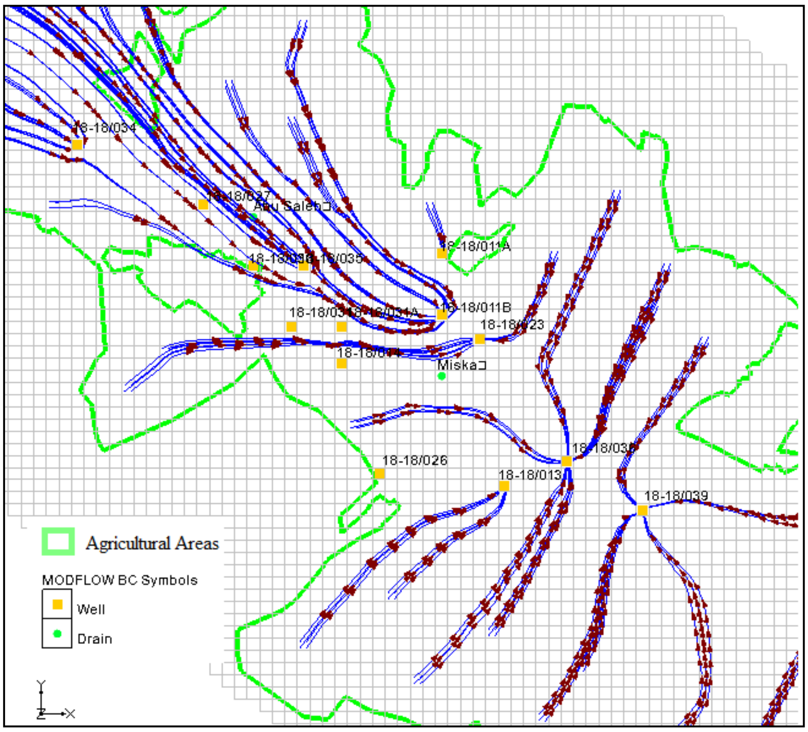

Figure 6.8: Particle tracking of agricultural areas

2- Backward particle tracking

the wellhead protection zone is an area within which there is a complete pathway between any given location at water table (top of the unconfined aquifer) and the groundwater extraction point (water well). this zone is usually defined by the time required for all water particles inside the zone to be extracted, i.e., captured by the well (Mikszewski & Kresic, 2013).

MODPATH can identify protection zones by backwards tracking starting from the water resource. The protection zones for wells are delineated and figure 6.9 and 6.10 illustrate the protection zones for well no.18-18/039 and 18-18/011A.

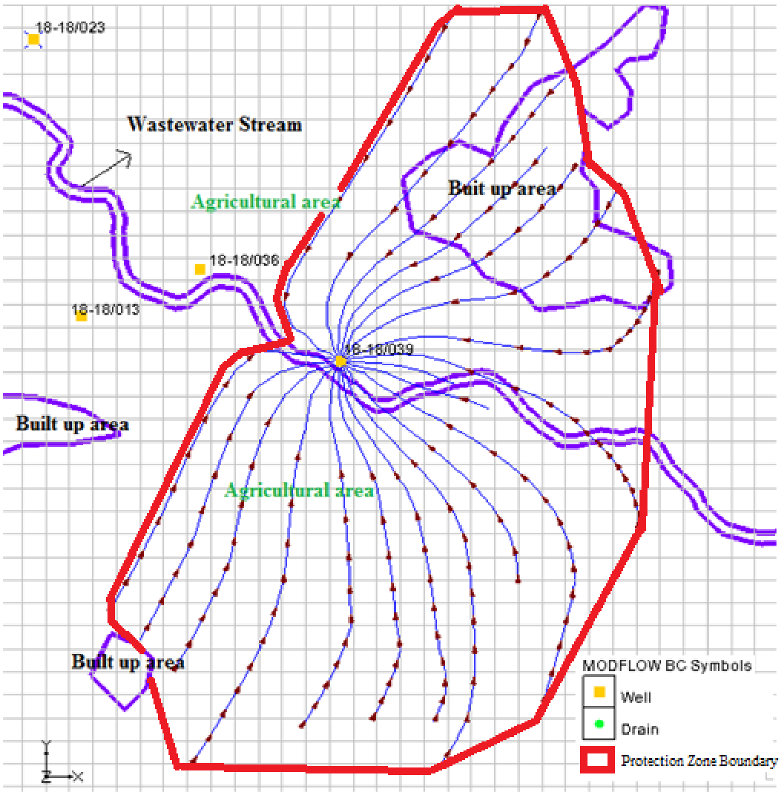

Figure 6.9: Protection zone for well 18-18/039

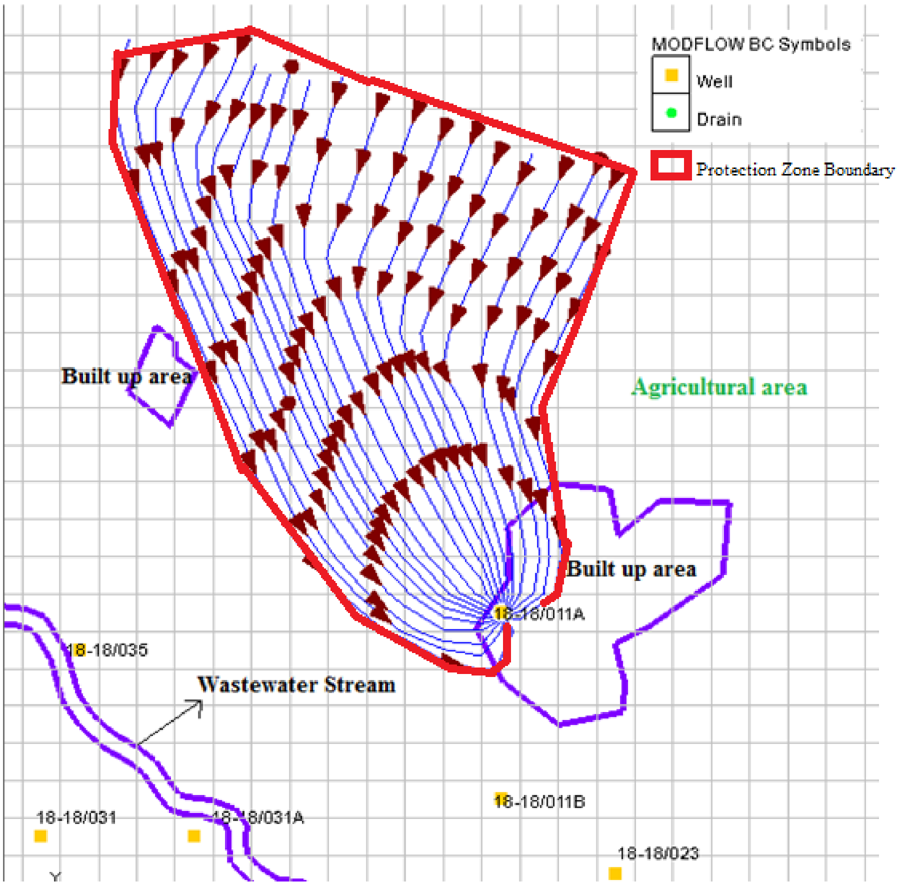

Figure 6.10: Protection zone for well 18-18/011A

6.3 Potentially affected wells and springs

Each source of pollution was defined and set of particles were allocated to be tracked by MODPATH so the particles (represented as pollution source) were tracked (table 6.1) to recognize the affected wells and springs. The results stated that most of wells are exposed to pollution. The Assessment of Groundwater Quality in Al-Faria Catchment by Shadeed, Haddad, & Sawalha in 2015 confirm the results of this study.

Many samples in Al-Faria catchment were collected and analyzed for various parameters, comprising $SO4^{-2}$, $NO3^{-}$, $HCO3^{-}$, K^{+}, Na^{+}, Ca^{+2},

Mg^{+2}, Cl^{-1}, total dissolved solids (TDS), electrical conductivity (EC), acidity (pH) and Fecal Coliform (FC). Some of the tested chemical parameters exceed the desirable limits, though most of the tested parameters are within the highest permissible limit for drinking water. Induced pollution from anthropogenic nature was detected. Additionally, FC bacteria were detected in groundwater wells and springs, which indicate the impermissible use of groundwater without disinfection for drinking purposes. Based on EC as salinity hazard and SAR as alkalinity hazard, the obtained results indicate the permissible use of groundwater for irrigation purposes in the Faria catchment (Shadeed, Haddad, & Sawalha, 2015).

Table 6.1: Potentially affected wells and springs

potentially polluted wells and springs	Source of pollution		
	wastewater Stream	Built up Areas (Cesspits)	Agriculture (Pesticides, Pests,..)
18-18/002	√	√	√
18-18/005	√	√	√
18-18/011A	√	√	√
18-18/011B	√	√	√
18-18/013	√	√	√
18-18/014		√	√
18-18/023	√	√	√
18-18/026		√	√
18-18/027	√	√	√
18-18/030		√	√
18-18/031		√	√
18-18/031A	√	√	√
18-18/034	√		√
18-18/035	√	√	√
18-18/036	√	√	√
18-18/039	√	√	√
El Faria	√	√	√
Abu Saleh	√	√	√
Miska		√	√

Table 5.2-A overview the water quality results of some wells while table 5.2-B the Palestinian water quality standards. The microbial analyses result of wells indicate that wells were highly contaminated.

Table 6.2-A: average values of chemical, physical and microbial parameters of some tested wells in Al-Faria catchment (Shadeed, Haddad, & Sawalha, 2015).

Parameters	Well ID	
	(W1): 18-18/31A	(W1): 18-18/34
SO_4^{-2}	5.7	6.3
NO_3^{-}	21	21
HCO_3^{-}	302	315
Cl^{-1}	116	95
Mg^{+2}	32	33
Ca^{+2}	94	85
Na^{+}	19	19
K^{+}	2.9	3.1
TDS	522	486
EC	816	759
pH	7.3	7.4
FC	163	179
Values of ions in mg/L, EC (µS/cm), TDS (mg/L).		

Table 6.2-B: Palestinian and WHO standards for drinking water (PSI, 2005), (WHO, 2011)

Parameters	Palestinian Standards		WHO Standards	
	Maximum Desirable	Highest desirable	Maximum Desirable	Highest desirable
SO_4^{-2}	200	400	200	600
NO_3^-	50	70	-	50
HCO_3^-	200	600	200	600
Cl^{-1}	250	600	250	600
Mg^{+2}	50	120	30	150
Ca^{+2}	100	200	75	200
Na^+	200	400	50	200
K^+	10	12	100	200
TDS	1000	1500	500	1500
EC	750	1500	750	1500
pH	6.5-8.5	9.5	7-8.5	6.5-9.2
FC	0	0	0	0
Values of ions in mg/L, EC (µS/cm), TDS (mg/L).				

6.4 Travel time for certain built areas pollutants as case study

Certain built-up areas were chosen as case study to detect the travel time of these pollutants from source into selected wells 18-18/013 and 18-18/039. The cesspits within the built-up areas A, B, C and D (represent different communities) were studied to track particles from the previous sources into the wells18-18/013 and 18-18/039. As revealed in MODPATH (Figure 6.11) and for each source of pollution, the shortest path was selected to find travel time and travel distance. This is indicated in the figure by the travel time (t) and the distance (d). For example, cesspits in built-up area A requires 18864.7 days (nearly 62 years) with distance 666.67 m to reach well 18-18/013. Which means these particles needs 52 years or less to reach that well.

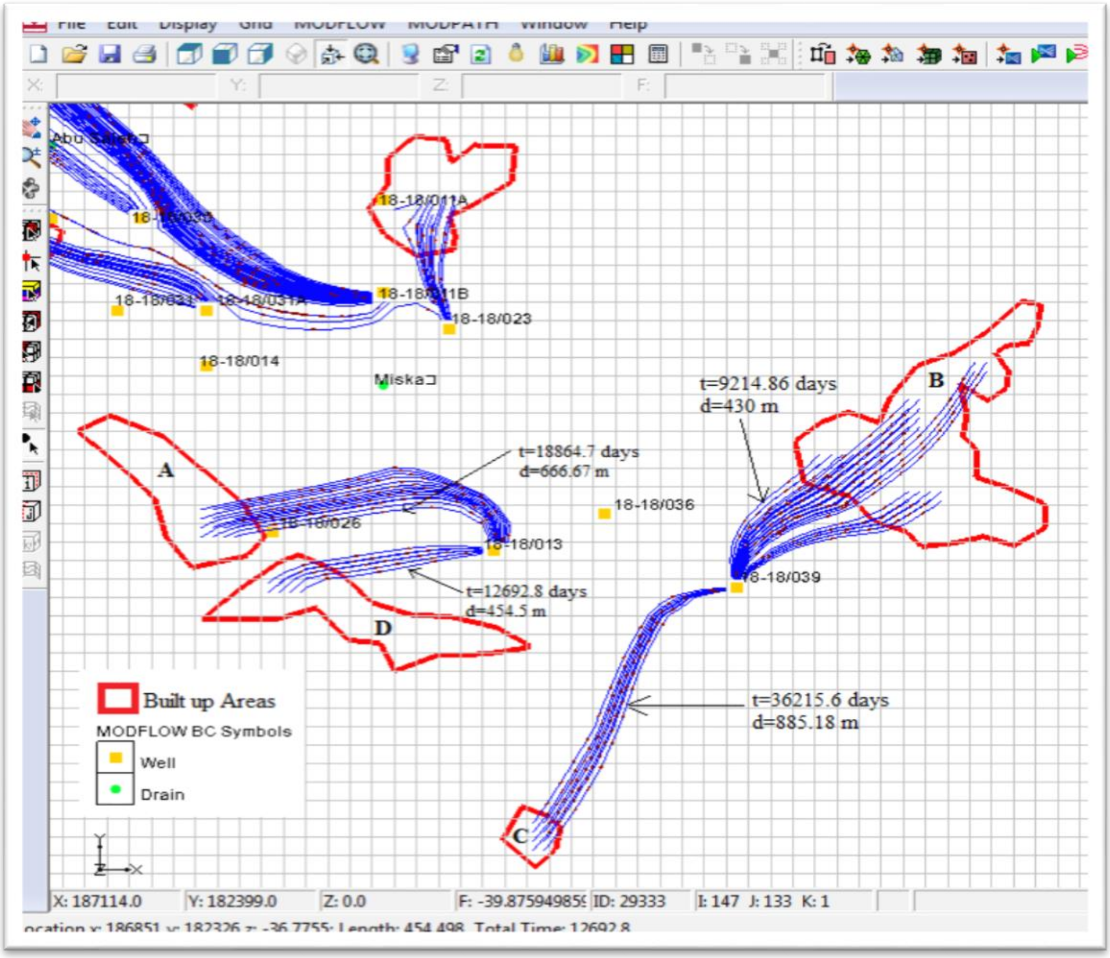

Figure 6.11: Travel time for particles

Chapter Seven

Conclusions and Recommendations

The present study focuses on three main parts; the first is conceptual modeling for the Quaternary aquifer at upper part of Al-Faria. The second is groundwater modeling; and the third is simulation of the pollutants transport of the aquifer. The protection zone for the water resources is defined.

7.1 Conclusions

Trial and error was used to calibrate the flow model by changing hydraulic conductivity values of Quaternary aquifer, the obtained hydraulic conductivity values after calibration ranges between 0.1 to 3.4 m/day Based on the present groundwater model for year of 2011.

The simulation is very strong in defining the protection zones within boundary. Protection zones are particularly effective to control pollution from diffuse sources (e.g. agriculture or traffic) (Chave, et al., 2001).

In general, in case of delineating the protection areas for water resources, the degree of restriction becomes less as the distance from the abstraction point increases, but it is common to include the area of the whole aquifer from which the water is derived in one of the zones, and to restrict activities in such areas in order to give general long-term protection (Chave, et al., 2001).

The applied model determined the protection; many considerations should be formulated to set immediate actions to minimize risk and prevent worse situation.

The applied model also defines the path lines of contaminants from the contaminants source to the end point. The potential polluted wells and springs are listed in 5.1. According to MODPATH results and water quality data, some the wells are already polluted or it will be polluted after certain years.

It was found that most of wells are affected by the pollution sources. Since most of the wells and springs are located nearby the sources of pollution.

7.2 Recommendations

A set of recommendations can be generated after conducting this study:

- The related authorities should control the sources of pollution.
- Importance of monitoring network.
- The related authorities should play their role in raising awareness among people about the severity of the situation if the sources of population are not controlled.
- Adoption of laws and regulation that regulate the use of land particularly the areas around the water resources such as springs and wells.
- Optimization for pumping taking into account the protection zones that are defined as constraints for the objective function (optimizing pumping).
- To construct wastewater networks for Faria region.
- Rehabilitation for fresh water networks to minimize leakage.
- Develop transport pollutants model using MT3D, to be able to study the target contaminants.

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كلية الدراسات العليا

انتقال الملوثات من سطح الارض الى المياه الجوفية- حوض الفارعة كحالة دراسية

إعداد

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اشراف

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قدمت هذه الأطروحة استكمالا لمتطلبات الحصول على درجة الماجستير في هندسة المياه والبيئه بكلية الدراسات العليا في جامعة النجاح الوطنية، نابلس، فلسطين.

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الملخص

تعتبر المياه الجوفية من اهم مصادر المياه في فلسطين. لها تأثير على اوضاع الفلسطينين من نواحي بيئية واجتماعية و اقتصادية. هناك حاجة لتقييم خطورة تلوث المياه الجوفية نتيجة سلوكيات بشرية من ضمنها المياه العادمة و التلوث الناتج عن مكبات النفايات والممارسات الزراعية.

الحوض الجوفي في منطقة الفارعة يلعب دورا رئيسا كمصدر لمياه الابار والينابيع ليلبي الاحتياجات المنزلية والزراعية في المنطقة. كلا الاحتياجين هما وسيلة لنقل الملوثات الرئيسية الى المياه الجوفية بشكل رئيسي عن طريق المياه العادمة والملوثات الزراعية كالمبيدات الحشرية والاسمدة.

الجزء العلوي من الحوض الجوفي غير المحصور في منطقة الفارعة يقع في المنطقة الشمالية الشرقية من الضفة الغربية. وتم اختياره لدراسة حركة الملوثات من السطح الى المياه الجوفيه.

تم اجراء هذا البحث لدراسة حركة الملوثات من السطح عبر طبقة التربة غير المشبعة التي يمكن أن تكون وسطاً لانتقال الملوثات وصولاً الى المياه الجوفية. تم تطوير نموذج افتراضي (Conceptual model) الذي تم تحويله الى نموذج عددي (numerical steady state flow model, MODFLOW) الذي يمثل حركة المياه الجوفية. وبعد ذلك تم استخدام قالب (GMS) لربط النموذج العددي (MODFLOW) مع نموذج نقل الملوثات (MODPATH) لتتبع حركة الملوثات في الحوض الجوفي لمنطقة الفارعة

والذي يعد جزء من حوض الشرقي للضفة الغربية.

تم تتبع اثر الملوثات الرئيسية بالمنطقة وايجاد الابار والينابيع المعرضة لاحتمالية التلوث نتيجة الملوثات التي تم طرحها. وتم دراسة الزمن اللازم لوصول هذه الملوثات للانتقال من المصدر لبئر

محدد كحالة دراسية. وبالتالي تم التعرف على مصادر التلوث وخطورتها. تم ايجاد منطقة الحماية لابار معينة باستخدام تقنية (Backward tracking).

النتائج تثبت ان المياه العادمة والفضلات الزراعية تعتبر من مصادر التلوث الرئيسة للعديد من الابار والينابيع في منطقة الدراسة. تحديد ورسم مناطق الحماية لكل مصادر المياه تعتبر من اقوى الطرق وخطوة بداية لخطة ادارية فعالة لتقليل خطر تلوث المياه الجوفية. ويجب الاهتمام بخطورة المشكلة. وعلى السلطات المختصة إتخاذ قرارات حاسمة للسيطرة على الوضع و الحد من ازدياد الوضع سوءا. تم التوصية بانشاء وتطبيق نماذج مثل النموذج المنفذ في هذه الدراسة و لكل فلسطين لانها اداة مهمة للمراقبة والسيطرة وللتحليل والدراسة سواء على المستوى الحالي او على مستوى فرضيات ومحاور محتملة.