Deanship of Graduate Studies

Al-Quds University

Evaluation of Groundwater Resources In Kufr-Dan Area Using Groundwater Modeling

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Evaluation of Groundwater Resources

In Kufr-Dan area Using Groundwater Modeling

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Thesis Approval

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Dedication

I dedicate this work to my beloved parents, brothers and sisters, for their encouragement and support that made me enabled me to complete my thesis

To All those people who helped me in my thesis

I also dedicate this work to my beloved country

Palestine

Ahmad Khawaja

Declaration:

I Certify that this thesis submitted for the degree of Master is the result of my own research, except where otherwise acknowledged, and that this thesis (or any part of the same) has not been submitted for a higher degree to any other university or institution.

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Signed:

Date: 27/07/2015

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Abstract

Ground water is the main source of drinking water in Palestine. It is also one of the most important resources for agriculture. The increase in the population has an impact on groundwater resources and has created problems in aquifers such as declining water tables and also deterioration of water quality. Palestine is facing a serious problem in managing groundwater due to its limited availability and the excessive pumping of groundwater. The acute shortage of groundwater has an adverse impact on the agricultural production which leads to a stagnant economy.

This study has been conducted in the village of Kufr-Dan which aims at studying the shallow aquifer in the area which is Eocene Aquifer.

This study used Groundwater Modeling System (GMS) to develop a conceptual model on the basis of data from cross section and several boreholes and to calibrate a numerical Model.

Seven wells ware selected for model calibration. The difference between the simulated and observed wells was less than 8 meters. After adjusting the permeability value in the model for the study area, we found that there is an amount of 2,500 m^3/day that enters the northern part of the study area ager doing the calibration.

The groundwater table ranges from 50m a.s.l in the northern part to 170m a.s.l in the southern part, where the groundwater flow is towards the north eastern side.

The model has 73 wells taping the Eocene aquifer. Most of them are dry due to over pumping. The boundary of model is classified in to: flow boundary and non-flow boundary. The total input is 0.43 MCM/year from boundary of the model, the total output is 0.85 MCM/year from the boundary of the model. The total quantity of recharge water for model is determined from rainfall (88%), leakage from network water (0.5%), the quantity of infiltration water from cesspits (1.4%), and the quantity of residual water that passes through irrigation (10%) is 2.27 MCM. The total input and output from model was 2.98 MCM/year 2012/2013. The well abstraction from the model is 2.13 MCM/year which is about 70% of the aquifer budget.

Four scenarios have been applied based on the model. The climate change has been taken into account in which the rainfall has decreased by 30% composed with average amount of rainfall for the previous years. The total amount water input and output in the model is 1.86 MCM, and the amount of abstracted water is 1.3 MCM.

In another scenario, the rainfall has been increased by 10% based on the previous years. We did not notice any noticeable change in the input and output in the model, which is 3.19 MCM, and the amount of abstracted water was 2.34 MCM.

The third and fourth scenarios were based on abstraction.

The third scenario is based on addition of three new wells in the northern part of the study area each of them has a capacity of 40 m^3/h.

The fourth scenario is based on artificial recharge, where seven dry wells have been selected to be injected with 3,750 m^3/day treated wastewater from nearby Jenin wastewater plant. The yield of the wells in the area has improved to 4.85 MCM, which is enough to meet the water demand of the farmers in the area. The water output and input of the model was 4.89 MCM.

It was concluded that another well could be digged in the northern part of the study area which can have a capacity of 20m^3/h, and the water input and output of a model well increase to 5.00 MCM/year.

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Definitions

Ka-LBK	**Lower Beit Kahil Formation**
LBK1	**Lower Beit Kahil Formation One**
LBK2	**Lower Beit Kahil Formation Tow**
UBK1	**Upper Beit Kahil Formation One**
UBK2	**Upper Beit Kahil Formation Tow**
Ka-Y	**Yatta Formation**
Ka-H	**Hebron Formation**
Ka-BL	**Bethlehem Formation**
Ka-J	**Jerusalem Formation**
Ka-N	**Abu-Dis Formation**
Te-J	**Jenin Subseries Formation**
Te-B	**Bayda Formation**
Qh-a	**Quaternary Rocks deposits**
k/T-c	**chalk with minor chert**
Te-c/l	**chalk with inter-bedded nummulitic limestone**
Te-l/c	**Limestone with minor inter-bedded chalk**
Te-l	**bedded massive nummulitic limestone reef limestone**
Kh	**Permeability**
MCM	**Million Cubic Meter**
WHO	**World Health Organization**
PWA	**Palestinian Water Authority**
GIS	**Geographic Information System**

GMS	**Groundwater Modeling System**
3D	**3 Dimension**
a.s.l	**Above sea level**
b.s.l	**Below sea level**
WWTP	**Wastewater Treatment Plant**
HCO_3	**Bicarbonate**
NO_3	**Nitrate**
Cl^-	**Chloride**
GP	**Geophysics**

Chapter One

Introduction

1.1 Background

There are many countries in the world where ground water is one of the major sources of drinking water. With the increasing development of the groundwater resources and the growing impacts of human activities on the aquifers, problems such as decline of groundwater heads and deterioration of groundwater quality have been observed in many places in last decades. Approaches of sustainable development and integrated groundwater resources management must be developed and implemented to guarantee the right of use of the limited water resources for our future generations.

Increase of world population has resulted in the increase of water demand and the consumption of available water resource. In Palestine, the depletion of groundwater is especially crucial since groundwater is considered the only fresh water available for all sectors, (Meadows, D. H., Meadows, D.L., and Randers, 1992). Table (1.1) shows the domestic water supply and consumption in the Palestinian governorates. (PWA, 2011).

The Palestinians depend directly on ground water, which is the main source for the different uses; rain water is the second source of water. Palestine faces a big problem in managing its water due to the limited amount of natural water available, and due to over exploitation of water resources. This causes pollution and increase in the salinity of groundwater as is noticed in the Eastern Basin (Aquifer) of the West Bank. (A. Marei, 2010)

Table 1.1: domestic water supply and consumption in the Palestinian governorates (PWA, 2011).

Governorate	**Population**	**Total quantity supplied (MCM)**	**Total quantity consumed (MCM)**	**Total Losses (MCM)**	**Percent of Losses %**
Jenin	281,158	5.7	3.9	1.8	31
Tubas	56,642	1.5	1.1	0.4	29
Tulkarem	168,973	5.2	3.3	1.9	36
Nablus	348,023	15.0	10.2	4.8	32
Qalqilya	100,012	4.7	3.4	1.3	28
Salfit	64,615	2.5	1.8	0.7	27
Ramallah	310,218	16.6	12.5	4.2	25
Jericho	46,718	3.8	2.9	0.9	24
Jerusalem	147,489	4.7	3.1	1.6	33
Bethlehem	194,095	11.3	7.5	3.8	34
Hebron	620,418	17.3	12.6	4.7	27
Total – West Bank	2,338,361	88.3	62.3	26.0	30

Water consumption is the water delivered to customers from distribution network. The total water loss in the West Bank is 30% of the supplied water, and the water loss in Jenin reaches 31% which is considered very high. The term “Real Losses” is defined by the Environmental Protection Agency (EPA) as the physical leaks that consist of leakage from transmission and distribution mains, leakage and overflows from the utilities storage tanks and leakage from service connections up to and including the meter. (PWA, 2011).

1.2 Water Resource Mentioning Wells and Spring

The total number of the Palestinian wells in the West Bank tapping all aquifer systems is 383 wells, of which 119 wells are not pumping or abandoned and in need for rehabilitation. figure (1.1) shows the sources of water at West Bank. (PWA, 2011)

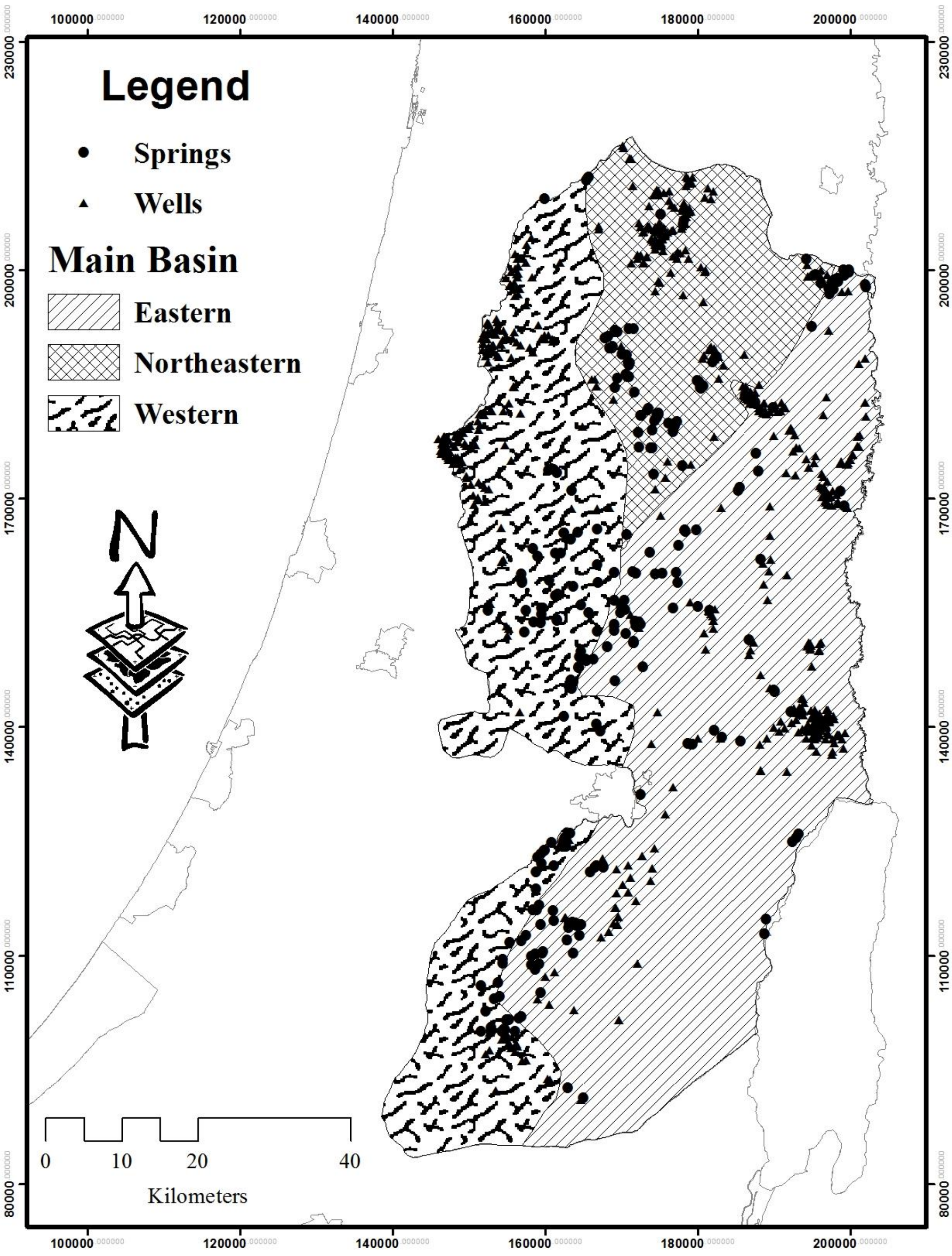

Figure 1.1: location of wells in the West Bank (PWA, 2011)

Table (1.2) and Table (1.3) summarize the total abstractions from Palestinian wells per use and per aquifer, respectively. Consequently, the cumulative water deficit is still increasing. (PWA, 2011).

Table 1.2: Summary of total abstraction from Palestinian wells per use (PWA, 2011)

Basin	**Palestinian Abstractions (MCM) in 2010/2011**				
	Domestic	**Agriculture**	**Total Abstractions**	**Total Recharge**	**Long-term Average Recharge**
Western Basin	7.9	17.1	25.0	311	318-430
Eastern Basin	7.13	12.0	25.7	153	125-197
North-eastern Basin	11.9	2.9	14.8	134	135-187
Total West Bank	**33.5**	**32**	**65.5**	**598**	**578-814**

It is obvious from the table above that the total recharge rates for all aquifers, which is 598 MCM in the 2010/2011 season, is less than the long-term annual average rates which is 578-814 MCM. If this trend continues, it will have a negative impact on the water resources in the West Bank. (PWA, 2011).

The total of abstractions for all aquifers in the 2010/2011 season was almost 10% of total recharge. In the Western Basin, the abstraction of water for domestic uses is less than that for agriculture uses, as opposed to North-Eastern basin, so the North-Eastern Basin cannot provide enough water for agricultural use.

Table 1.3: Summary of 2011 Palestinian wells abstractions per aquifer West Bank (PWA, 2011).

Basin	**Aquifer**	**Type**	**Abstraction (MCM)**
Eastern	Alluvium	Shallow	6.7
	Beida	Shallow	1.7
	Eocene	Shallow	3.3
	Upper Cenomanian	Upper Aquifer	2.2
	Lower Cenomanian	Lower Aquifer	11.8
Total Eastern Basin			**25.7**
Western	Upper Cenomanian	Upper Aquifer	24
	Lower Cenomanian	Lower Aquifer	1.0
Total Western Basin			**25**
North-Eastern Basin	Beida	Shallow	0.7
	Eocene	Shallow	3
	Upper Cenomanian	Upper Aquifer	5.6
	Lower Cenomanian	Lower Aquifer	5.5
Total North-eastern Basin			**14.8**

Each basin is classified in to three types of Aquifer: shallow Aquifer, upper and lower Aquifer. In the Eastern Basin the higher abstraction comes from the Lower Aquifer which is about 11.8 MCM which represent 46% of the total Eastern Basin abstraction.

Most of the abstraction from the Western Basin comes from the uppe Aquifer (24 MCM) which represent 96% of the total abstraction of the Western basin.

In the North-Eastern Basin the most of the abstraction come from the Upper and Lower Aquifers (5.6, 5.5 MCM) respectively, while the Shallow Aquifer abstraction is 3.7 MCM which represent 25% of the total North-Easter Basin Abstraction. (Table 1.4).

Table 1.4: The type of Aquifers and the number of wells taping each Aquifer in the West Bank (Head of Studies and hydrogeology department, PWA, October 2012, interview)

Aquifers	**Number of wells**
Shallow Aquifer	320 wells
Upper Aquifer	180 wells
Lower Aquifer	65 wells

The total abstraction from the pumping wells is approximately 65.5 MCM in year 2011 of which 33.5 MCM is used for domestic purposes and 32 MCM for agricultural uses (PWA, 2011). Figure (1.2) shows the annual average abstraction from Palestinian wells during the period of 2007-2011. (PWA, 2011).

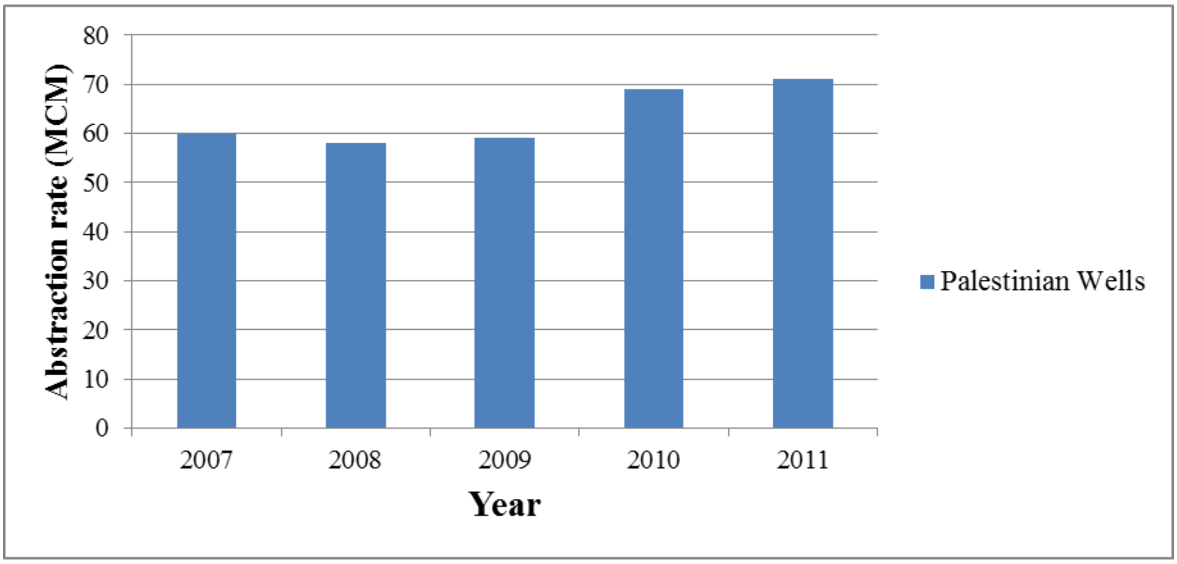

Figure 1.2: Average annual abstraction rate from all Palestinian Wells in the West Bank (PWA, 2011).

The number of Israeli wells inside West Bank is 39 wells, and the average annual abstraction of these wells is estimated at about 54 MCM (PWA, 2011). Furthermore, Israel has more than 500 wells inside the Green Line (mainly in the Western Basin), which abstract more than the annual recharge rate of all aquifers. As a result, the Palestinians are adversely affected by that due to general decline of water level in the aquifers, as the total annual abstraction greatly exceeds the recharge rate. (PWA, 2011).

There are 69 wells in the Jenin district; they are used for both irrigation and domestic purposes. Of these, 61 wells are owned by the Palestinian private sector and used for irrigation. The remaining eight wells are public, owned by Palestinian municipalities and used for domestic purposes.

All irrigation wells in Jenin district are tapping the Eocene shallow aquifer while domestic wells are tapping the Upper Cenomanian Aquifer, except one of them (Jalbun well) which taps the Eocene aquifer. (Head of Studies and hydrogeology department, PWA, October 2012, interview).

Palestinian wells are all controlled by the Palestinian Water Authority or the Israeli Civil Administration in regard to pumping quotas and licensing. Figure (1.3) shows the location of wells in the Jenin district.

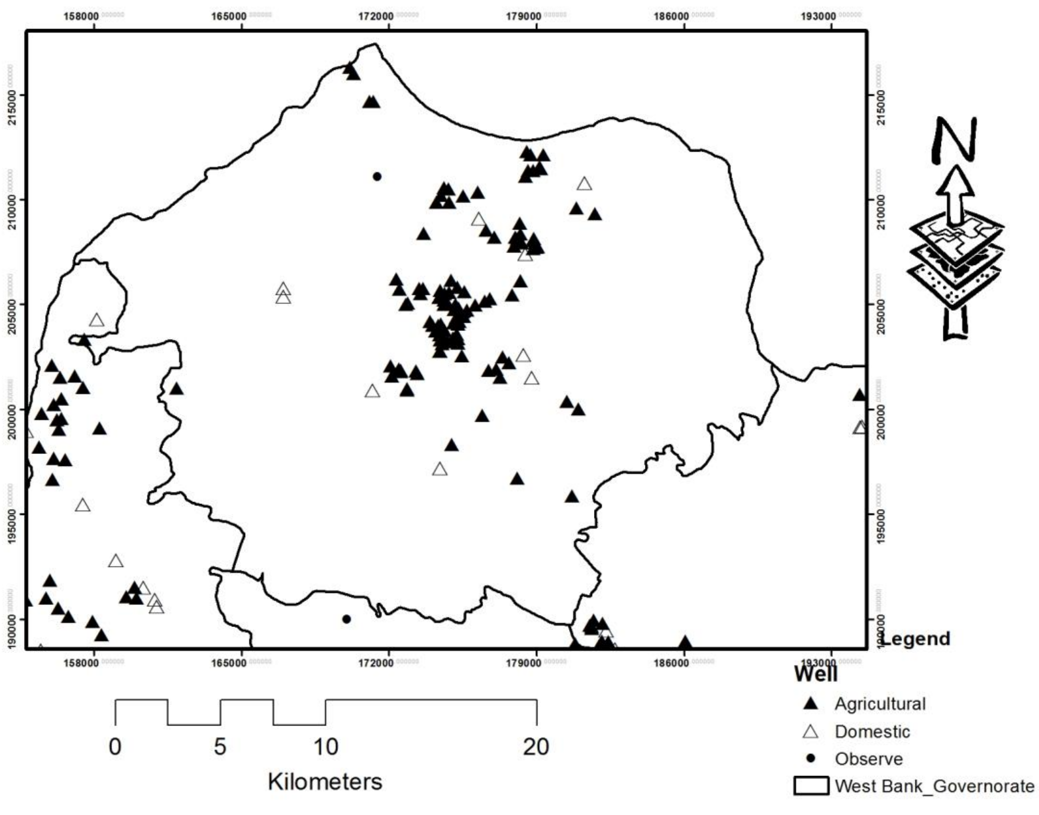

Figure 1.3: Location of wells in Jenin district

The bodies responsible for the management of water resources in the Jenin district are:

1. Jenin and Ya'bad municipalities.
2. West Bank Water Department and Mekorot and
3. Private owners managing irrigation wells.

There are 7 springs in the Jenin district, but the majority lose water through seepage. They are seasonal and subject to drought effects. Springs are mostly used for low-scale agricultural and domestic purposes. Six springs are monitored by the Palestinian Water Authority, with a discharge rate exceeding 0.1 l/sec. The all of the springs at this time are dry. (Head of hydrogeology department, PWA, October 2012, interview).

1.3 Groundwater Aquifer Systems

There are two exposed aquifer systems in the Jenin district. These aquifer systems are:

1.3.1 Upper Cenomanian-Turonian Aquifer System

This system is composed of carbonate rocks (dolomite and limestone) with thickness ranging from 185 to 475 m (Rofe and Raffety, 1965). This system is separated from the Eocene aquifer system by a variable poor aquiclude formation of chalk and chert of the Senonian geologic age of the Upper Cretaceous. The system is composed of (from the oldest to the youngest):

a. Hebron formation which is composed of dolomite, limestone, cherts and chalk. The thickness ranges from 105 to 260 meters and forms an excellent aquifer of the Upper Cenomanian age of the Upper Cretaceous.

b. Bethlehem formation which overlies the Hebron formation of a thickness ranging from 30 to 115 m and is composed of dolomitized limestone, dolomite and chalk. It forms a very good aquifer of the Upper Cenomanian.

c. Jerusalem formation which is composed of limestone and dolomite of the Turonian of the Upper Cretaceous geologic age. It forms a very good aquifer with a thickness ranging from 50 to 100 meters.

1.3.2 Eocene Aquifer System

This aquifer system overlies the Upper Cenomanian-Turonian aquifer system, with a transition zone of chalk of variable thickness ranging from 0 to 480 m in between. This system is represented by the Jenin subseries of the Tertiary age. (Rofe &Raffety, 1965).

Due to limited data, the Eocene will be modeled as one aquifer, even though it consists of three aquifers. (SUSMAQ, 2003):

- Upper Eocene – mainly chalk and marl, considered a poor aquifer.
- Middle Eocene – mainly limestone and chalk, considered a good aquifer.
- Lower Eocene – chalk and chert, considered a fair aquifer.

The regions of chalk and chalky limestone are limited in area and isolated. The main Eocene lithology in the Nablus-Beit Qad Syncline is limestone and limestone with some marl horizons, which may be regarded as a continuous aquifer (Roffe & Raffety, 1965). The Eocene limestone aquifers in the center have a large outcrop and are fringed by a smaller area of upper Cenomanian formations. Figure (1.4) show the cross section from previous studies. While the cross section is located in the north of the West Bank, and the direction of cross section from south to north, and it lies within the study area.

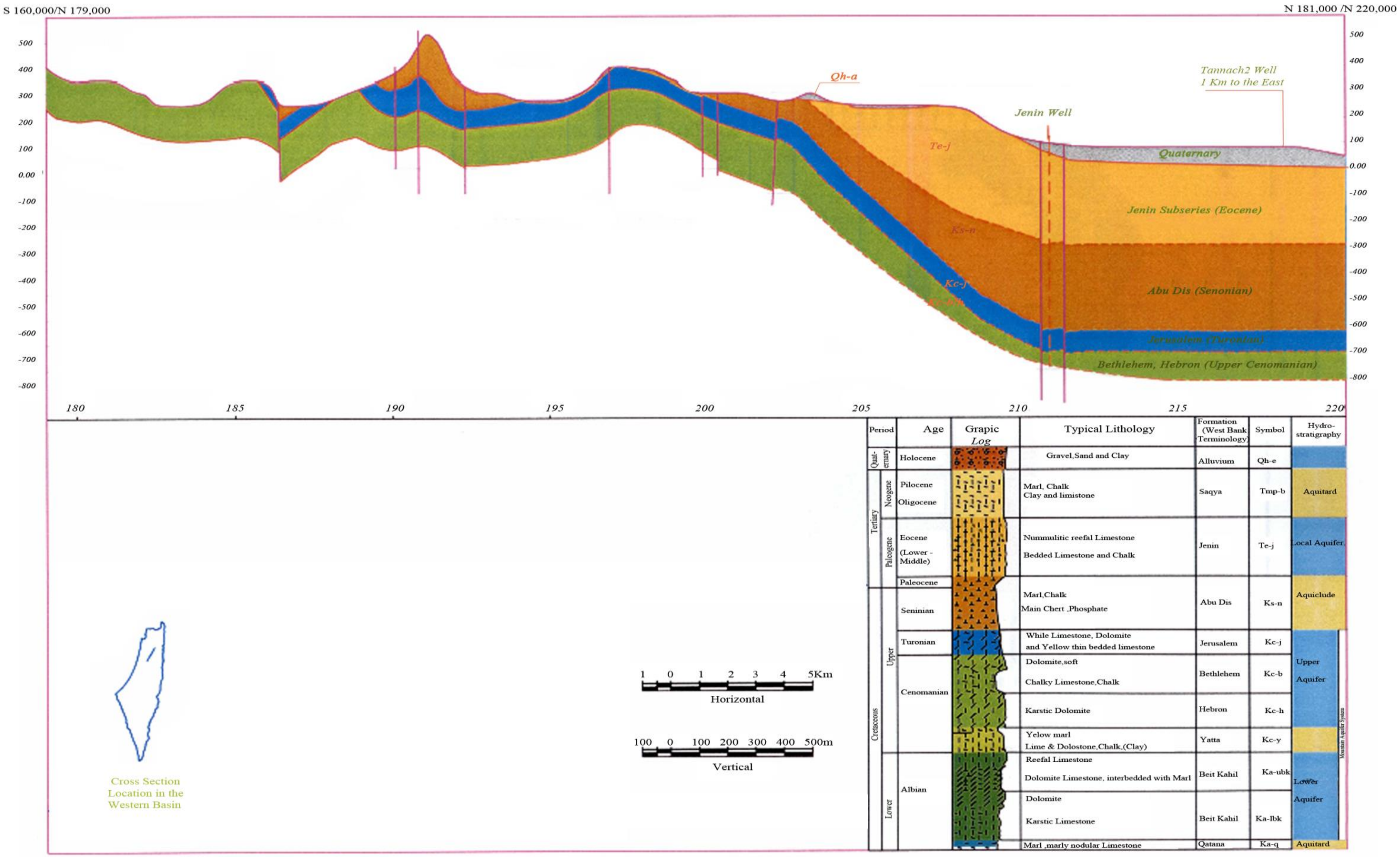

Figure 1.4: Northeastern Cross Section (SUSMAQ, 2003)

1.4 Study Area

Kufr-Dan is one of agricultural area in Jenin District. It is located 2.5 km west of Jenin city, and is 160 m a.b.l. Figure (1.5) show the location of the study area. Kufr-Dan is an extension of Marj Ben Amer. The area of Kufr-Dan is about 7,500 donums which include 300 donums of urban area. Bordering it are Burqin village from the south, Al-Yamoun village from the west, and Jenin city from the east.

Kufr-Dan has a large agricultural area located in Marj Ben Amer. Different agricultural crops are grown in this area which include cucumber, pepper, eggplant, Mulukhiyah and different vegetables. Kufr-Dan was known for growing watermelon which was considered the best watermelon in the Arab World and was used to be exported to the Arabian Gulf until 90's. The area has many greenhouses.

People had drilled many wells in Kufr-Dan area which are manly used for agriculture, since farmers produce plenty of vegetables which need a lot of groundwater for irrigation.

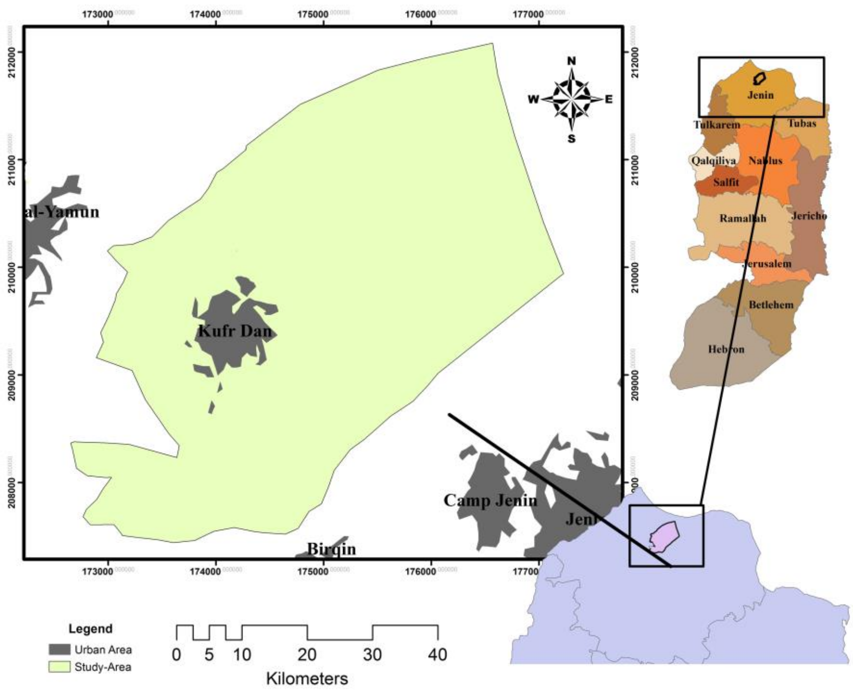

Figure 1.5: Study area, Kufr-Dan Village

The population of Kufr-Dan is 7,700 (PCBS, 2013). Many of them are farmers who depend on groundwater for domestic and agriculture uses. There are around 9 license agricultural wells in Kufr-Dan. Table (1.5) shows the ID and coordinates of the 9 license wells in Kufr-Dan.

Table 1.5: ID and coordinates of the 9 license wells in Kufr-Dan

No.	**ID**	**X-Coordinate**	**Y-Coordinate**	**Elevation**
1	17-21/007	174620	210560	110
2	17-21/009	176000	210800	100
3	17-21/010	174480	210200	115
4	17-21/012	174600	210400	110
5	17-21/013	174850	210500	105
6	17-21/014	175500	210140	100
7	17-21/034	174250	209850	135
8	17-20/041J	173700	208400	170
9	17-20/046	174430	209800	130

Due to the unlicensed wells drilled during the last 10 years, 7 of the licensed wells have dried up and the abstraction of the other two wells has declined.

The number of unlicensed wells is 73 in the study area. Figure (1.6) shows the unlicensed well and licensed well in study area.

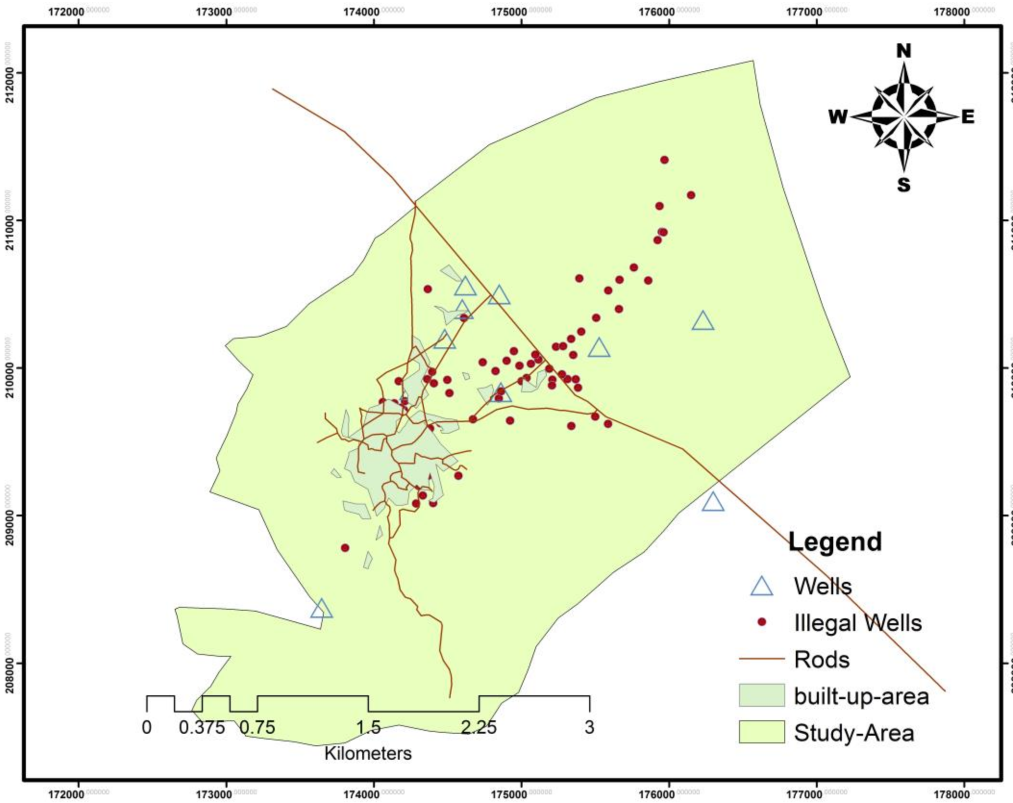

Figure 1.6: Location of unlicensed wells and licensed wells

1.5 Wastewater

Many Palestinian communities are not connected to the main sewage systems. Most of the Villages or rural areas are using cesspits and surface drainage in open channel (Hadded, 1990). kufr-dan village has 970 cesspits for wastewater.

The City of Jenin is located in the northern part of the West Bank close to the 1967 borders, and located east of the study area. The total population of the city of Jenin in addition to the refugee camp is estimated at 45,000. (Jenin Municipality, 2012).

The Wastewater treatment plant (WWTP) of Jenin was constructed in 1972 west of the city. Figure (1.7) shows the location of WWTP which consists of four aerated lagoons in series followed by a polishing pond which is the type of technology used for the treatment in vertical aeration and oxidation ditch that reaches the secondary treatment.

Discharge from WWTP to Wadi Al Muqatta' is about 3,750 m^3/day (Jenin Municipality, 2012), while it discharges to the 1967 borders, the Palestinians while had to pay Israel for the cost of treatment.

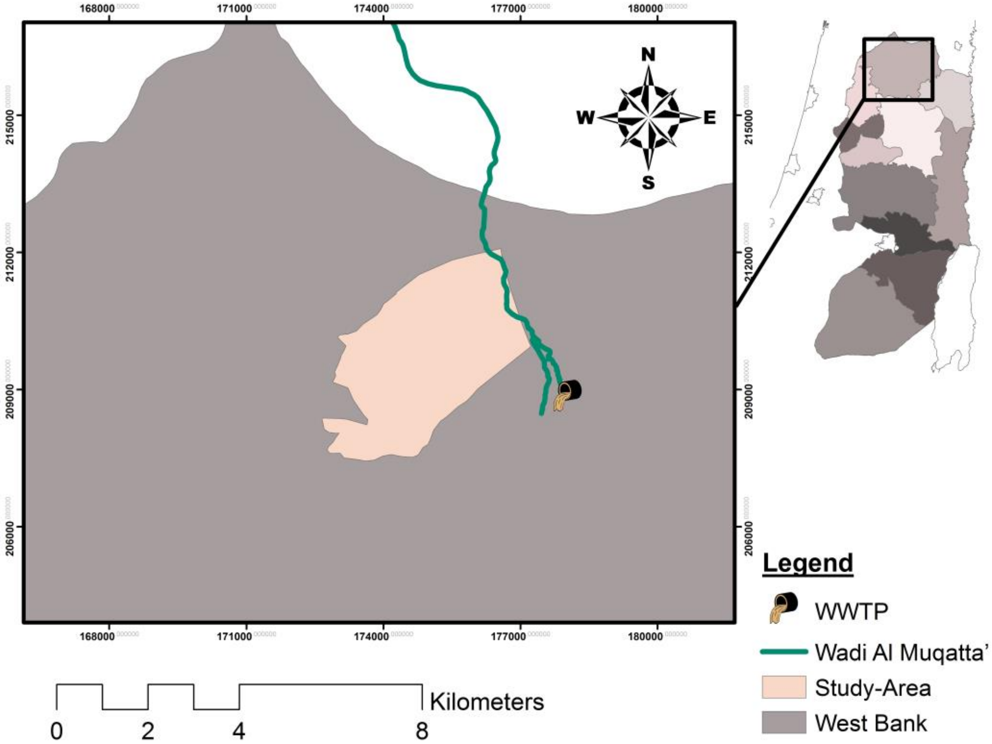

Figure 1.7: Location of WWTP of Jenin and Wadi Al Muqatta'

(Table 1.6) shows the characteristic of wastewater that discharge from WWTP of Jenin.

Table 1.6: The characteristic of wastewater for WWTP of Jenin (Head of laboratory department, PWA, November 2014, interview)

	Inlet	**Outlet**
PH	7.6	7.4
COD mg/l	1105	63
BOD mg/l	452	19
TSS mg/l	404	17.5
N mg/l	141	53
NH_4 mg/l	97	21
PO_4 mg/l	15	10.8

1.6 Problem statement

The scarcity of the water resources in the West Bank, due to arid to semi-arid climate, overexploitation and mismanagement, are of great importance. (Z. Qannam, 2003).

The amount of water used for domestic purposes in the West Bank in 2011 was estimated at 62.3 MCM (70% of the total available quantity) (PWA, 2011) to 2.338 million capita in 2011 (PCBS, 2011), with an average daily water supply rate of 70 liters per person. Table (1.7) shows water consumed and supplied for each district.

Table 1.7: Water Supply and Consumption Rate in the Palestinian Governorates (PWA, 2011)

Governorate	**Total Supplied (MCM)**	**Total Consumed (MCM)**	**Per capita Supply Rate (l/c/d)**	**Per capita Consumption Rate (l/c/d)**
Jenin	5.7	3.9	56	38
Tubas	1.5	1.1	73	52
Tulkarem	5.2	3.3	84	54
Nablus	15.0	10.2	118	80
Qalqilya	4.7	3.4	129	93
Salfit	2.5	1.8	106	77
Ramallah	16.6	12.5	147	110
Jericho	3.8	2.9	223	169
Jerusalem	4.7	3.1	87	58
Bethlehem	11.3	7.5	160	105
Hebron	17.3	12.6	76	56
Total	**88.3**	**62.3**	**103**	**73**

The cultivable land in the study area is about 3000 dunums, of which 2,300 dunums are cultivated, of which 850 dunums are greenhouses which produce various agricultural crops. The rest of the land is grown with crops without irrigation. Table (1.8) shows the quantity of water required for the seasonal crops. Part of the land is reserved for the seasonal crops while the rest of the land is being used for other types of produce.

Table 1.8: crop water requirements

	Water needs dunums/ m^3 **	Cultivated area with main crops (Dunums) ***	Cultivated area with minor crops (Dunums) *	Amount of water needed by main crops m^3/y	Amount of water needed by minor crops m^3/y	
Spring cucumber	600	900	1400	540000	560000	
Pepper & eggplant	500	300	2000	150000	800000	
Mulukhiyah	400	300	2000	120000	800000	
Greenhouse cucumber	500	850	850	425000	425000	
Others	400	0	2300	0	920000	
Total				1235000	3505000	4740000

* The rest area is not cultivated with main crops.
** MoA, 2014.
*** Head of Kafr-Dan Cooperative Society for Agriculture and Irrigation, 2014.

The quantity of water needed for land cultivation is nearly 4.7 MCM/y. However, the quantity of water extracted from wells in the study area is nearly 2.3 MCM/y, so there is a severe shortage of water required by farms in the area.

In the study area, there were 9 licensed wells with a discharge of about 1.5 MCM until 2002. At the present time, there are only two ramming wells with an abstraction of 44,700 m^3/year. The other 7 wells have dried up.

To satisfy the increasing demand, new wells have been drilled during the last 10 years, in addition to many illegal shallow wells (up to 200 m depth). .

While the ground water aquifer in the Study Area depends on the rainy season water for recharge, identifying this component is of key importance to the aquifer's sustainability, (starts in November and ends in March). The productivity of these wells is normally the highest in spring season period. In the summer period, the water table usually drops down due to over pumping in these wells which results in the dryness of most of them.

The economic situation of the agricultural sector is deteriorating despite the fact that Palestine is one of the agricultural countries, especially the city of Jenin. However, the farmers are turning away from farming due to several factors: high agricultural costs, (compared with imported produce), lack of regulatory means which safeguard the farmers, and the Israeli measures of land annexation, expansion and confiscation. (PCBS, 2013)

1.7 Objectives of research

Understand of water system at the study area is the main goal to achieve in this investigation. Specific objectives are:

1. To identify the lithology of Kufr-Dan aquifer.
2. To determine the thickness and depth of the rechargeable layers in Kufr-Dan aquifer.
3. To specify hydraulic parameters of the Kufr-Dan aquifer.
4. To Model the groundwater resources.
5. To identify the safe yield of the area.

Chapter Two

Geology and Hydrology

2.1 Geology

The geology is important factor to determine the basins layers of recharge, aquiclude layers, fault surfaces, and joints.

Outcrops in the Jenin district are mainly carbonate rocks, including limestone, dolomite, chalk and chert. They range in age from Upper Cretaceous to Recent. Figure (2.1) shows the geological map at West Bank

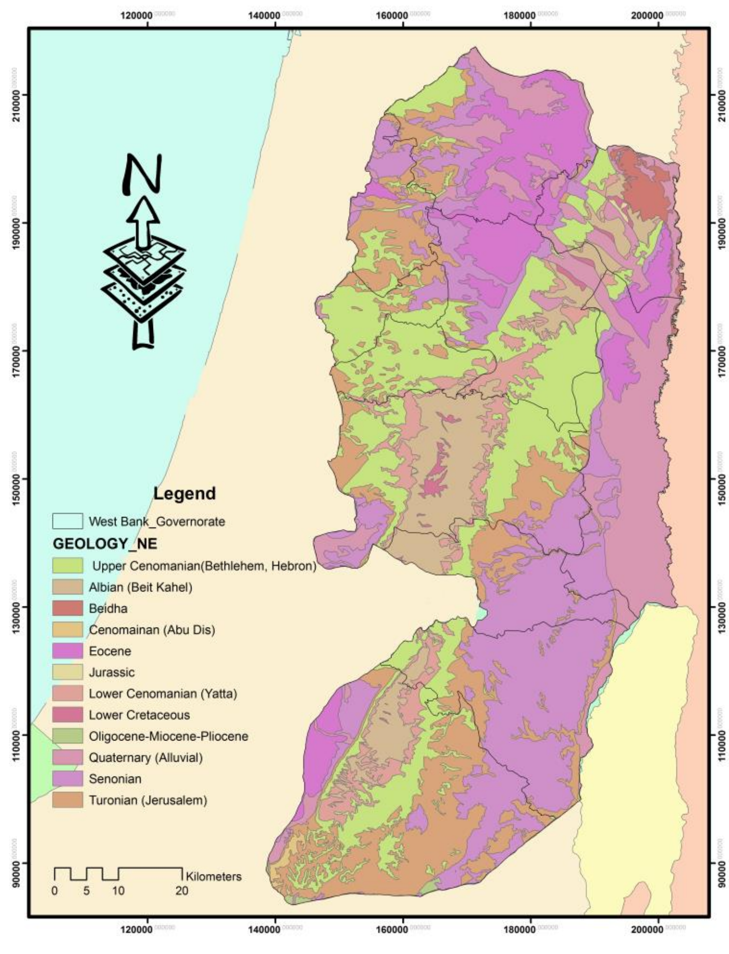

Figure 2.1: geological map of West Bank

2.2 Lithology

According to the Jordanian nomenclature (Rofe and Raffety, 1965) the detailed geology of the Jenin district shows the following geological formations:

2.2.1 Cretaceous Rocks

2.2.1.1 Hebron Formation (Ka-H) (Middle Cenomanian)

This formation refers to the upper part of the middle Cenomanian. The lithological composition consists of dolomitic limestone that is hard, whereas the base of this formation consists of hard dolomite and dolomitic limestone. The Hebron Formation has a thickness of 105 – 260 m and it is a good aquifer. (Roffe & Raffety, 1965). The depth of Hebron Formation at the study area reaches up to 950 m. (Log of Jenin well 2).

2.2.1.2 Bethlehem Formation (Ka-BL) (Upper Cenomanian)

The age of Bethlehem formation is Upper Cenomanian. It outcrops in the Fari'a Anticline and the A'nabta anticline. This formation consists of dolomite, limestone and chalky marl. A number of shelly beds are included within the chalky and dolomitic facies. The Bethlehem Formation has a thickness of 40-110 m and is a very good aquifer. (Roffe & Raffety, 1965). The depth of Bethlehem Formation reaches up to 830 m in the study area. (Log of Jenin well 2).

2.2.1.3 Jerusalem Formation (Ka-J) (Turonian)

The age of Jerusalem formation is Turonian. Its most extensive outcrops are in the A'nabta anticline which is west of study in Jenin district and Fari'a anticline to the east of Jenin. It consists of massive, bedded limestone, dolomite and chalky limestone. Generally, the formation forms a good aquifer, and it has a thickness of 50-120m. (Roffe & Raffety, 1965). The depth of Jerusalem Formation reaches up to 760 m in the study area. (Log of Jenin well 2).

2.2.2 Rocks of Cretaceous to Tertiary Transition Chalk, Abu-Dis Formation (Ka-N) (Senonian)

This formation consists mainly of chalk of Senonian to Paleocene age. The chalk is major component of this formation, and it is usually dark colored due to the presence of bituminous materials and has a variable thickness due to the earth's movements during its deposition. It also includes conglomerated, thin-bedded limestone. The outcrops exist in the western limb of the Nablus - Beit Qad syncline. The presents of chalk makes the formation a good aquiclude since chalk is impermeable. The thickness of the Abu-Dis formation ranges from about 60-450 m. the highest thickness is found in the synclinal area, with corresponding thinning of rocks in anticlinal areas. (Roffe & Raffety, 1965). The depth at the study area reaches up to 400 m. (Log of Jenin well 2).

2.2.3 Tertiary Rocks

These are represented by two lithological units:

2.2.3.1 Jenin Subseries (Te-J) (Palaeocene and Eocene)

This consists mainly of chalk of Eocene age. Outcrops are widely spread covering large areas of the district. It consists of five facies of limestone and chalk which are described as follows:

- Chalk with minor chert (k/T-c).
- Chalk with inter-bedded nummulitic limestone (Te-c/l)

- Limestone with minor inter-bedded chalk (Te-l/c).
- Bedded massive nummulitic limestone (Te-l).
- Reef limestone (Te-l).

Generally, it forms a good aquifer except in the chalk zones, where it forms an aquiclude. Variable thickness reaches about 300 meters in some places of the Jenin district. Its outcrop at study area and some places is found at a depth of 100 m. (Roffe & Raffety, 1965).

2.2.4 Quaternary Rocks (Qh-a) deposits

This consists of unconsolidated:

- Alluvium (Qha): Alluvial soils mainly form alongside the valleys and streambeds. The source of this soil is mainly derived from the adjacent rock formations. The thickness of these sediments reaches 10 m.
- Outwash Fans and piedmont Cones: They occur where the valleys cross the abrupt changes of slope connected with the rift faulting. The gravel fans are important sites of groundwater transfer from limestone aquifers.

2.3 Structural Patterns

2.3.1 Folds

The Main foldings in this study area, as shown in (figure 2.2), are as follows: (1) the Nablus-Beit Qad syncline, (2) the Anabta anticline, which lies on the western water divides of the North-Eastern aquifer, and (3) the Fari'a anticline, which is the result of compressive forces from east and west and from southeast and northwest. (Roffe & Raffety, 1965).

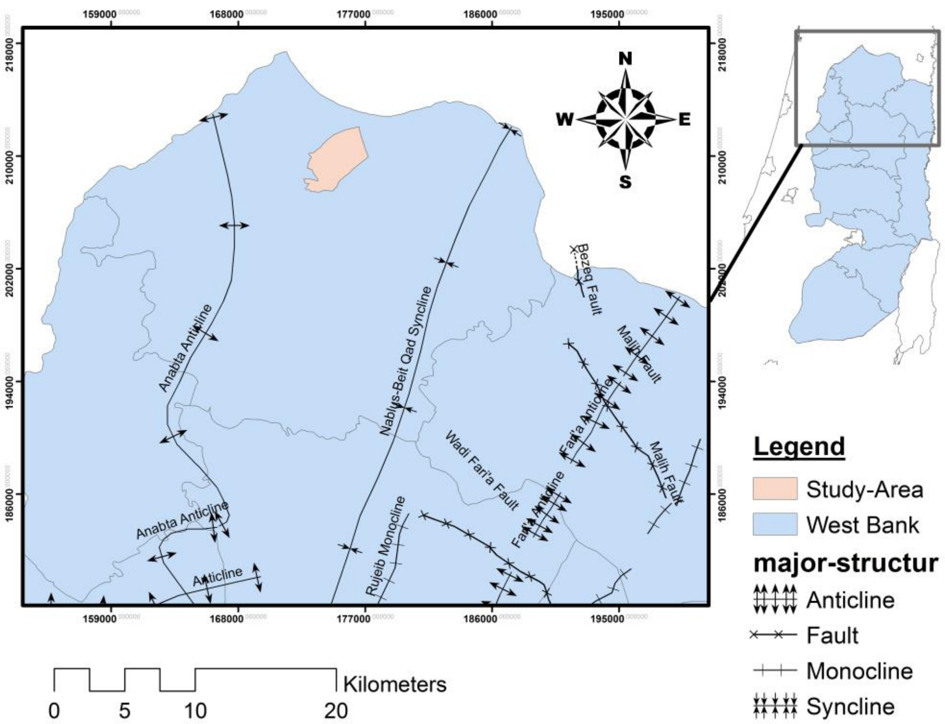

Figure 2.2: The major structure at the northern part of the West Bank (Roffe & Raffety, 1965)

2.3.2 Faults

Most of the faults trend is northwest to southeast. Faulting has resulted in the formation of several graben structures in the area. The effect of faulting on the Eocene limestone of the western West Bank is less visible than on the dolomitic limestone of the Turonian-Upper Cenomanian. There are also tear faults which are classified as minor. (Roffe & Raffety, 1965).

The aquifer in Jenin area starts from Anabta Anticline, which routes the groundwater towards the city of Jenin in the east or towards the Palestinian coast in the west. The Nablus-Bait-Qad Syncline serves as a basin and constitutes the lowest point in the aquifer while the Faria Anticline constitutes the highest point. This Syncline routes the groundwater towards the city of Jenin in the west or towards the Jordan Valley in the east. So this aquifer serves as a water basin where the water moves from the east and the west to the center, i.e. Nablus-Bait-Qad Syncline (Figure 2.2).

2.4 Climate

Jenin is dominated by Mediterranean climate which has six months (from May to October) of hot dry summer and a winter with rain from November to April. The climate can be characterized as hot and dry during the summer and cool and wet in winter. The minimum temperature in winter is 9 C°. The average annual rainfall is 530 mm. Prevailing wind directions liens between southwest and northwest. (I Isam, Palestinian Meteorological, 2014).

The rain starts from October and ends in April, while it is the heaviest in December and January. The maximum amount of rain in January 2013 was 258.7 mm, and the minimum amount in March was 3.6 mm. (I Isam, Palestinian Meteorological, 2014). Table (2.1) summarizes the precipitation in 2012/2013.

Table 2.1: Precipitation at 2012/2013 (Jenin Withering Station/ (I Isam, Palestinian Meteorological, 2014))

Month	**Precipitation (mm)**
September /2012	00.0
October /2012	30.6
November /2012	67.6
December /2012	121.0
January /2013	258.7
February /2013	18.1
March /2013	03.6
April /2013	24.0
May /2013	00.4
June /2013	00.0
July /2013	00.0
August /2013	00.0
Total	**524**

Precipitation depends on climate change, so the quantity of rainfall fluctuates every year. The quantity of rainfall during the previous ten years ranged from 370 mm and 580 mm. Thus, the quantity of rainfall may go down below the level of the study year 2012/2013 of about 30% and sometimes it reaches 10% above the level of the study year. Figure (2.3) shows the rainfall quantities during ten years.

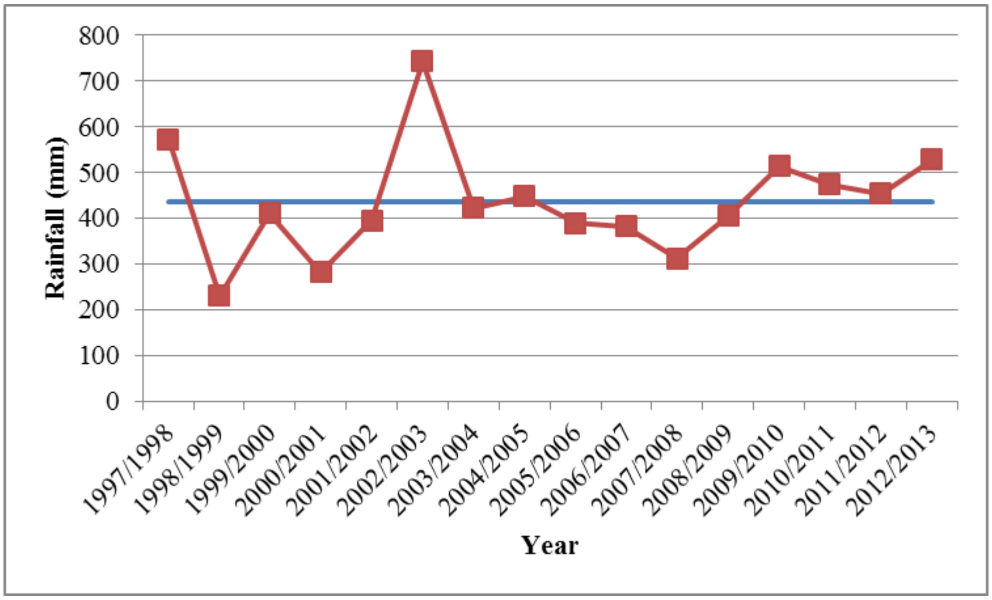

Figure 2.3: Rainfall during previous ten years (I Isam, Palestinian Meteorological, 2014)

The average annual rainfall for the last 16 years was 435 mm, four years of which had an average above that range, and five years had an average below that range, the remaining seven years had an average within that range.

The researcher conducted interviews with the wells owners who gave information about digging methods, layer penetration during digging, irrigated area, type of crops, and the history of each well.

Chapter Three

Literature Review

Various scientific papers on modeling have been investigated. Some papers studied the models in general and built the numerical model based on studying joints. Other studied built the numerical model for the pre-quaternary based on the objective of knowing the hydraulic head and the abstraction quantity from wells.

Other studies have been conducted in unconsolidated setting and multi aquifer by using GMS program, based on available data of the wells.

And on the available local scientific papers in the West Bank among which was a study on Eocene aquifer in the northern West Bank. Which was built based on the wells data and layers in the region.

There is a study on the quantity of recharge in each of the West Bank basins.

Jacek Gurwin. 2005, build a numerical modeling in the complex, unconsolidated, multi-aquifer system of the Swidnica area. This study used Groundwater Modeling System (GMS) to develop a conceptual model on the basis of data from several hundred boreholes and to calibrate a numerical, multi-aquifer model.

By using historical natural groundwater table data and abundant pumping test transmissivity data was performed to a study area. The calibrated recharge was distributed based on surface lithology. The quasi-natural simulation budget input of ~165,000 m^3/day consisted of 40.5% of lateral inflow from the SW fault model boundary. 34.5% of average net recharge from precipitation, 13% of infiltration from the Mietkowskie Lake and 12% of river infiltration. The budget output (the same as input) consisted of ~ 88% of river drainage and ~ 12% of lateral outflow.

Abstraction-influenced simulation representing the current stationary condition was used to verify the model by cross referencing present well drawdowns with well abstractions and by comparison of the groundwater discharge to the rivers with the field base-flow measurements.

In this simulation, the total well abstraction of ~53,000 m^3/d resulted in 9% increase in overall water balance up to ~180,000 m^3/day. 38% increased river infiltration. 24% reduced river drainage. 17% reduced lateral outflow and ~3 times increased downward leakage to the deepest. Productive aquifer.

At study area the abstractions of wells show a decline of groundwater table and river discharges. Concluding that reserves of renewable water resources are still available. It shows also, that by setting up a conceptual model within the numerical model environment and by applying a quasi-3D solution, complex multi-aquifer systems can be well and efficiently modeled.

Robert W. 2008, build a numerical model and defined it as “is described for coupled flow and mechanical deformation in fractured rock”. He depend on rock joints as mechanical process that effect on geometric characteristics to change in hydraulic pressure. The concept of his work is to combine straightforward finite element solutions with complex and realistic fracture surface geometry in order to reproduce the non-linear stress-deformation-permeability coupling that is commonly observed in fractures.

Building on the numerical model he applied method and developed it to generate a finite element mesh representing discrete fractures with realistic rough surface geometries embedded in a rock matrix. The finite element code GeoSys/Rockflow was then used to simulate the coupled effects of hydraulic stress, mechanical stress, and surface geometry on the evolving permeability of a single discrete fracture.

Dorte Seifert. 2008, build two numerical groundwater models at a buried valley, were produced to help quantify the effect of the valley on groundwater vulnerability. Both models to calibration and were found to describe hydraulic head and river discharge equally well. One model included the buried valley and the other did not. The buried valley incised into a sequence of pre-Quaternary sediments is shown to seriously affect the vulnerability of groundwater.

The groundwater at study area placed in the pre-Quaternary deep aquifer surrounding the buried valley was different for the two models, with significantly higher vulnerability when the valley was included in the model.

Based on the results it is concluded that a buried valley may not always be detectable when calibrating a wrong conceptual model. If reliable results should be obtained a good geological model has to be constructed.

A. Marei. 2010. The quantification of natural recharge rate is a prerequisite for efficient and sustainable groundwater resources management. Since groundwater is the only source of water supply in the West Bank, it is of utmost importance to estimate the rate of replenishment of the aquifers. The chloride mass-balance method was used to estimate recharge rates at different sites representing the three groundwater basins of the Mountain Aquifer in the West Bank.

The recharge rate for the Eastern Basin was calculated as between 130.8 and 269.7 mm/year, with a total average replenishment volume of 290.3×10^6 m^3/year. For the Northeastern Basin, the calculated recharge rate ranged between 95.2 and 269.7 mm/year, with a total average recharge volume of 138.5 × 10^6 m^3/year. Finally, the recharge rate for the Western Basin was between 122.6 and 323.6 mm/year, with a total average recharge volume of 324.9 × 10^6 m^3/year.

The scientific papers have been utilized in building the model, and on the basis of Geo/sys in order to stimulate the model with the real situation on the ground. And to build a reliable model we have to build a good geological model.

And to build a model we have to collect data on the wells in the area. The literature papers were very useful in the method presentation of data in the model.

The local scientific papers was useful in determining aquifer permeability in the study area and the direction of groundwater flow and the amount of water recharge in the groundwater basis in the study area which is the North Eastern Basin.

Chapter Four

Methodology

There are many methods to determine the Eocene aquifer at study area and to build a model. I began by surveying study, to determine different wells and there locations, then Geo-physical methods, cross sections, GIS program, and modeling program (GMS program).

4.1 Survey study

Study area is an important agricultural area, that which is manly dependent on groundwater. Many of the wells in the area are dried or semidry.

The topography of study area is hilly in the south and the elevation decreases towards the north where it became flat in the plains, I used the GPS for calculating the elevation and location of these.

By interviewing owner of the wells, data on drilling methods, type of layers penetrated during drilling, and the area that is to be irrigated, types of crops and the wills history was collected during the interviews.

A list of names of the wells owners and their locations was prepared. In this list, the wells were classified, and the data that includes the well depth, and if the well was dug up to the Senonian formation, the well capacity, and the water level in each well that was measured by a water level meter.

Data on the adjacent wells was gathered in which types of layers are demonstrated like will number 17-20/051J which belong the PWA, and these data where used for building the for the required model.

4.2 Geo-physical methods

Since the publication of the *Applied Geophysics* in 1990 many changes and development had been witnessed as result of better instrumentation, the extensive application of computer techniques, and more complete understanding of the factors that influence mineral accumulations. (Applied Geophysics book, 1990).

Geophysics was applied at the study area to determine the structure, hydrogeology and lithology of the study area. Geophysics can be used to determine the kind of formations that lies under ground. From the previous studies there are 9 geophysical points used in the study area, which are located at the middle of the study area and covering most of the wells. Then we applied 8 geophysical points at the east and the middle site of study area. Figure (4.1) shows the points of geophysics at the study area.

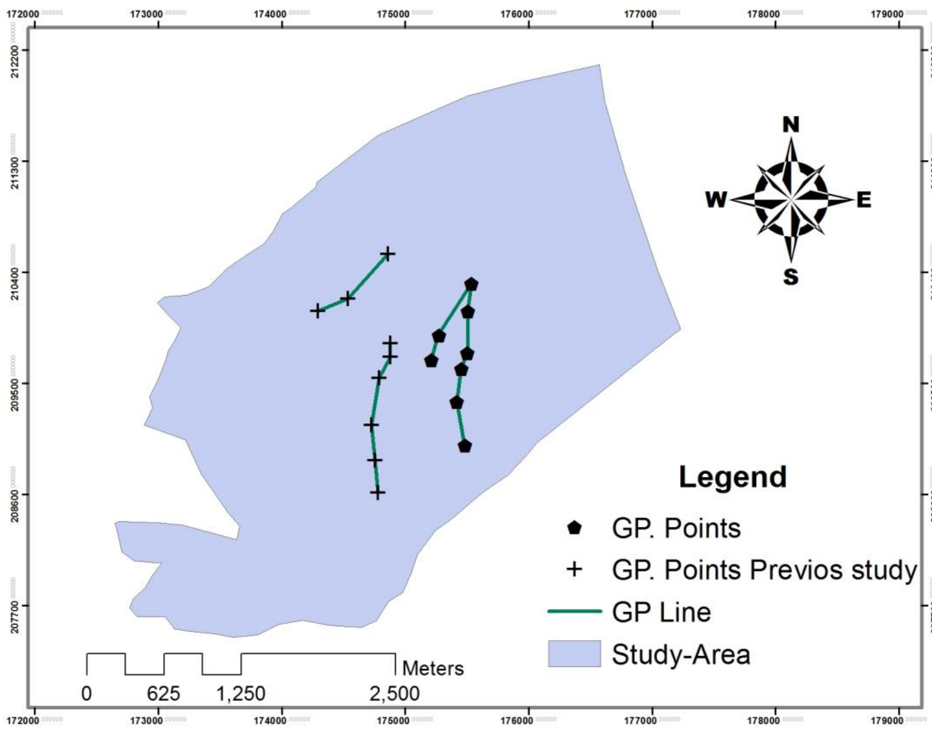

Figure 4.1: Geophysics points at the study area

4.3 Cross sections

Detailed descriptions of the lithology were made and geophysical logs were recorded. Lithology of wells was carried out for stratigraphical interpretation. Lithology data of the study area consisting of four profiles across the study area with a total length of 4 Km was performed to obtain information about the study area cross sections profile. Figure (4.2) shows the location of cross sections with geophysical profiles at study area.

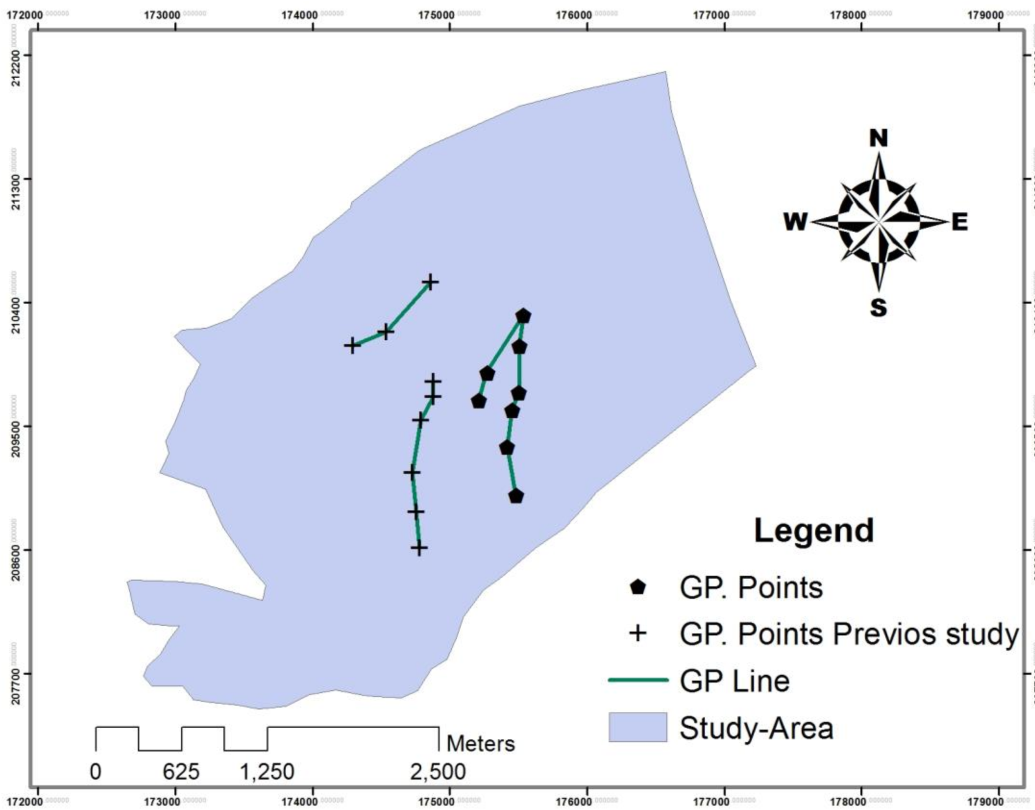

Figure 4.2: Cross section with geophysical points

4.4 Recharge

Monitoring of groundwater levels, the analysis of groundwater quality and testing of aquifer hydraulic properties are required to determine the performance of a groundwater system in response to natural and induced conditions. These parameters were used to assist with developing a conceptual model for Kufr-Dan area.

In the study area there are many factors to calculate a recharge for groundwater, recharge from rainfall, water losses from water network, infiltration of wastewater from cesspits, and infiltration from irrigated water.

The quantities of groundwater recharge through rainwater were calculated by working out the amount of rainwater in the area and then multiplying it by a constant rate to calculate the amount of water infiltration. To calculate the amount of water infiltration, the quantity of water was multiplied by the loss rate (31%) then multiplied by the constant rate. As for the amount of water leakage from cesspits, the number of people living in the area was identified along with the amount of their water consumption that was multiplied by 80%, that is this amount makes the waste water which is then multiplied by 90%. Regarding the amount of water leakage through irrigation, the amount extracted from groundwater for irrigation was calculated then multiplied by 10%, which is the remaining quantity of irrigated water that leaks into the ground water.

The land was divided into three sections: agricultural land, populated land, and deserted land. The water leaks from the agricultural land to the underground through rain and irrigation. From the populated land, rainwater, lost water and wastewater infiltrate into the groundwater, whereas rain water infiltrate from the deserted land to the groundwater.

4.5 GIS Database

All relevant data were tabulated and were used to create the shape files under ESRI-GIS software to cover the geological, hydrogeological and hydrological aspects in the study area.

Structured contour maps, drainage boundary, groundwater flow systems and the topographic map were digitized and converted into shape files (themes). Formation thickness, saturation thickness and depth to water levels were calculated.

4.6 GMS Software

GMS software (MODFLOW) was used as the modeling software for this study. MODFLOW is a 3-D cell-centered, finite difference, saturated flow model developed by the United States Geological Survey (McDonald & Harbaugh, 1988). The input data for MODFLOW are generated by GIS and saved to a set of files. These files are read by MODFLOW when it is launched from the GMS menu. The output from MODFLOW is then imported to GMS for post-processing.

4.7 Boundary Conditions

The boundary conditions are constraints imposed on the model grid to represent the interface between the model calculation domain and the surrounding environment. There are three major types of boundary conditions table (4.1). All of which may vary with time. The type of boundary selected should be consistent with the conceptual model and the water budget, and should be located and oriented consistent with the physical features it represents. In particular, model domain boundaries should be set far from the area of interest (eg. a water supply borefield) so that imposed stresses on the grid interior do not reach the boundaries. Alternatively, the boundary needs to be configured such that the simulated boundary effect is realistic (eg. using a head-dependent flow boundary at a groundwater divide or a surface-groundwater interaction feature).

Boundary conditions should be designed to take advantage of physical or hydraulic boundaries. Physical boundaries usually relate to the physical presence of an impermeable geological formation or a large body of surface water. An impermeable boundary typically forms the lower and/or lateral boundaries of modeled systems, and may be justified provided there is at least a two order of magnitude contrast in hydraulic conductivity between the two units (Anderson and

Woessner, 1992). Hydraulic boundaries form as a result of hydrologic conditions, notably at groundwater divides and streamlines, although these features are not permanent, and may shift their location or magnitude (of flux or head). Care must be taken in specifying hydraulic boundary conditions, whereas physical boundaries are more easily handled.

Table 4.1: Major Types of Model Boundary Conditions (K. Spitz and J. Moreno, 1996).

Boundary Type	**Technical Description**	**Common Applications**	**Effects of Boundary Condition on Solution**	**Comment**
Specified Head (the head value is specified and the model calculates the flow across the boundary to or from the model domain)	First Type	Rivers, coastlines, lakes, groundwater divides, known pumping water levels in bores, dewatering targets.	Easiest to solve, but constrains solution to greatest degree (can artificially constrain solution too greatly).	Commonly used because head data can be measured much easier than flow data. A specified head allows an inexhaustible amount of water flow (calculated by the model) into or out of a model.
Specified Flow (the flow value is specified and the model calculates the head at the boundary)	Second Type	Impermeable boundary, groundwater divide or streamline, infiltration source, evaporation sink, lateral inflow or outflow, other known sink or source fluxes (eg. adjacent aquifer or pumping bore)	Moderately difficult to solve, and involves moderate constraints on solution.	The "no flow" boundary is a special version of the specified flow boundary, and is the most commonly used boundary, especially to define low permeability formations adjacent to or underlying aquifers, or for streamlines (flow directions transverse to groundwater level contours).
Head-dependent Flow (the model calculates the flow for the given head)	Third Type	Leaky rivers, drains, flow to or from adjacent aquifers, basement leakage, springs.	Most difficult to solve, and involves least constraints on solution. Can form a very complex and sensitive boundary condition.	Care is required in some cases, as the model-calculated flow is subject to a conductance parameter, which may need to vary with time, and this may violate some calibration assumptions.

The boundary condition at the study area is determined by studying the geological siting, the structural geology of Eocene formation. It was determined from the south by the topography. From the west, it was determined at the edge of the Senonian formation as aquiclude formation and on the basis of topography. From the east and the north, the boundary was determined on the basis of the boundary of study area. Figure (4.3) shows the boundary condition of the study area.

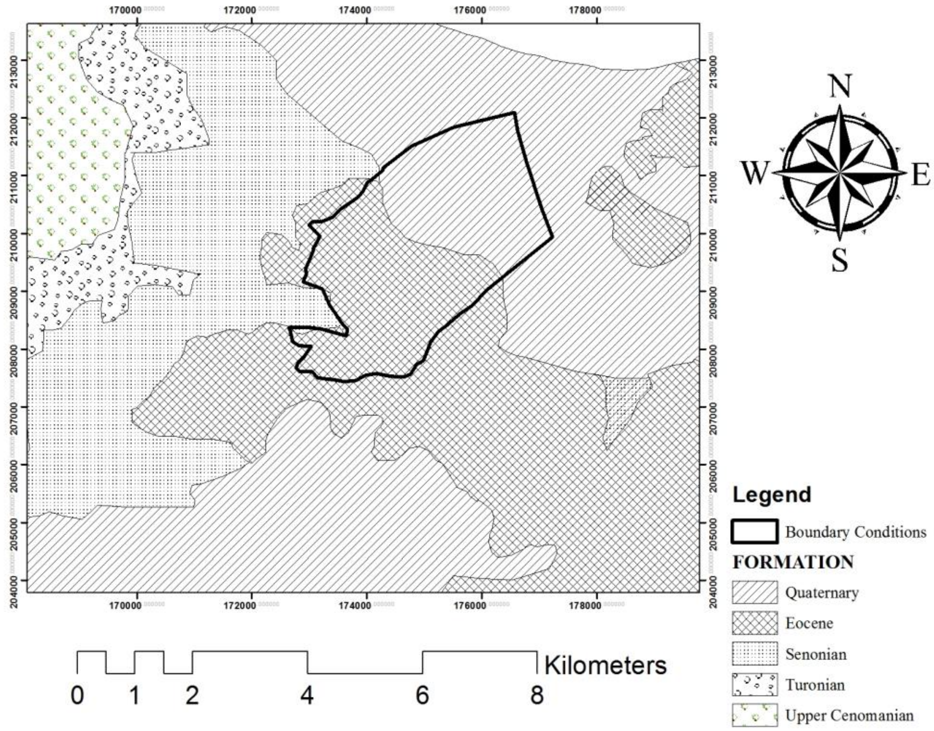

Figure 4.3: Boundary condition of the study area

4.8 Layers

Layers are used in models to represent hydrostratigraphic units, which comprise geological units with similar aquifer properties. Several geological formations may be combined into one hydrostratigraphic unit (or model layer), or a geological formation may be subdivided into aquifer and confining units (or several layers). Quasi-3D (multi-layer) models usually simulate horizontal flow in each of the stacked aquifer layers, and vertical leakage through confining units between layers.

Aquifer head and storage is often not simulated in the confining unit. This is considered an acceptable approximation when there is more than two orders of magnitude contrast in hydraulic conductivity between the aquifer and confining units (Anderson and Woessner, 1992).

4.9 Profile Models

Profiles models consist of two-dimensional models oriented vertically, and are used when vertical flows or vertical hydraulic gradients are important, but a fully-3D model may not be warranted. A profile model is usually a vertical slice of unit width of aquifer, which must be oriented along a flow-line to remain consistent with the assumption of conservation of mass. As more layers can be accommodated in a profile model (than a real model) for the same level of computational demand, profile models are suitable for situations in which detailed simulation of vertical flow components is essential.

4.10 Water Budget

The preliminary water budget should be outlined in terms of the major components of natural recharge and discharge, and human-induced stresses (abstraction and seepage). The locations where these inputs and outputs are manifest must be detailed, along with known or expected changes with time (due to climatic variations, pumping, seepage and surface-groundwater interaction). The water budget needs to be viewed in conjunction with the conceptual model to estimate the overall throughputs of water through the groundwater system. The initial estimates should be cross-checked with subsequent modeling estimates of long term and short term water budget components.

4.11 Groundwater Quality

Physico-chemical parameters were recorded from a random selection of wells in the study area during measuring water levels and collecting groundwater samples, where the concentration of the nitrate, chloride, and bicarbonates was analyzed, to determine if there was any contamination from wastewater.

Chapter Five

Data Acquisition

The study focuses on 73 wells, 38 wells are operating and the rest are not working. The depth of these wells ranges from 90-220 m as shown in table (5.1.a/b).

Table 5.1.a: Name, coordination, elevation, depth, water level and Pumping of wells

Id	Name of the owner of the well	X-Coordinate	Y-Coordinate	Elevation (m) (a.s.l)	Depth (m)	Water Level (m) (a.s.l)	Pumping (hour)
1	Lutfi Marai	175369	209924	135	204	-38	13
2	Nedal Marai	175384	209866	132	160	-25	Not Pumping
3	Shaker Marai	175313	209925	112	218	82	Not Pumping
4	Mohammad Marai	175338	209607	141	165	26	8
5	Azmi Marai	175500	209671	140	220	-4	5
6	Nader Marai	175587	209622	147	200	105	2
7	Mahmoud Saleh	175665	210598	97	170	No Data	8
8	Amjad Sabri	175762	210682	97	180	No Data	10
9	Mohammad Marai	175923	210866	96	207	No Data	15
10	Mohammad Marai	175951	210923	95	190	No Data	25
11	Alaam marai	175936	211097	93	170	No Data	22
12	Mahmoud Hardan	176150	211171	93	No Data	No Data	15
13	Hatem Slah	174401	209085	170	153	-60	5
14	Saleh Marai	174287	209082	170	123	-50	5
15	Hesham Slah	174332	209137	165	173	-48	8
16	Abdallah Drwesh	174305	209201	162	140	-51	5
17	Samer Slah	174369	209270	165	150	-100	6
18	Husam Marai	174572	209270	170	170	No Data	8
19	Nader Marai	175275	209957	136	No Data	107	2
20	Murad Kamamjah	175210	209922	134	No Data	-1	Not Pumping
21	Amjad Kamamjah	175208	209883	134	No Data	67	Not Pumping
22	Louai Abed	175115	210057	140	158	37	4
23	Amen Souqi	175095	210091	136	189	63	10
24	Mohammad Marai	175189	209995	134	No Data	71	Not Pumping
25	Samer Marai	175065	210029	140	220	57	10
26	Soufian Tahainah	174986	210016	144	195	49	13
27	Mohammad Marai	174900	210050	147	200	No Data	4
28	Rabea Marai	174949	210115	145	180	38	6
29	Isam Marai	175035	209933	146	200	50	8
30	Amen Marai	175001	209911	150	183	7	8

Table 5.1.b: Name, coordination, elevation, depth, water level and Pumping of wells.

Id	Name of the owner of the well	X-Coordinate	Y-Coordinate	Elevation (m) (a.s.l)	Depth (m)	Water Level (m)	Bumping (hour)
31	Omar Marai	174847	209794	146	90	63	8
32	Isam Marai	174824	209979	147	150	-66	4
33	Kamel Marai	174738	210039	150	195	15	7
34	Nader Marai	174671	209652	150	No Data	17	5
35	Adnan Marai	174512	209830	153	185	91	4
36	Saed abed	174498	209920	147	140	No Data	8
37	Faiq Abed	174362	209925	154	168	84	6
38	Mohammad Abed	174396	209975	149	130	27	Not Pumping
39	Ahmad Marai	174463	209397	169	No Data	No Data	5
40	Fatehi Marai	174398	209397	164	No Data	94	Not Pumping
41	Namer Marai	174212	209375	149	190	70	4
42	Mohammad Marai	174106	209502	153	No Data	83	1
43	Nezar Marai	174180	209707	133	No Data	No Data	4
44	Nawaf Khalel	174203	209716	135	No Data	No Data	Not Pumping
45	Anwar Abed	174184	209732	134	No Data	No Data	Not Pumping
46	Nezar Marai 2	174169	209910	125	No Data	25	Not Pumping
47	Lutfi Marai	174061	209770	131	No Data	6	12
48	Mahmoud Abed	174071	209659	133	No Data	No Data	4
49	Nezar Abed	174297	209575	136	No Data	91	2
50	Mohammad + Naser	174277	209537	136	No Data	91	Not Pumping
51	Mohammad + Naser	174278	209540	136	No Data	No Data	Not Pumping
52	Mohammad Marai	174381	209591	141	No Data	105	Not Pumping
53	Ameen Abed	174407	209896	132	No Data	No Data	5
54	Abd Alsalam Marai	174610	210339	110	No Data	10	Not Pumping
55	Alaam Marai	174366	210535	123	95	71	Not Pumping
56	Lutfi Marai	174450	209626	150	No Data	No Data	5
57	Mohammad Marai	174139	209762	133	No Data	No Data	Not Pumping
58	Lutfi Marai	175860	210593	93	No Data	No Data	Not Pumping
59	Ahmad Jabaren	175235	210145	107	No Data	No Data	Not Pumping
60	Sobhi Marai	175282	210148	107	No Data	No Data	6
61	Mohammad Marai	175351	210089	108	No Data	No Data	Not Pumping
62	Bahaa' Marai	175337	210197	105	No Data	No Data	Not Pumping
63	Moustafa Abed	175406	210247	102	No Data	No Data	Not Pumping
64	Tareq Abd-Alqader	175506	210341	99	No Data	No Data	5
65	Ameen Abed	175588	210526	98	No Data	No Data	Not Pumping
66	Subhi Abed	175393	210607	101	No Data	No Data	5
67	Jamal Marai	175963	210920	95	No Data	No Data	2
68	Ahmad Abd Al-	174862	209843	110	160	-4	11
69	Alaam Marai	175661	210400	99	170	No Data	10
70	Mohammad Marai	174431	209440	168	No Data	-120	Not Pumping
71	Sadiq marai	174923	209644	130	No Data	-95	Not Pumping
72	Marwan	174211	209776	140	170	No Data	Not Pumping
73	Ameen Marai	175970	211409	91	200	No Data	Not Pumping

The operational wells are operated 18 hours a day where they work an hour and rest for the next hour because the permeability of the Aquifer is low.

The long-term average of well abstractions from Eocene aquifer was about 2.3 MCM in 2012/2013. The wells locations are shown in figure (5.1).

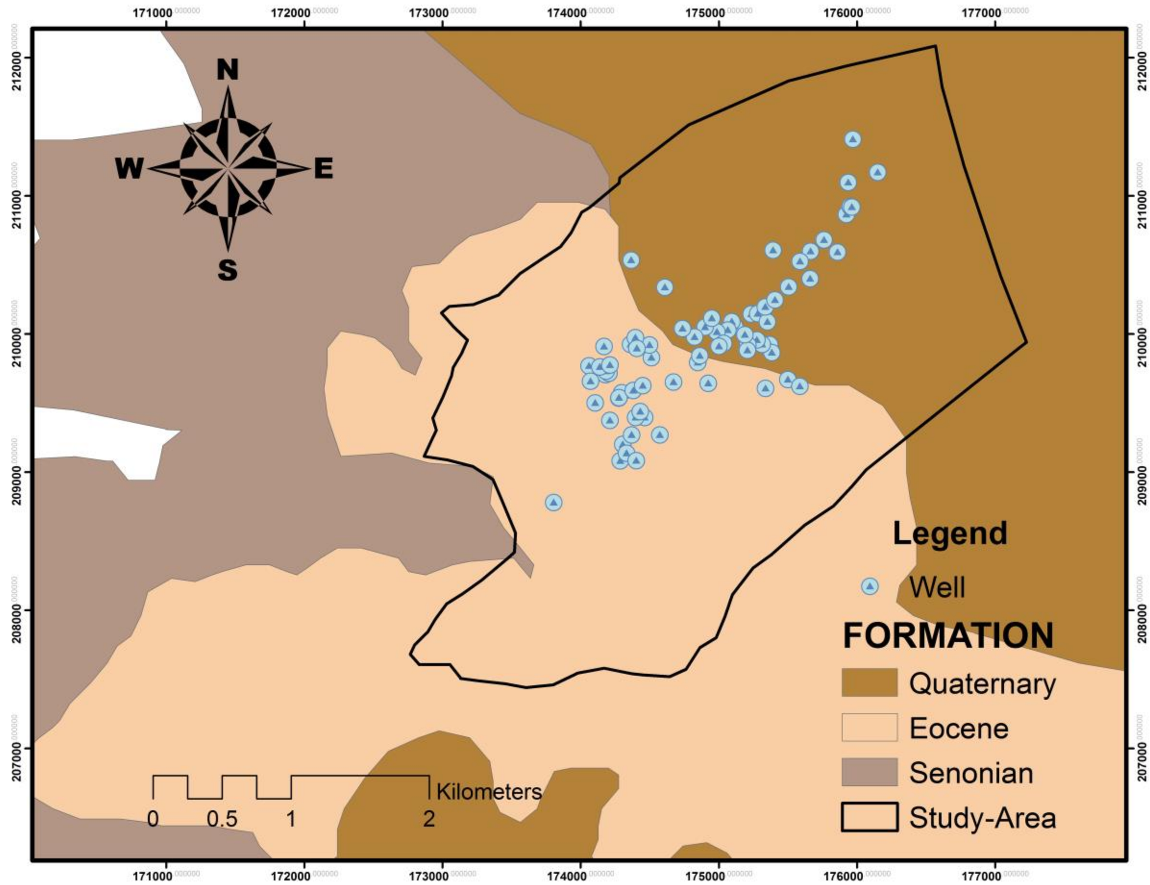

Figure 5.1: Well locations in the study area

The Water Table in wells is 120 m b.s.l to 107 m a.s.l, while the pumping rate ranges from 1-25 m^3/h. Figure (5.2) shows the pumping rate of wells according to location.

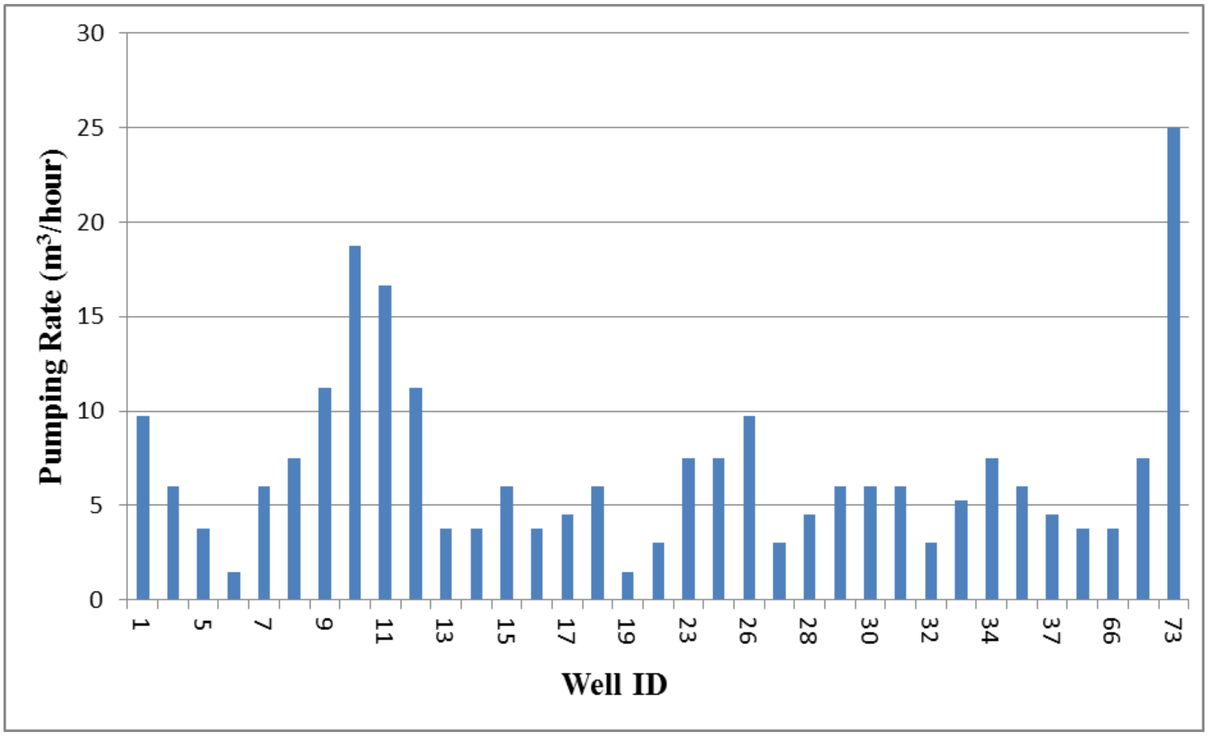

Figure 5.2: Pumping rate of wells

From the graph above, most of the wells discharge is less than 10m^3/h, and only five wells have a discharge over 10m^3/h.

Relation between depth and water column

Most of these wells reach a depth of 160-200 m, and despite of that depth, the discharge is considered low. Figure (5.3) shows the comparison between depth of the wells and the water column at these wells.

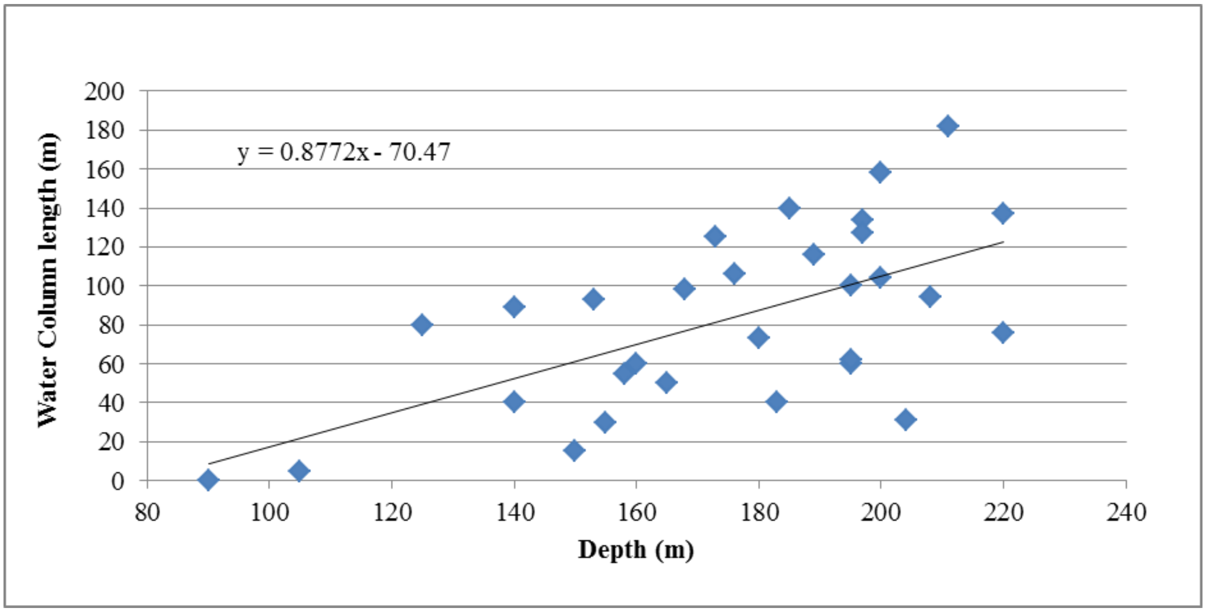

Figure 5.3: Depth of well compared with water column

As shown above, there is a relationship between depth and the length water column. With the increasing depth of the wells, the water column increases, so there is a direct proportional relationship between the depth of wells and the length of the water column. This is an indication that all these wells tap the same aquifer (shallow aquifer).

A higher water column does not mean a higher productivity. The discharge of the wells depends on the physical parameters of this aquifer. The Eocene aquifer has varying physical parameters because the lithology and the structure of the layer vary from one location to another. Figure (5.4) shows the comparison of pumping rate with water column length.

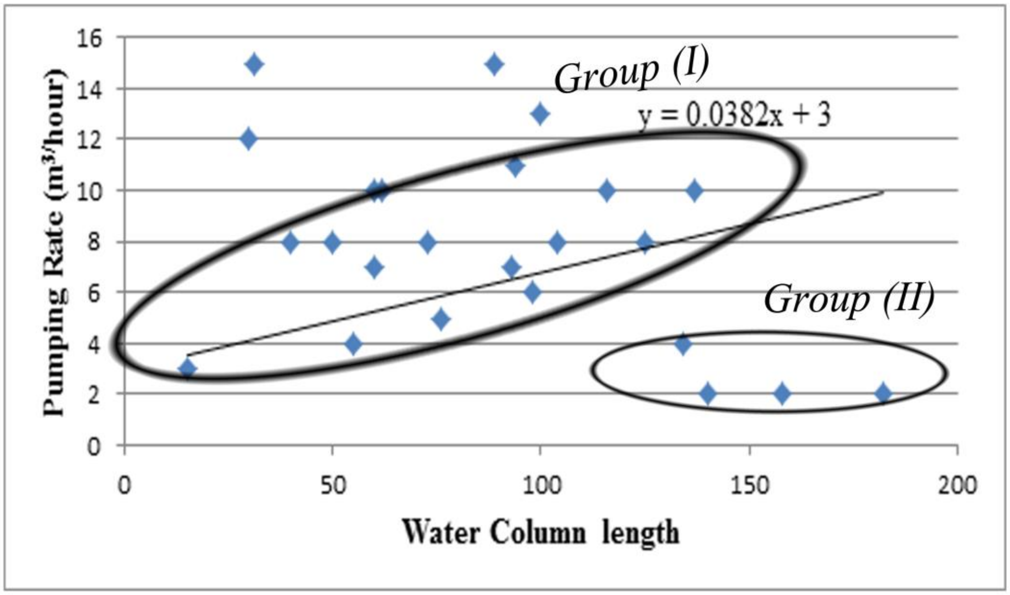

Figure 5.4: Comparison of pumping rate with water column

Group I: By increasing the water column length and the depth of boreholes the pumping rate increase. This is due to the fact that by increasing depth more formation are penetrated and more water is collect.

Group II: The water column length in these wells is high but the pumping rate is very low. Because the permeability in the Aquifer at is very low, and the over bumping in these wells, the abstraction from these wells is rabidly declining and most of wells have dried up.

5.1 Water level

A static water table has been recorded from most of the wells in the study area, and the contour map was drawn for the static water table. Figure (5.5) shows the contour map of the static water table of the area for the year 2011/2012.

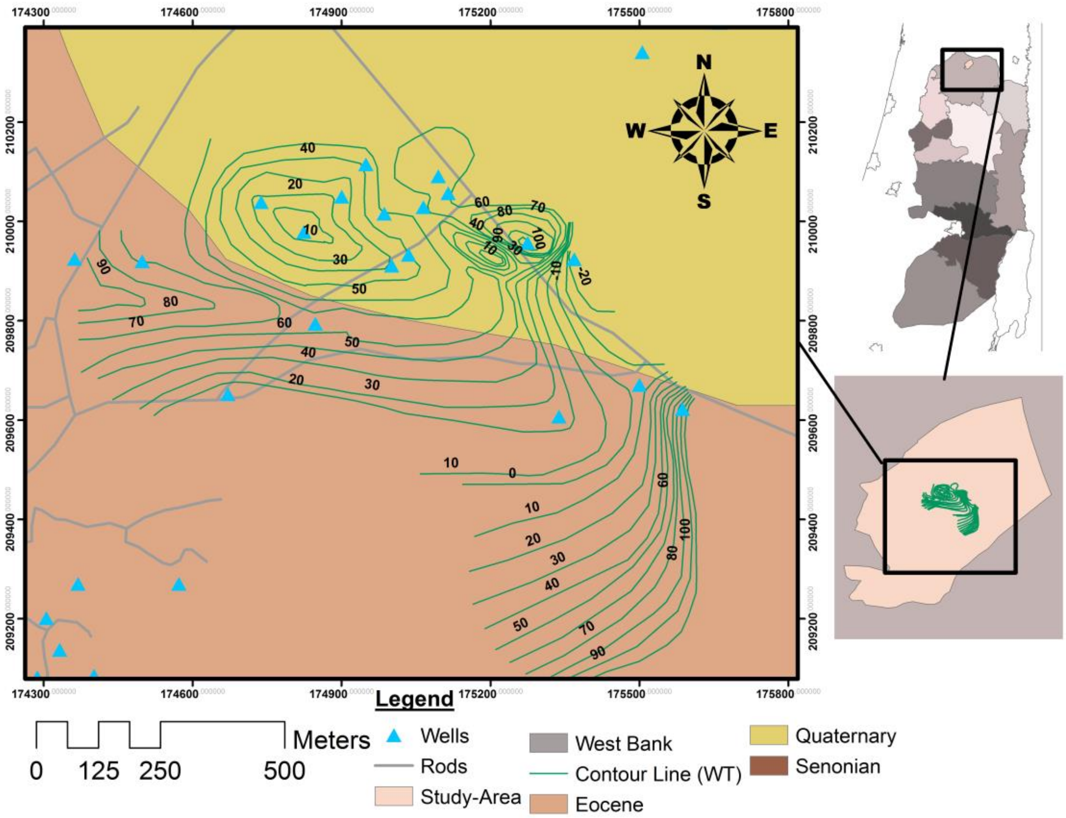

Figure 5.5: The contour map of water table at the study area

The water table in the study area declines from the southern site to the northern site. This is in agreement with the changing topography of the area. The water table ranges from 40-90 m a.s.l. The direct of lateral movement of the groundwater is from south to north and north easte. At the middle of the study area, over pumping and too many wells in the area, have led to more decline in the water table until it reaches the sea level.

The abstraction rate for these wells ranges from 2-25 m^3 /hour. Most of these wells dry up in the summer season. Table (5.2) shows the distribution of abstraction rates of wells in the area.

Table 5.2: Distribution of abstraction rates of wells

Range of pumping rate	Number wells	Percentage %
Dry	26	36
1-5	22	30
6-10	17	23
11-15	6	8
16-20	0	0
21-25	2	3
Sum	**73**	**100 %**

Most of wells are dry and have very low pumping rate. This will increase the running of cost for abstract a groundwater. The capacity of the wells varies from area to area. But the best capacity wells are concentrated in one area. Figure (5.6) shows the distribution of the operating wells in the study area.

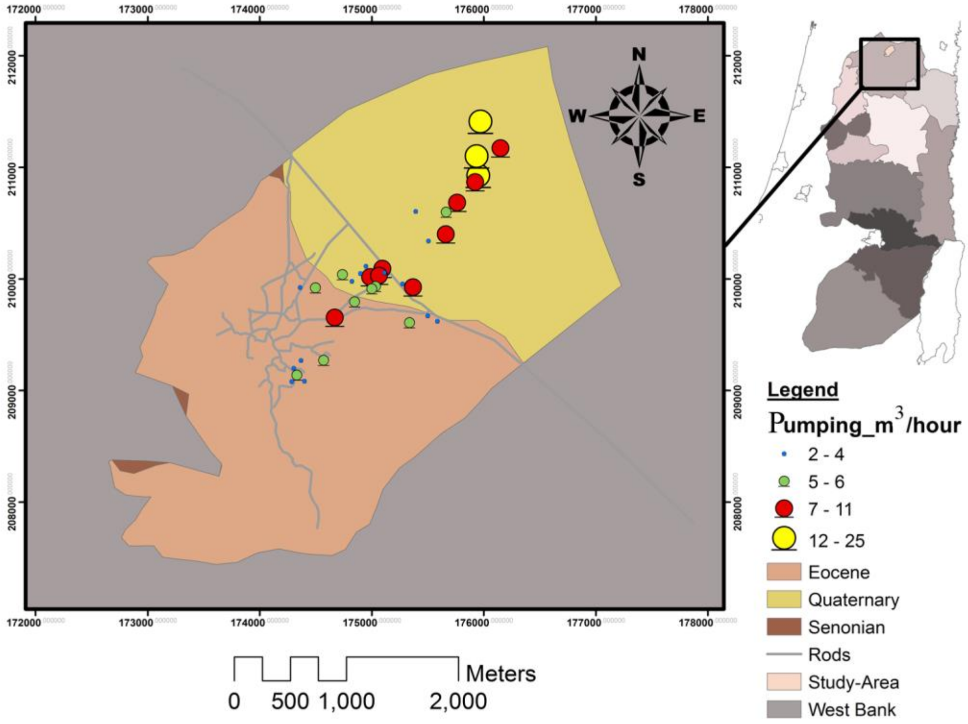

Figure 5.6: Pumping of wells at the study area

The wells location is concentrated at the center of village but most of them are dry. The pumping wells which have a productivity over $7m^3$/hour are concentrated along a line with north east direction at the center of the study area as shown in the figure (5.6).

5.2 Geo-physical studies

Two profiles have been used for conducting geophysics studies in the study area. The first profile has six measuring points in the north-south direction. The second profile has three points with a northeast-southwest direction as shown in (figure 5.7).

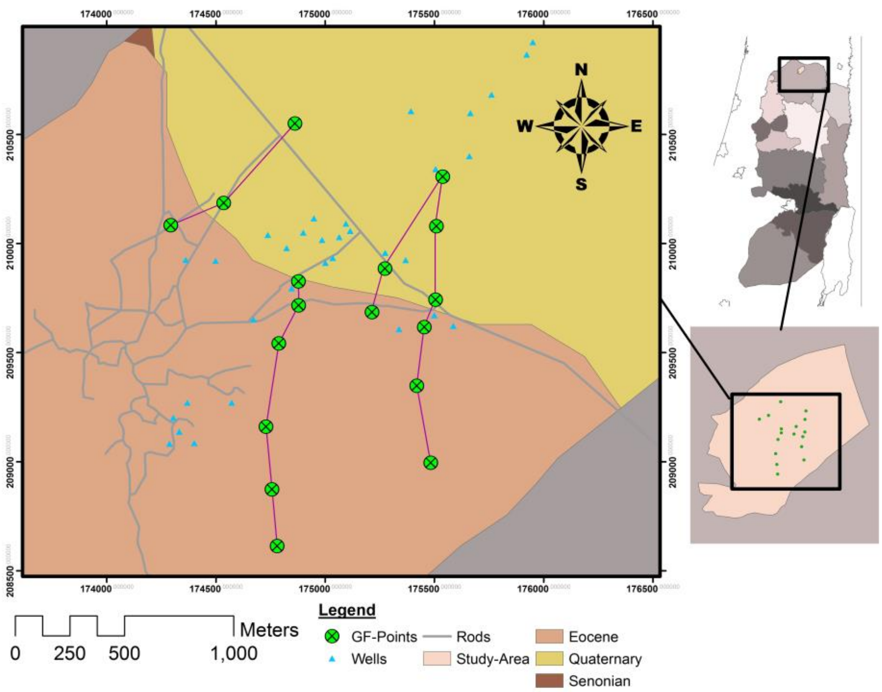

Figure 5.7: Geophysical profiles in the study area

The aim of the geophysical investigation is to determine the lithology of the underground which is important for the ground water modeling. The stratigraphy of the study area is Eocene and Quaternary formation. See appendix (1-4) of a detail of geophysics studies. So the model building was one formation as one layer, (shallow aquifer).

5.3 Groundwater Quality

The water quality is important to determine if there is any contamination from wastewater from cesspits or from Jenin WWTP. The groundwater use is mostly for agricultural, and few wells are used for domestic purpose.

Samples from wells are randomly collected in the study area. Figure (5.8) shows the well samples in the study area.

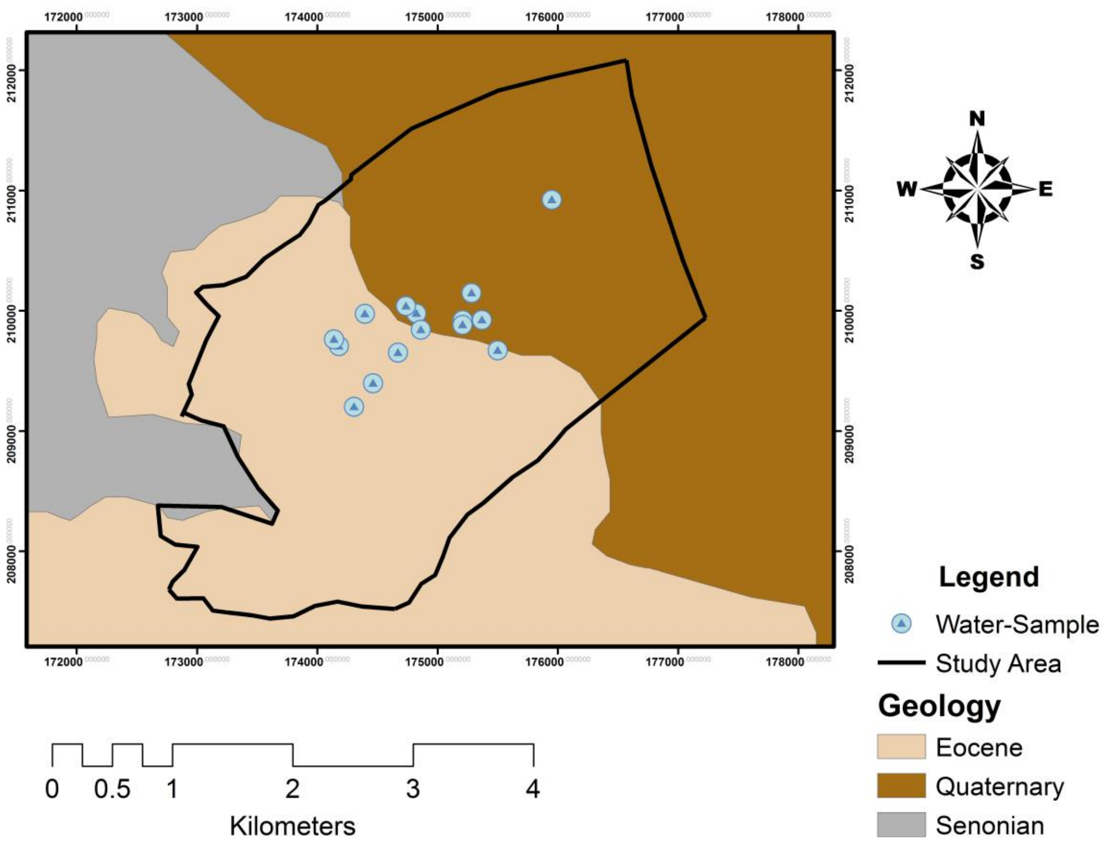

Figure 5.8: Location of water samples collected from the wells in the study area

The measuring of the concentrations of Cl^-, HCO_3 and NO_3 shows the location of water sample in figure (5.9). Table (5.3) shows the concentrations of sample.

Table 5.3: Data analyses of Water Sample

ID	Cl (mg/l)	HCO_3 (mg/l)	ID	Cl (mg/l)	NO_3 (mg/l)
1	212.7	305.1	**10**	177.3	49.5
5	106.4	317.3	**16**	106.4	47.4
20	127.6	311.2	**34**	88.6	21.5
21	124.1	311.2	**39**	88.6	39.0
32	106.4	305.1	**43**	106.4	48.0
33	99.3	317.3			
34	85.1	311.2			
38	106.4	335.6			
57	99.3	323.4			
60	109.9	292.9			
68	113.4	305.1			

The concentration of Cl^- and HCO_3 is in the safe range for domestic purpose. Cl^- is between 80–130 mg/l, and HCO_3 is in between 290–330mg/l. Figure (5.9) shows the concentration of Water Sample.

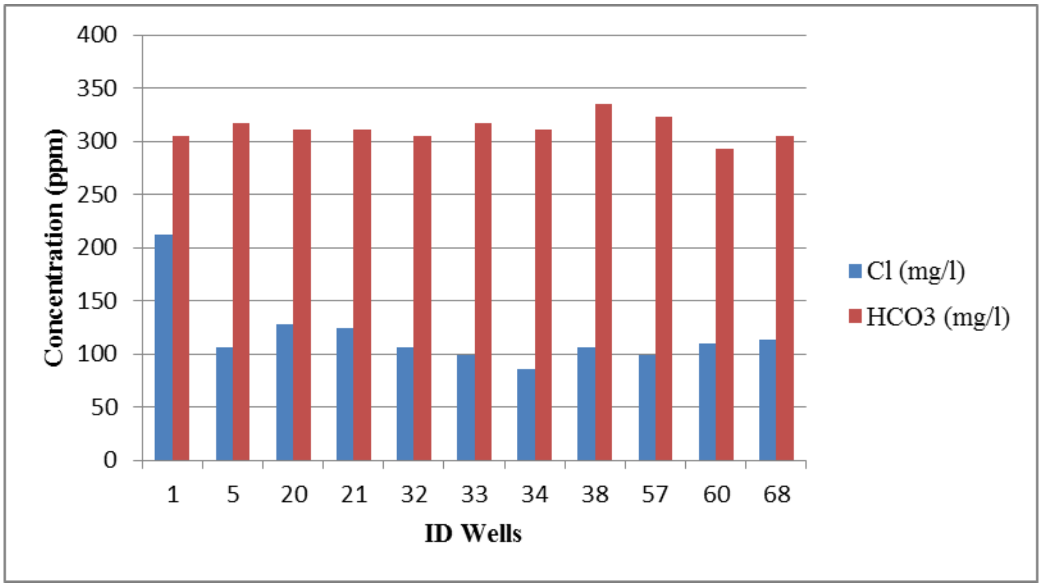

Figure 5.9: Shows the analysis of Cl^- and HCO_3 of water sample

The concentration of nitrate is in the safe range for domestic purpose. Its range is 20–50mg/l. Figure (5.10) show the concentration of nitrate and chloride of the water sample.

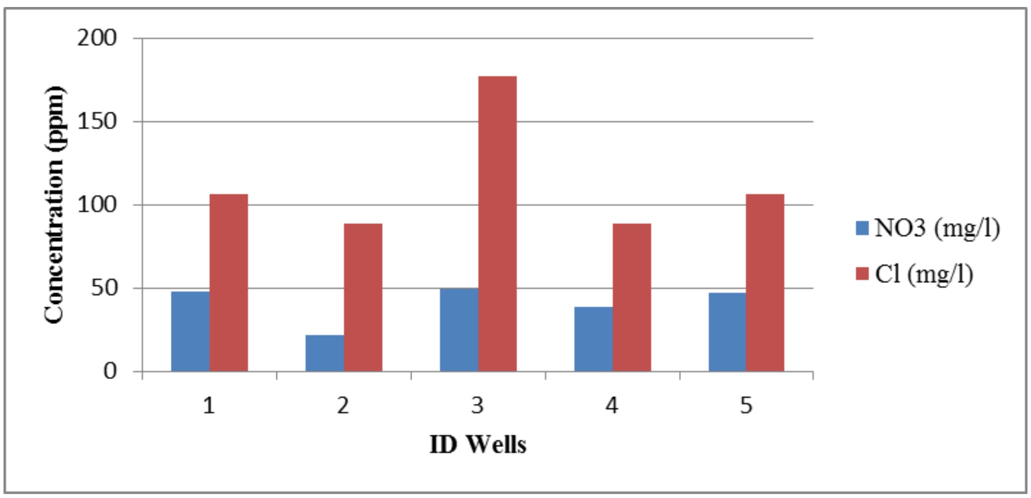

Figure 5.10: Shows the analysis of Nitrate and Cl^- of water sample

5.4 Conceptual model

The boundary condition is important to determine the border of a model. It is an important feature of groundwater model. The water budget is one of the most important features of the groundwater model. A water budget is determined by the amount of water that enters through and leaves an open system; in this case it is groundwater aquifer.

5.4.1 Boundary conditions:

The Boundary conditions of the modeled area depend on many considerations, such as model domain, model stratigraphy, lithology, water bodies and physical features within the study area. Figure (5.11) is a boundary conditions assumed in the study area.

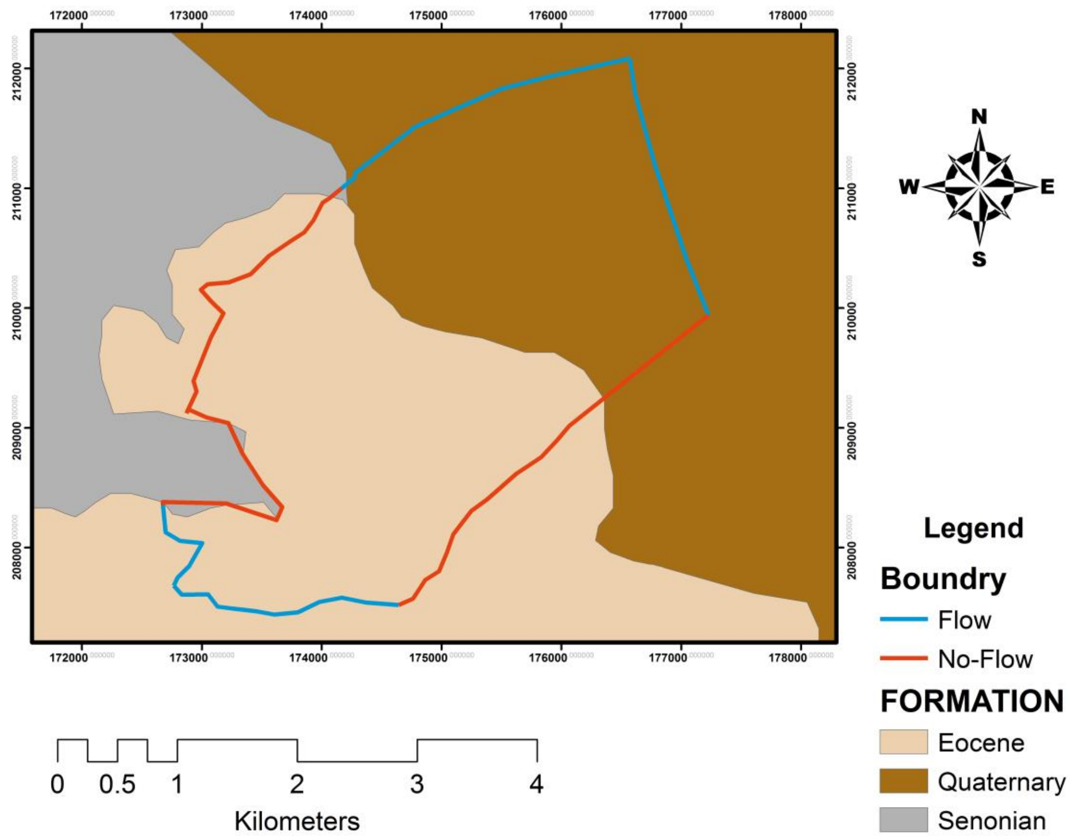

Figure 5.11: The boundary of the study area

The northeast site where the end of model and the north site of model until three formation contacts are simulated as a flow boundary, the remaining boundaries are structurally separated from the adjacent formations and will be modeled as no-flow boundaries. In the south side there is lateral flow (flow boundary).

No-Flow Boundary

A no-flow boundary is assumed for west site where the Eocene outcrop ends and is impermeable, i.e. the Senonian aquiclude. In addition, the north-east part of the Eocene is covered by alluvial deposits, where the general flow directions are to the north and northeast.

Flow boundary

The general flow boundary simulates the boundaries that allow groundwater to pass through it towards the northeastern site and from the southwestern site.

5.4.2 Geological Cross Sections and thickness of layers

From data about geophysics and lithology of wells we built three across section crosses the study area as shown in figure (5.12).

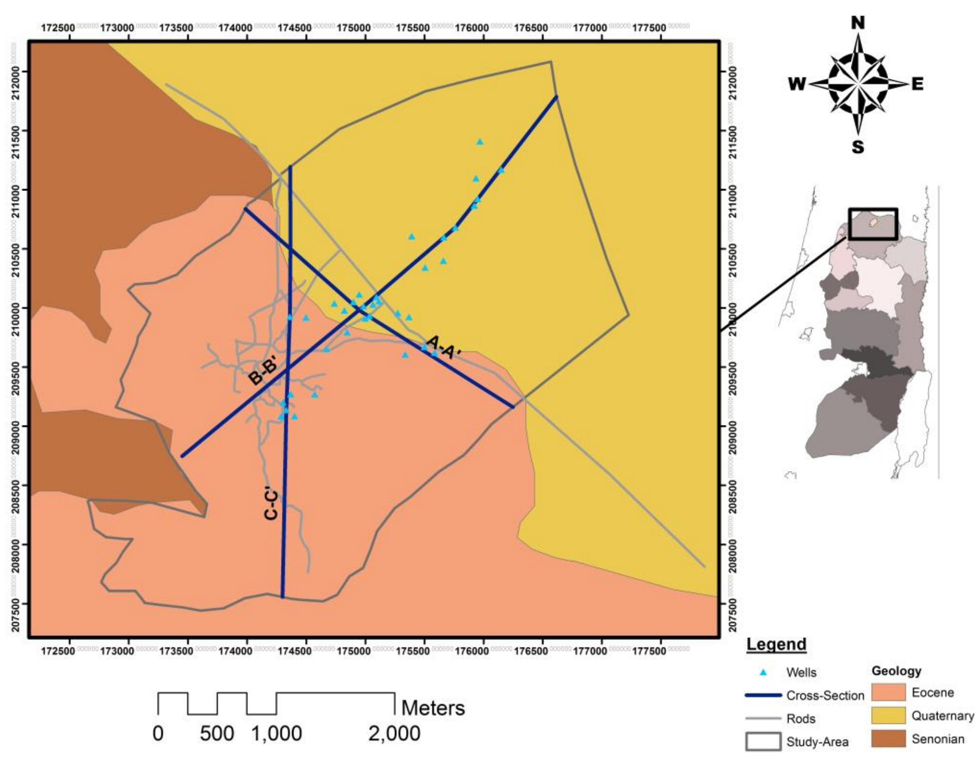

Figure 5.12: Cross sections location in the study area

The formation in the study area is Eocene formation, and is divided into saturated and unsaturated layers. The thickness of the cross sections is up to 350 m.

The Eocene formation overlies the Senonian formation which is composed of a chalk layer which acts as an aquiclude. Figure shows (5.13/14/15) the crosses section for the study area.

Figure (5.13) shows a 3,000 m cross section extending from west to east of the study area. This cross section represents the shallow aquifer layer (Eocene Formation), which overlies a clay layer (of a Senonian formation).

Well number (55) located in the western part of cross section has elevation 123m a.s.l and penetrate the shallow aquifer which has a deep 120m. The thickness the groundwater saturated layer is 80 m, while the unsaturated layer has a thickness of 40 m.

The thickness of the shallow aquifer decreases towards the west.

The thickness of the shallow aquifer layer at the middle of the cross section near well number (1) which has an elevation of 135m a.s.l increases until it reaches 220 m. the thickness of the saturated layer 120 m, and the unsaturated layer reaches 100 m.

Then the shallow aquifer layer decreases in thickness towards the east until it becomes 100 m thick, and the saturated layer becomes 40 m thick, where the eastern part the elevation increases up to 160 m a.s.l.

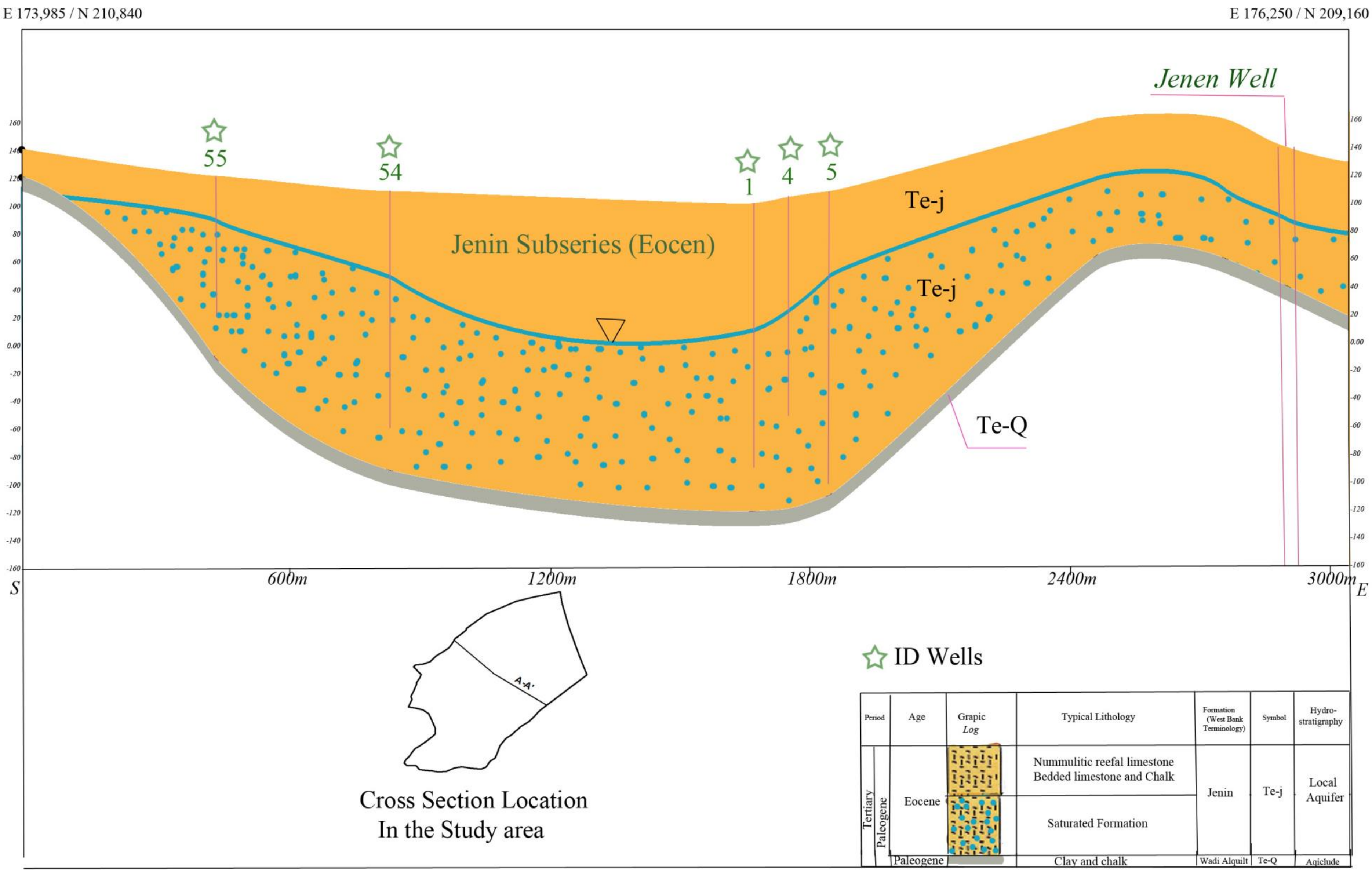

Figure 5.13: Cross section A-A’

Figure (5.14) shows a 5,500 m long a cross section that extends from the southwestern site to the northeastern site of the study area. This cross section shows the shallow aquifer layer of the Eocene formation, which overlies clay layer.

Well number (41) located at the middle of the southern part of the cross section at an elevation of 149 m a.s.l penetrates this shallow aquifer layer, which has a depth of 200 m.

The thickness of the saturated layer is reaches up to 140 m while the unsaturated layer reaches up to 60 m.

The thickness of the shallow aquifer layer decreases towards to south until it reaches a thickness of 50m.

The thickness of the shallow aquifer layer increases towards the northern part of the cross section, where the saturated layer reaches up to 160 m and the unsaturated layer up to 60 m.

After that shallow aquifer layer decreases towards the east till it reaches a thickness of 100 m, and that of the saturated layer decreases in thickness until it reaches a thickness of 40 m. The elevation of southeastern part increases to 160 m a.s.l.

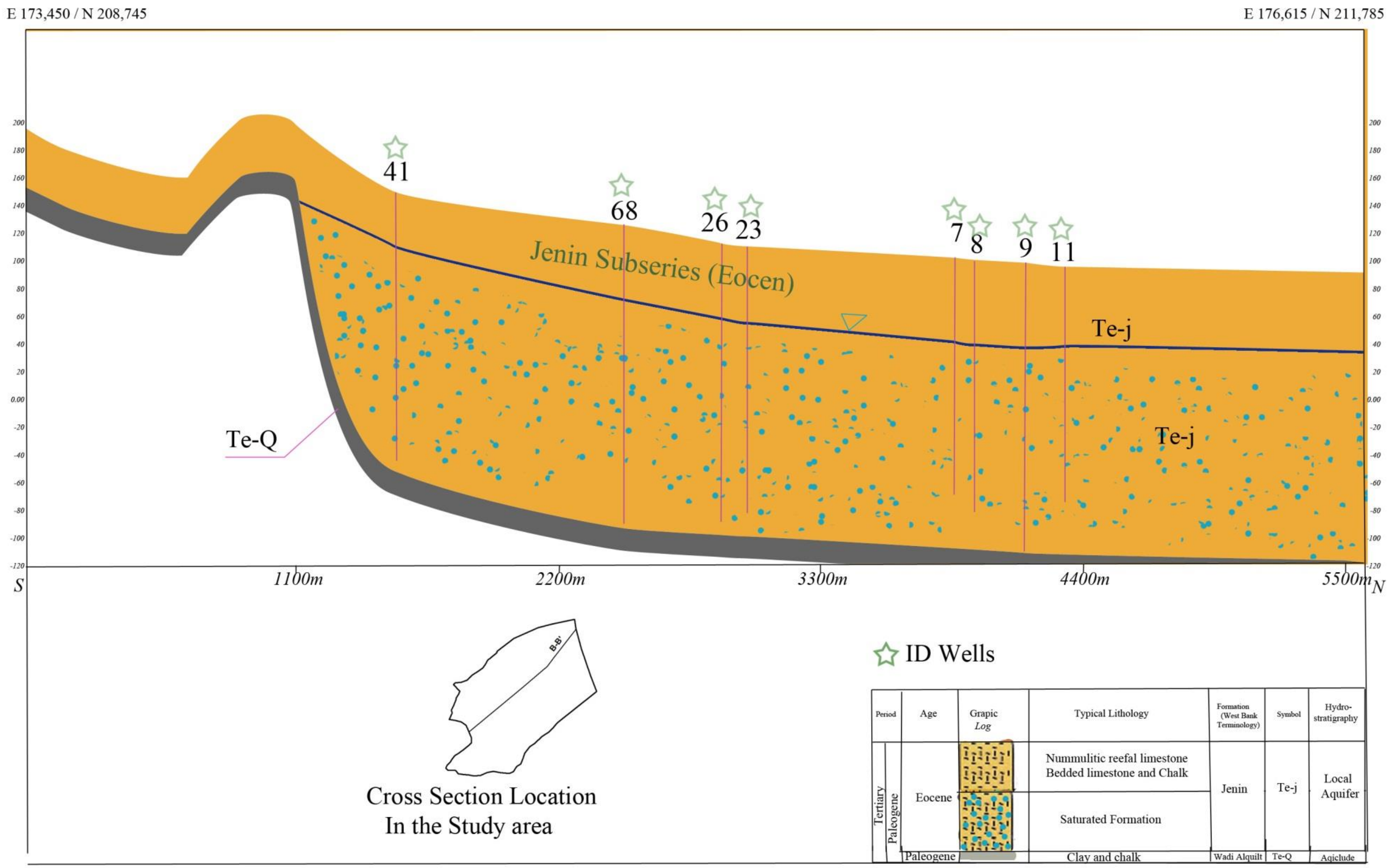

Figure 5.14: Cross section B-B’

Figure (5.15) represents a 3,500 m cross section that extends from the south to the north of the study area. This cross section represents shallow aquifer layer of the Eocene formation which overlies a clay layer.

Well number (55) located in the northern part of the cross section and it elevation of 123 m a.s.l penetrates the shallow aquifer layers which has a depth of 120 m. The saturated layer and the unsaturated layer reach a depth of 80 m and 40 m respectively. The shallow aquifer layer decreases in thickness towards the north.

The shallow aquifer layer increases in thickness at the middle of the cross section near number (37) which has an elevation of 154 m a.s.l, this layer reaches a thickness of 170 m, the saturated layer and the unsaturated layer reach a thickness of 120 m and 50 m respectively.

The shallow aquifer thickness remains constant till we reach the well number (15) where it starts decreasing towards the south. And then it starts decreasing in the southern area of the section till it reaches 50 m in thickness. The thickness of saturated layer decreases till it reaches 30 m. The southern area has an elevation of 240 m a.s.l.

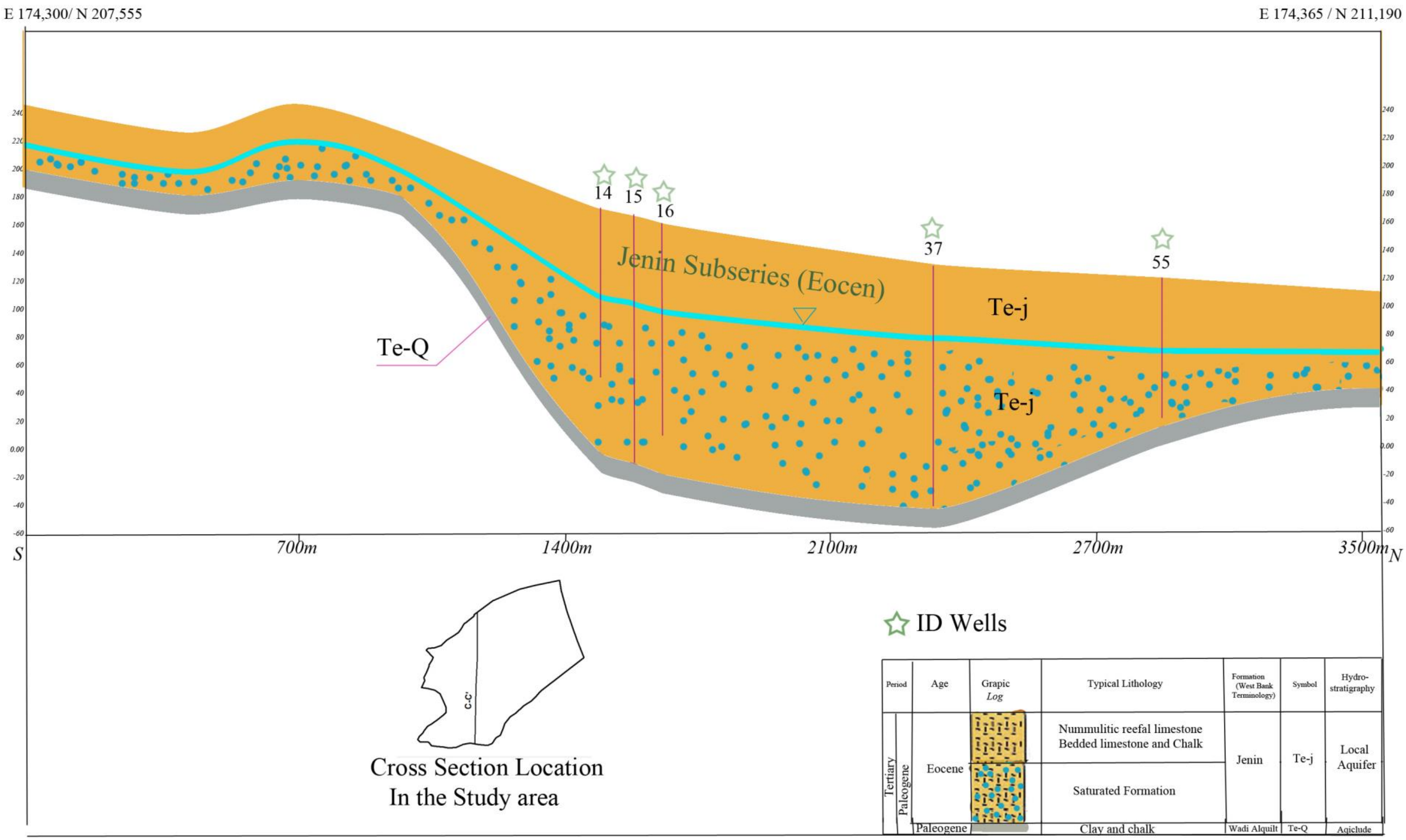

Figure 5.15: Cross section C-C’

5.4.3 Recharge Quantity

Groundwater recharge include water from rainfall, water losses from water network, infiltration of wastewater from cesspits and infiltration from irrigated water.

5.4.3.1 Rainfall

Rainfall amount were collected from two Meteorological stations in the study area in (2012/2013): Jenin stations and Yamoun stations. Table (5.4) and Table (5.5) show the data for both stations.

Table 5.4: Yamoun Station precipitation data 2012/2013

Day	Month											
	Sep.	**Oct.**	**Nov.**	**Dec.**	**Jan.**	**Feb.**	**Mar.**	**Apr.**	**May.**	**Jun.**	**Jul.**	**Aug.**
1												
2												
3												
4				16.4								
5				8	40	0		0				
6				4								
7				1.6	97							
8					86							
9			21					1.3				
10			20	17.8	86							
11			11.7	2.8		3						
12			3.1	0								
13									2.8			
14												
15												
16						3.1	3.5	3.3				
17							3.8					
18						1						
19				6.4								
20				30				31.8				
21				10				0				
22												
23			18.7			1	0					
24			3									
25												
26		30	0									
27												
28												
29					11.2							
30					19.6							
31												
Total	0	30	77.5	97	339.8	8.1	7.3	36.4	2.8	0	0	0
All Total	**598.9**											

Table 5.5: Jenin Station precipitation data 2012/2013

Day	Month											
	Sep.	**Oct.**	**Nov.**	**Dec.**	**Jan.**	**Feb.**	**Mar.**	**Apr.**	**May.**	**Jun.**	**Jul.**	**Aug.**
1						4.9						
2												
3												
4				16.2	7.3			1.5				
5				16.8	23.2			0				
6				14.8	37.5	1.2						
7				0.7	41.3	3.3						
8					81.5			0.8				
9			23.1		12.4							
10			13	13.3	2.2							
11			13.4	2.2		3.2						
12			2.8	0.4								
13									0.4			
14												
15						0.5		1				
16						3.8	1.1	5.2				
17			0.3				2.3	0.9				
18						0.2						
19				1.6				1				
20				38.6				12.8				
21				16.4				0.8				
22			7.6									
23			7.2			1	0.2					
24			0.2									
25		25.2			0.5							
26		5.4	0									
27												
28					2.2							
29					7.1							
30					23							
31					20.5							
Total	0.0	30.6	67.6	121.0	258.7	18.1	3.6	24	0.4	0	0	0
All Total	**524**											

The comparison between the two stations shows that the Jenin Station is more accurate, so we relied on the data of that station.

In previous studies which area shown in the flowing in the table (5.6), recharge has been calculated as a percentage of the long-term average rainfall over the basin as a whole, regardless of the nature of outcropping formations or the spatial distribution of rainfall. In this study, a spatial approach was used.

Table 5.6: Rainfall-recharge percentage from different studies

Author	Year	% of recharge	Study area
Blacke & Goldschmidt	1947	25%	WAB*
		22%	Auja-Jericho
Rofe & Raffety	1963	20-45%	-
		55%	Local areas in wet years
Arad & Michaeli	1967	6-48%	EAB* (32%)
Scarpa	1994	20%	Upper aquifer-Jordan Valley-Jericho
Tahal	1995	0-60%	Lower aquifer
Blake & Goldschmidt	1947	22	-
Goldschmidt	1959	34	-
Rofe and Raffety	1965	25.7	-
Arad & Michaeli	1967	32	-
Tahal	1995	25-60	-
CDM	1997	20-30	-
ANTEA	1998	20	-

*EAB: East West-Bank

*WAB: West West-Bank

The equation from conceptual model report for estimation of the recharge values from rainfall is:

Rc = 0.8 [avp – 360] Rainfall > 650 mm ……..... (1)

Rc = 0.534 (avp-216) 650 mm>Rainfall>300 mm ……(2)

Rc = 0.15 (avp) Rainfall < 300 mm ………....(3)

(Gutman, 1995)

Where:

Rc = Recharge from rainfall in millimeters.

avp = long term average annual rainfall in millimeters.

Table (5.5) for Jenin Station the total rainfall at 2012/2013 was 524 mm/year, so equation (2) well applied:

Rc = 0.534 (avp-216) 650 mm>Rainfall>300 mm …..(2)

Rc = 0.534 (524 -216) = <u>164.4 mm</u>

The coefficient of rain water is

$$\text{Coefficient} = \frac{Rc}{avp}$$

$$\text{Coefficient} = \frac{164}{524} = 0.31$$

The area of study area is $12.1*10^6$ m^2.

This classified in to two area, one is mountain area which with $6.18*10^6$ m^2 and other area is agriculture area which it $5.94*10^6$ m^2. Table (5.7) shows the calculations about rainfall recharge of aquifer.

Table 5.7: Rainfall recharge for aquifer in the study area

Rainfall (mm/year 2012/2013)		524	
Recharge (mm)		164.472	
Area (m^2)	Mountain	$6.18*10^6$	$12.1*10^6$
	Agriculture	$5.94*10^6$	
Recharge coefficient		0.3138	
Recharge on area (m^3/year 2012/2013)		**$1.99*10^6$**	

As show in table (5.6) to calculate the amount of recharge at study area as total of study area:

$$\text{Recharge on area } (m^3/\text{ year}) = \left(\frac{Recharge\ (mm)}{1000}\right) * Area$$

$$\text{Recharge on area } (m^3/\text{ year}) = \left(\frac{164.4\ (mm)}{1000}\right) * 12.1 * 10^6 = 1.99 * 10^6\ m^3/\text{year}$$

The mountain areas has higher infiltration rate than the agricultural areas, so the coefficient for mountain area is 0.67 and the agricultural area 0.33 to calculate the infiltration rate in the mountain area is:

$$\text{Recharge on mountain area} = 0.67 * \left(\frac{164.4\ (mm)}{1000}\right) * 6.18 * 10^6 = 6.8 * 10^5\ m^3/\text{year}$$

And the infiltrate rate of rainfall in the agricultural area is:

$$\text{Recharge on agriculture area} = 0.33 * \left(\frac{164.4\ (mm)}{1000}\right) * 5.94 * 10^6 = 3.2 * 10^5\ m^3/\text{year}$$

5.4.3.2 Water losses capita

The supply of domestic water for Kufr-Dan is through Joint Services Council of the villages of west Jenin. Network losses are 35% from supply water (PWA, 2013). The population at Kufr-Dan village is 7,700 and the current water consumption is 25 l/c/d (PWA, 2013), so the water consumption is:

Total water supply = $\frac{Water\ consumption\ \left(\frac{l}{c}/d\right) * population\ (capita) * 365\ d/year}{1000\ l/m^3}$

Total water supply = $\frac{25\ \left(\frac{l}{c}/d\right) * 7700\ (capita) * 365\ d/year}{1000\ l/m^3}$ = 71,246 m^3/Year

The amount of losses from network is

Water losses = Total water consumption * percent losses

Water losses = 71,246 m^3/Year * 35% = 24,936.1m^3/year

The infiltration of water losses to groundwater is water losses multiplied by the coefficient (0.5). (Director of Research and Development, PWA, May 2013, interviews).

Water infiltration from losses = 25,000 * 0.5 = **12,500 m^3/year**

Table (5.8) shows the calculations of water loss from water network and water recharge to the aquifer.

Table 5.8: Recharge of aquifer from water network

Population	7700
Water Supply (m^3/year)	71,000
Water consumption as supply (l/c/d)	25
Network losses (%)	35
Water losses (m^3/year)	25,000
Consumption (m^3/Year)	46,000
Total urban area m^2	740,000
Infiltration from network (m^3/year)	**12,500**

6.5.3.3 Infiltration from wastewater

Palestinian communities lack of wastewater network, most of them dependent on cesspits, and which is harmful to the groundwater and the environment, because these cesspits are permeable and wastewater infiltrates to the groundwater.

Kufr-Dan does not have wastewater network. The amount of water consumed at Kufr-Dan is 580 m^3/day for a population of 7700, 80% of this consumed the water terns in to wastewater (PWA, 2013).

Wastewater produced = water consumption * 80%

$$= 46,000\ m^3/year * 80\% = 37,000\ m^3/year$$

From this produced wastewater 90% infiltrates in to the groundwater. (Head of Kafr-Dan Cooperative Society for Agriculture and Irrigation, August 2012, interview). So the amount of water infiltrated in to the groundwater is:

Wastewater infiltrated = Wastewater Produced * 90%

$$= 37,000\ m^3/year * 90\% = \mathbf{33,000\ m^3/year}$$

Table (5.9) shows the calculations of infiltrated wastewater from cesspits.

Table 5.9: Recharge from wastewater

No. of Population	**7700**
Water Supply (m^3/year)	71,000
Fresh consumption (m^3/year)	46,000
Potential WW. Produce (m^3/year)	37,000
Amount infiltration WW. (m^3/year)	**33,000**

6.5.3.4 Infiltration from irrigation

Kufr-Dan depends on agriculture, the agriculture area at study area is about $5.9*10^6$ m^2 and the total amount of irrigated water for this area is about 2.3 MCM/year (abstraction from all wells). The infiltrated water from this irrigated water is 10%. The infiltrated water from irrigation is:

Infiltrated water from irrigation = Total irrigation * 10%

$$= 2.3\ MCM/year * 10\% = 0.23\ MCM/year$$

Table (5.10) show the calculations of infiltration water from irrigated.

Table 5.10: Recharge from irrigation water

Agriculture Area (m^2)	$5.9 * 10^6$
Total Consumption (m^3/year)	$2.3 * 10^6$
Recharge coefficient (%)	10%
Recharge from agriculture (m^3/year)	**$0.23 * 10^6$**

6.5.3.5 Total recharge

The study area is divided into three sections. Figure (5.16) shows agricultural area, urban area, and mountain area. The total surface of these sections is $5.9*10^6$, $0.55*10^6$, and $5.63*10^6$ m^2 respectively. Each section contains different sources of recharge into the groundwater.

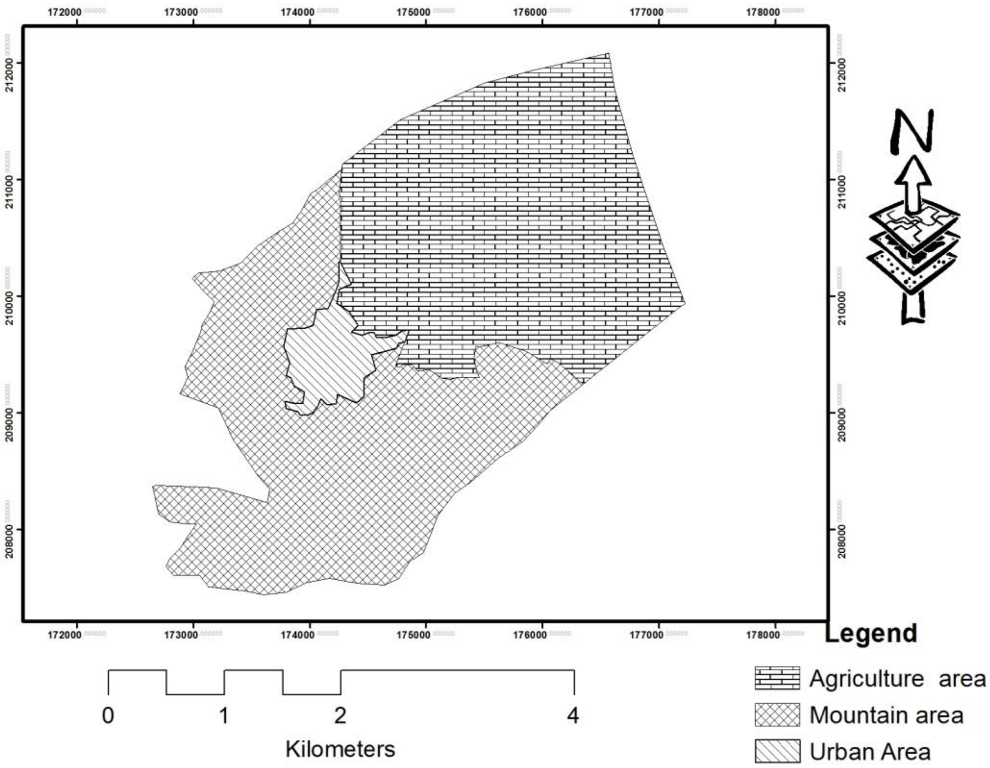

Figure 5.16: The recharge area

The source of recharge in the agricultural area is from rainfall and recharge from irrigation water. In the urban area the source of recharge is the network losses, the wastewater cesspits and the rainfall. In the mountain area the source of recharge is the rainfall only. Table (5.11) shows the distribution and recharge.

Table 5.11: The distribution and recharge amounts

	Source of recharge	**area (km^2) * 10^3**	**Recharge m^3/day * 10^3**	**Recharge m^3/year * 10^3**
Agriculture area	Rainfall and irrigation water	5.94	2.434	889
Urban area	Network losses, cesspits and rainfall	0.55	0.454	165
Mountain area	Rainfall	5.63	3.334	1,217
Sum		**12.13**	**6.22**	**2,271**
				2.27 MCM

The quantity of recharge from rainfall, leakage from a water network, cesspits and from irrigation is 2.27 MCM for the total area of 12.13 $*10^3$ km^2. The recharge from lateral flow is from the south site, which is 9 km^2 areas made up of Eocene formation that has an average rainfall of 1,500 m^3/year.

5.4.4 Permeability of aquifer

From previous studies the simulated hydraulic conductivity was characterized by low-range values from 0.01 to about 6.0 m/day, while the transmissivity ranged from 30 to 3000 m^2/day. (SUSMAQ, 2003)

5.5 Numerical model of the study area

5.5.1 Grids

The Model domain is uniformly discretized into 100 columns by 100 rows forming small grids with dimension ranging between 45-50 meters. All cells located outside the model domain are considered inactive cells. As a result, there are 5,600 active cells out of 10,000 cells as shown in figure (5.17)

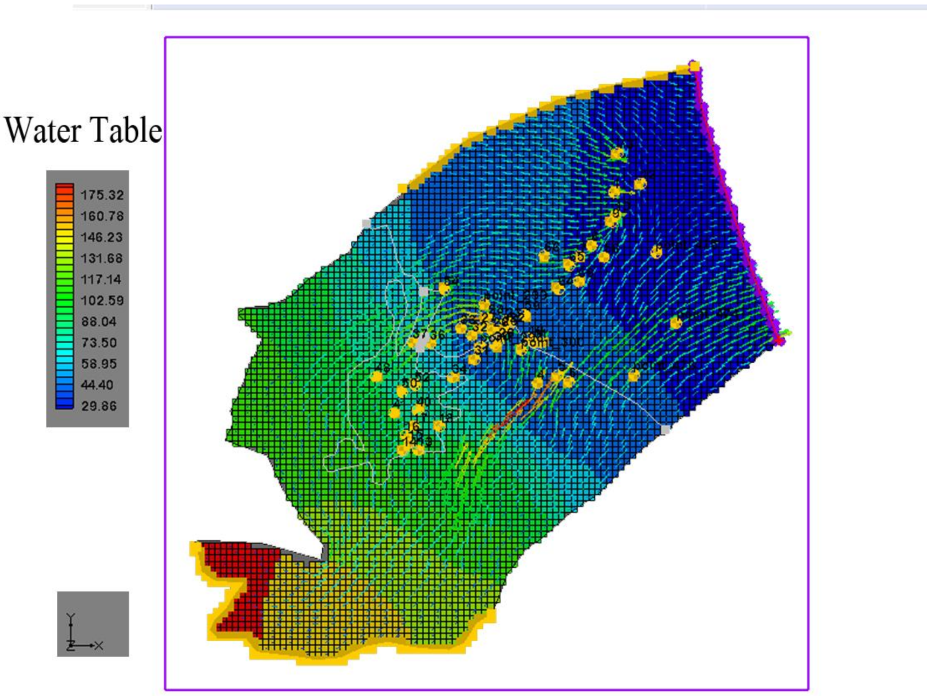

Figure 5.17: Shows the grids of model domain

5.5.2 Calibrations

Several observation wells are used for calibration fittings. The wells are selected based on data available on water table. The water level in the summer and the winter seasons was worked out. The difference between them was only 10 meters, and so the water level of the researched wells shall be ± 10 meters.

These wells cover the whole model domain. A maximum of 10 meters of difference between the observed and measured values are accepted for each well. Figure (5.18) shows the location of observation wells.

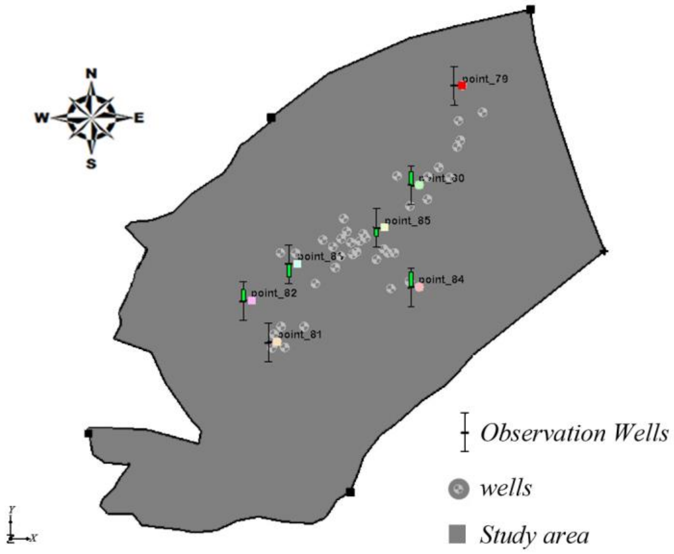

Figure 5.18: Location of observation wells in study area

At the end of the calibration process, the simulated hydraulic conductivity was characterized by low-range values from 0.7 to about 4 m/day according to the model. Figure (5.19) shows the 45° line that is a calibration line for observation wells.

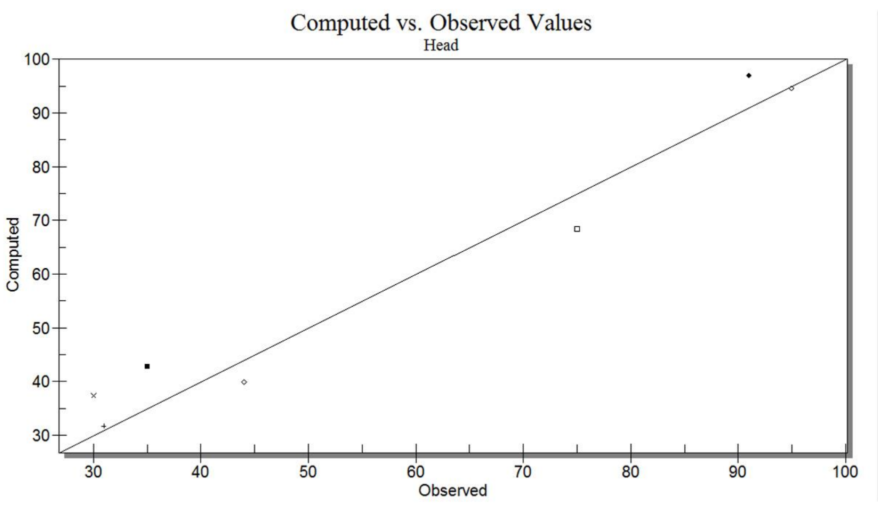

Figure 5.19: The 45° line of the calibration model

The simulated water table shows that in seven observation wells, there are less than 10 meters of difference between the simulated and observed water levels. The maximum discrepancy between simulated and observed values in any observation well was less than 8 m. The amount input from lateral flow is 2,500 m^3/day that feed the model from north sides to calibrate a model.

5.5.3 Water level distribution

The Eocene formation was studied thoroughly, including the geology, hydrogeology, and general groundwater flow system. Based on this information, the study area is composed mainly of carbonate rock of the Eocene formation underlain by the Abu Dies formation. The Eocene rocks are characterized by their thickness and extent, which make them ideal for an aquifer, and as a result, many production wells penetrate these rocks. Figure (5.20) shows the conceptual model of study area.

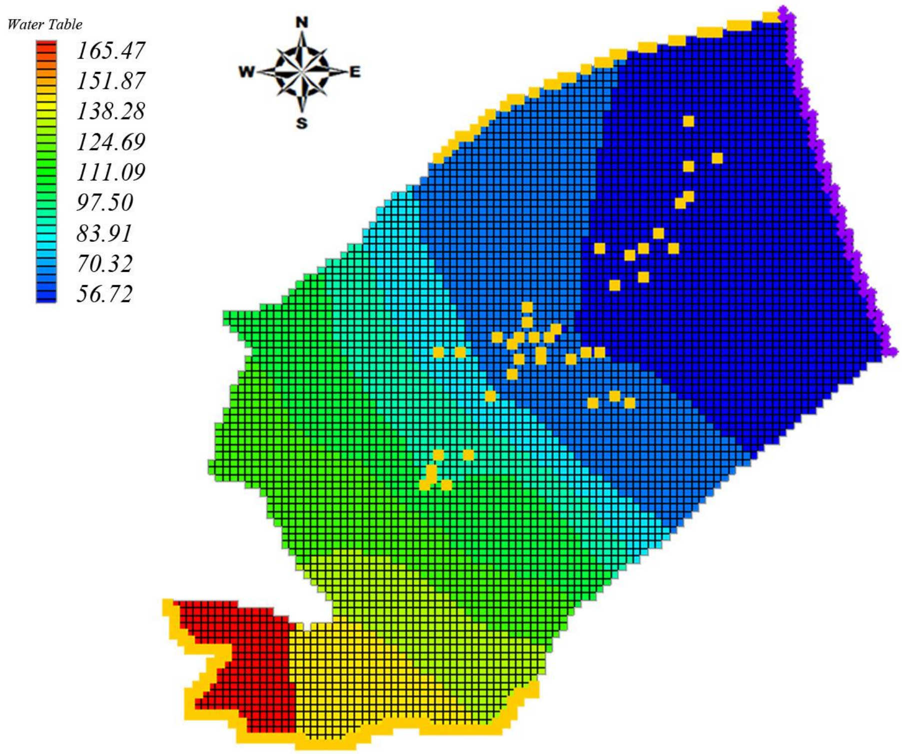

Figure 5.20: The Conceptual model of study area

Groundwater distribution in the area ranged from 50 meters above sea level in the northern area. In the south, it reached 170 meters. Accordingly, the depth of the water in the north was 60 meters and it declined until it reached 90 meters in the central area due to the excessive pumping.

5.5.4 Flow Direction

Groundwater flow direction is downward to the northern and northeast sides of the study area, figure (5.21) show direction of water table of result

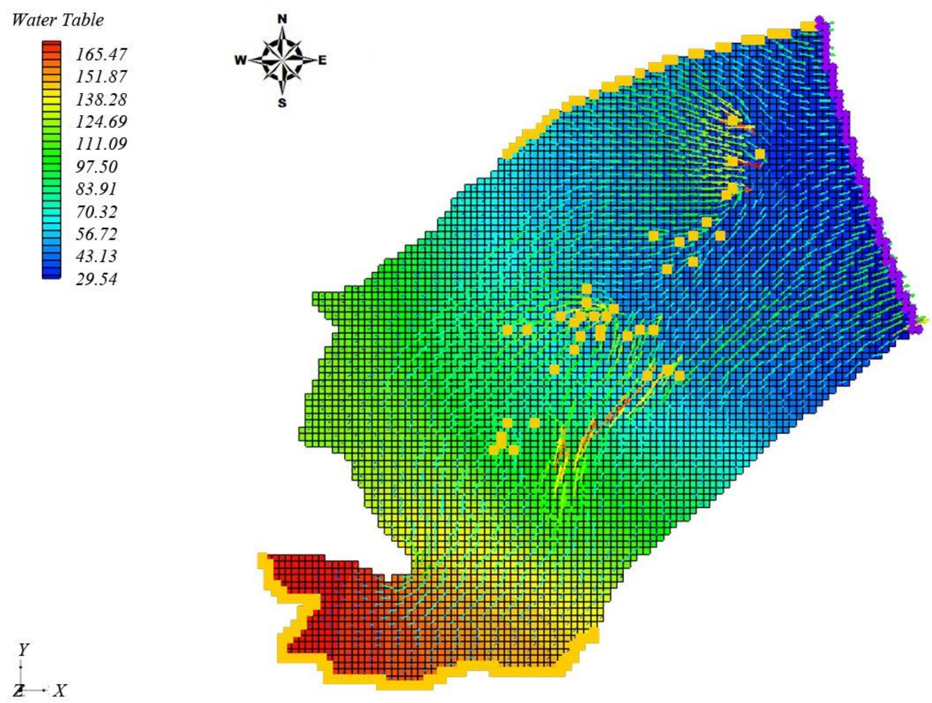

Figure 5.21: Flow direction of groundwater

5.5.5 Water budget

The conceptual water budget of the study area was analyzed to determine whether the indicated water sources and basins were generally in agreement with the conceptual hydrogeological model. Table (5.12) shows the water budget at the end of the steady-state conceptual.

Table 5.12: The water budget of conceptual water model

Budget Term	**Flow (MCM/year)**	
	Inflow	**Outflow**
Boundary flow	0.43	0.85
Direct recharge	2.55	0.00
Wells	0.00	2.13
Total	**2.98**	**2.98**

The table shows the quantity of water inflow and outflow of the system. The inflow to the system is estimated at 2.98 MCM, which includes the discharge from boundaries, the direct recharge and the abstraction from wells.

The amount of the water outflow from the system through wells, lateral outflow and which is equal to the amount of water that enters the system (inflow).

Chapter Six

Model Applications

6.1 Impact of climate change

The average annual precipitation is fluctuating. Sometimes it reaches only about 30% below the annual precipitation of the year, which the model shows; sometimes it rises and reaches about 10% above the average annual precipitation of the year. Therefore, we shall propose two suggestions or scenarios: the first for rainfall decline and the second for the rainfall increase.

6.1.1 The first scenario

Due to the decline in the average annual precipitation in some years (370 mm), the application of this hypothesis of the model will lead to a remarkable drop in the groundwater levels and the inability of the water basin to meet the farms' irrigation needs.

The decline of the average annual precipitation by about 30% will lead to a fall in the natural groundwater recharge. Table 6.1 shows the levels of the groundwater recharge in the study area.

Table 6.1: Recharge of the Groundwater for first scenario

	Source of recharge	**Area (km^2) * 10^3**	**Recharge m^3/day *10^3**	**Recharge m^3/year * 10^3**
Agricultural area	Rainfall and irrigation water	5.94	1.450	529
Urban area	Network losses, cesspits and rainfall	0.55	0.746	273
Mountain area	Rainfall	5.63	1.633	596
Sum		**12.13**	**3.829**	**1,398**
				1.40 MCM

The average drop in the natural groundwater recharge, which led to water level decrease in a storage basin system, led to a significant well-productivity decline that ranged between 2-10 m^3/hour (very few of them reach up to 20 m^3/hour). This situation led to a depletion of water levels, and so the farms' irrigation needs would not be met in the study area. Therefore, alternative plans and schemes should be set up to face the below-normal rainfall in drought conditions. Table (6.2) shows the inflow and outflow of water levels.

Table 6.2: Water budget of conceptual water model for first scenario

Budget Term	**Flow (MCM/year)**	
	Inflow	**Outflow**
Boundary flow	0.47	0.56
Direct recharge	1.39	0.00
Wells	0.00	1.3
Total	**1.86**	**1.86**

The volume of water extracted from the wells is estimated at 1.3 MCM in the year of drought, whereas the volume of water outflow from the model is estimated at 0.56 MCM. The figure (6.1) shows the model in this scenario and the amount of the water level increase in the study area.

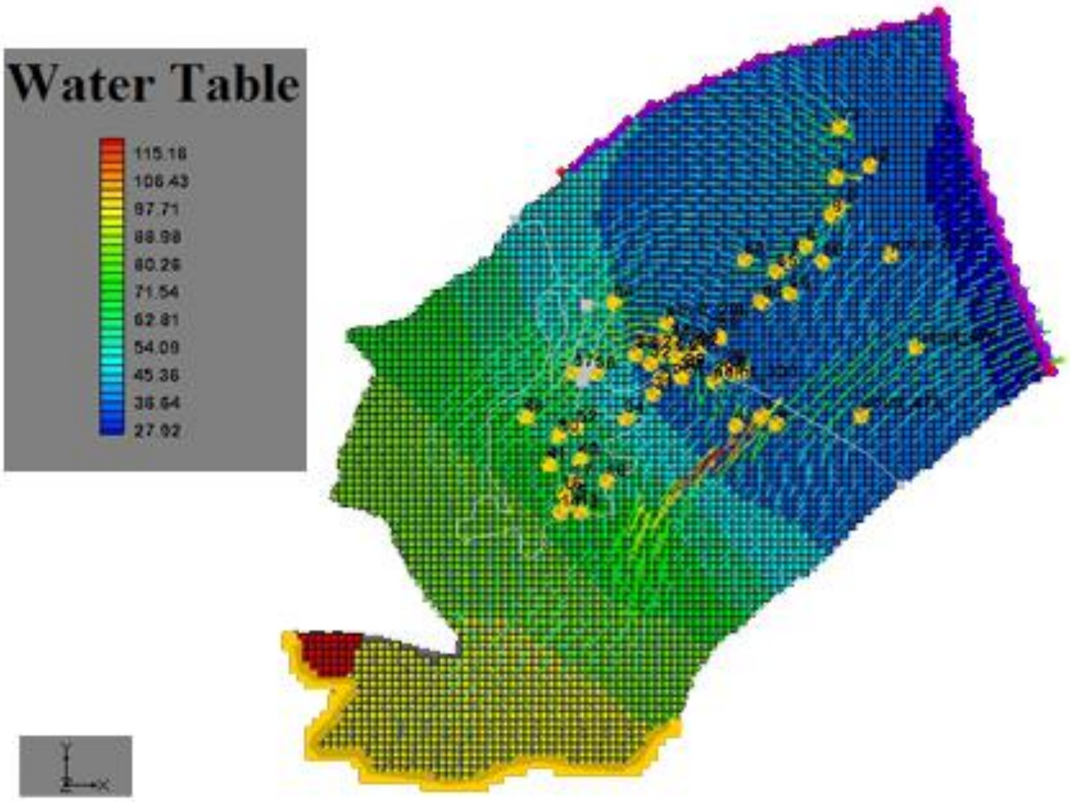

Figure 6.1: The conceptual Model of the study area for the first scenario

Figure (6.1) shows that the water level in the northeastern part will be 30m above the sea level. It is expected to rise up to 60m in the middle of the study area and will keep rising up to 100 m in the southern part of the study area.

6.1.2 The second scenario

The amount of rainfall in some years reaches up to 580 mm, so if we apply this hypothesis to the model, the water table will rise slightly.

About 10% increase in the rainfall levels leads to a rise in the amount of groundwater recharge. Table (6.3) shows the recharge amounts of groundwater inflow in the study area.

Table 6.3: Recharge of the Groundwater for the second scenario

	Source of recharge	**Area (km^2) * 10^3**	**Recharge m^3/day *10^3**	**Recharge m^3/year * 10^3**
Agricultural area	Rainfall and irrigation water	5.94	2.681	978
Urban area	Network losses, cesspits and rainfall	0.55	1.018	372
Mountain area	Rainfall	5.63	3.859	1,409
Sum		**12.13**	**7.558**	**2,758**
				2.76 MCM

A slight increase in the amount of groundwater recharge will not affect the well productivity. However, it will increase the boundary flow and thus it will have neither effect on the amount of water extracted from the wells nor will it solve any of the study problems. Table (6.4) shows the model inflow and outflow water levels.

Table 6.4: The water budget of conceptual water model for the second scenario

Budget Term	**Flow (MCM/year)**	
	Inflow	**Outflow**
Boundary flow	0.43	0.85
Direct recharge	2.76	0.00
Wells	0.00	2.34
Total	**3.19**	**3.19**

The volume of water extracted from the wells is estimated at 2.34 MCM in this scenario, whereas the volume of water outflow from the model is estimated at 0.85 MCM. The figure (6.2) shows the model in this scenario and the amount of the water level increase in the study area.

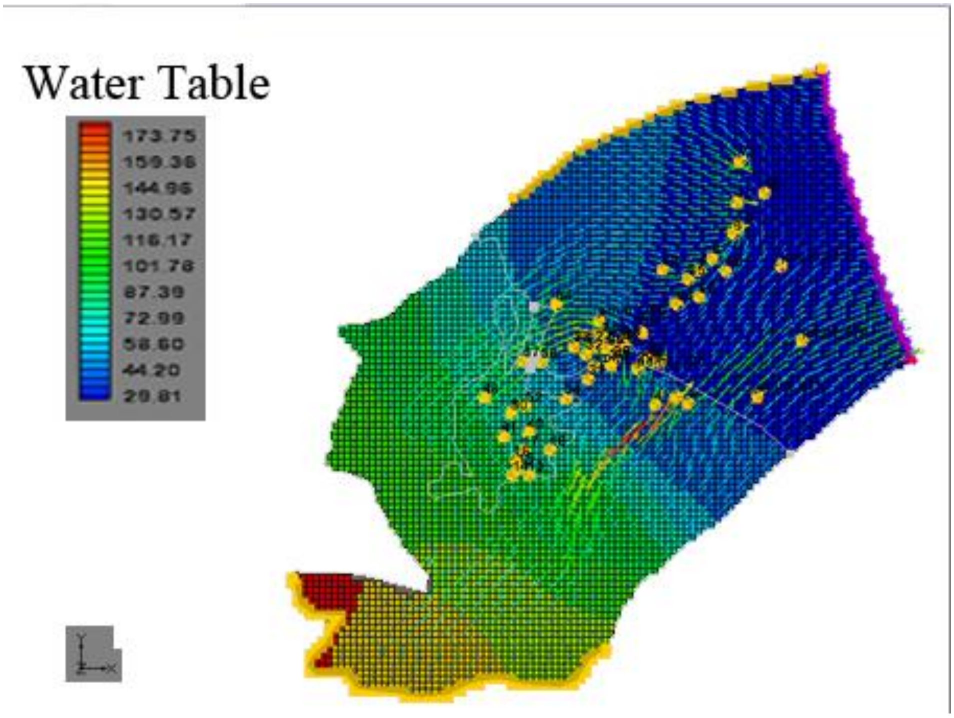

Figure 6.2: Conceptual model of the study area for the second scenario

Figure (6.2) shows that the water level in the northeastern part will be 30 m above the sea level. It is expected to rise up to 75 m in the middle of the study area and will keep rising up to 160 mm in the southern part of the study area.

6.2 Pumping Scenarios

The amount of water available currently for land farming in the study area is inadequate according to pumping from the wells. Consequently, based on the created model, we will work out some scenarios to find the best solutions for the severe water shortages. To achieve the objectives of this study, the suggested scenarios are as follows:

- Digging new wells to increase the quantity of water consumption and make up for water shortages.
- Artificial recharge to increase well productivity.

6.2.1 The third scenario

Obviously, there is around 0.85 MCM outflow from the model, which is concentrated as in the northeast part of the study area. Therefore, it is possible to dig three wells with average discharge of 40 m^3/h per well in the northeastern part of the study area which has coordinates (176267/210633, 176414/210069, 176094/209653) distributed according to Figure (6.3) When the pumping rate from old wells is the same, the total amount of the pumped water from wells at the new scenario reaches up to 2.9 MCM. The final model figure and the direction of groundwater flow will be as in figure (6.3).

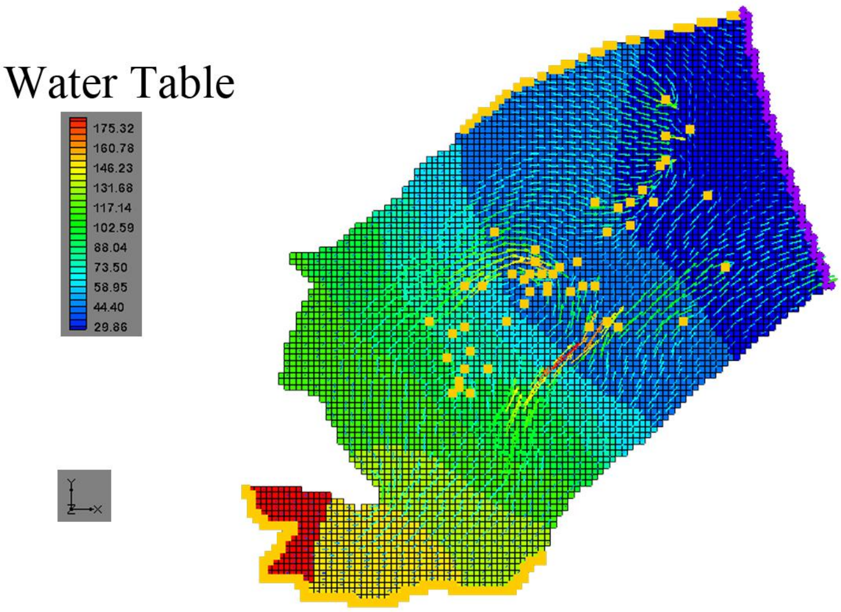

Figure 6.3: The Conceptual model of study area for the third scenario

And the water Budget of new scenario is shown in table (6.5).

Table 6.5: Water budget of conceptual water model for the third scenario

Budget Term	**Flow (MCM/year)**	
	Inflow	**Outflow**
Boundary flow	0.48	0.13
Direct recharge	2.55	0.00
Wells	0.00	2.9
Total	**3.03**	**3.03**

The amount of groundwater inflows and outflows in the model equals 3.03 MCM. The amount of groundwater outflow from the model of the limits of the study is equal to 0.13 MCM. Therefore, this scenario shows that the basin's capacity is 2.9 MCM, which is not sufficient to meet the farms' irrigation needs which are about 4.7 MCM. So we should think about other means to meet these needs such as groundwater recharge as shown in the following scenario.

6.2.2 Fourth scenario

On the eastern side of the study area, a wastewater treatment plant will be constructed in the northern West Bank city of Jenin, which will produce roughly 3,570 cubic meters per day of high quality reusable water. Seven wells were selected according to their depth and distance from the neighboring wells in order to inject the treated water and distribute it into the selected dry wells in the study area Figure (6.4).

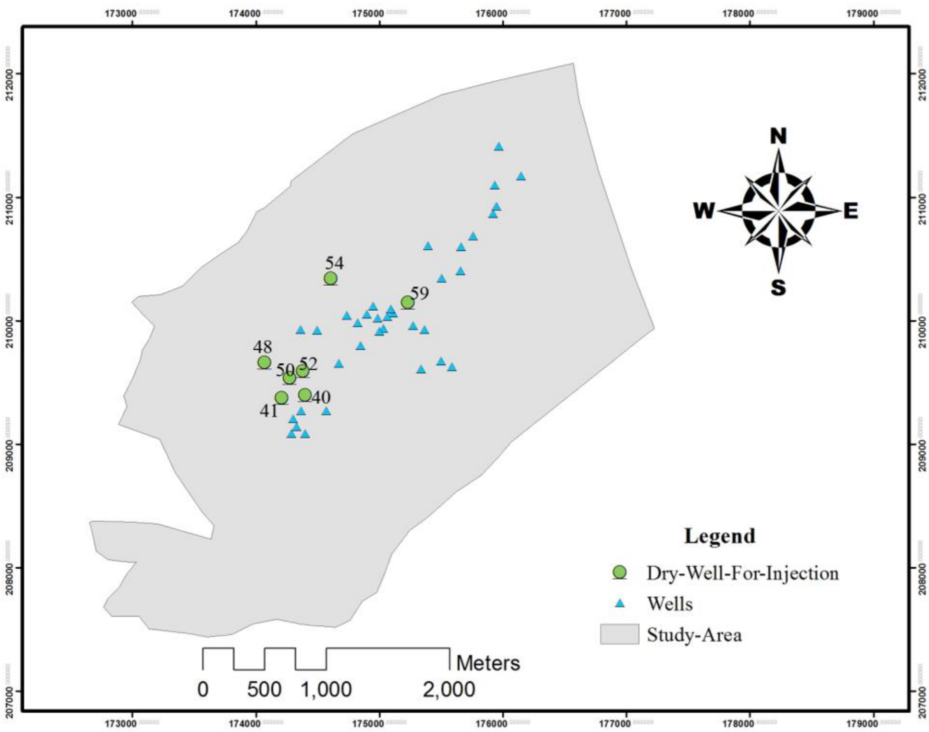

Figure 6.4: Location of dry wells in the study area for injection of recharge water

The water distribution varies, i.e. the quantity decreases from southern part to the northern part as shown in table (6.6).

Table 6.6: Amount of injected Treated Wastewater in to selected dry wells

	Name of the owner	**ID of well**	**Coordinates**		**Injection**
			X- Coordinates	**Y-Coordinates**	**m^3/day**
1	Namer Marei	41	174180	209707	750
2	Mohammad + Naser	50	174277	209537	600
3	Fatehi Marei	40	174398	209397	675
4	Mohammad Abed	48	174071	209659	525
5	Mohammad Marei	52	174381	209591	525
6	Ahmad Jabaren	59	175235	210145	300
7	Abed Alsalam Marai	54	174610	210339	375
				Sum	**3,750**

The groundwater flow direction is from the south west towards the north east, the quantity of water injected in to the selected (7 well) was in such a way that we started with large quantity for the wells in the south west and gradually decrease the quantity of the injected water for the wells in the north east so that the injected water will be evenly distributed in the total wells of the model.

When the water flows in the underground basin changes due to the injection of treated wastewater the water flows out from the northeastern and western sides. The groundwater table reaches 30 m a.s.l in the northern area, and up to 130m a.s.l in the middle of the study area. Figure (6.5) shows the conceptual model after artificial recharge. Thus, the quantity of water flowing out of the water system is nearly 1.9 MCM according to the current pumping rate.

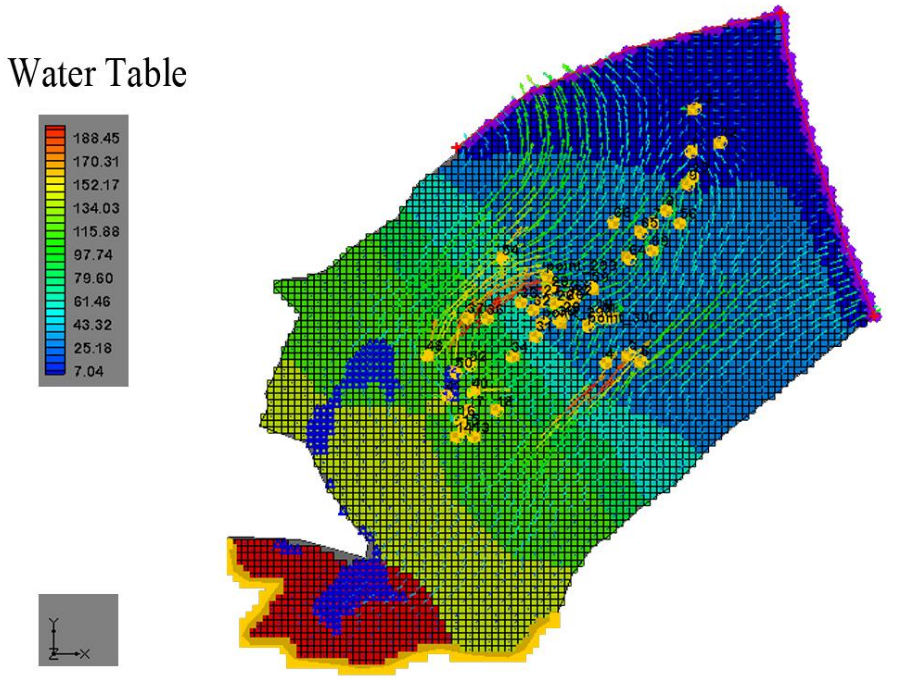

Figure 6.5: The Conceptual model of study area for fourth scenario after artificial recharge

After the groundwater inflow is increased for all wells and the efficiency is improved according to the suggested groundwater recharge, along with the water available in the aquifer, it is obvious that it is possible to pump water up to 4.85 MCM. The final figure scheme is as shown in Figure (6.6).

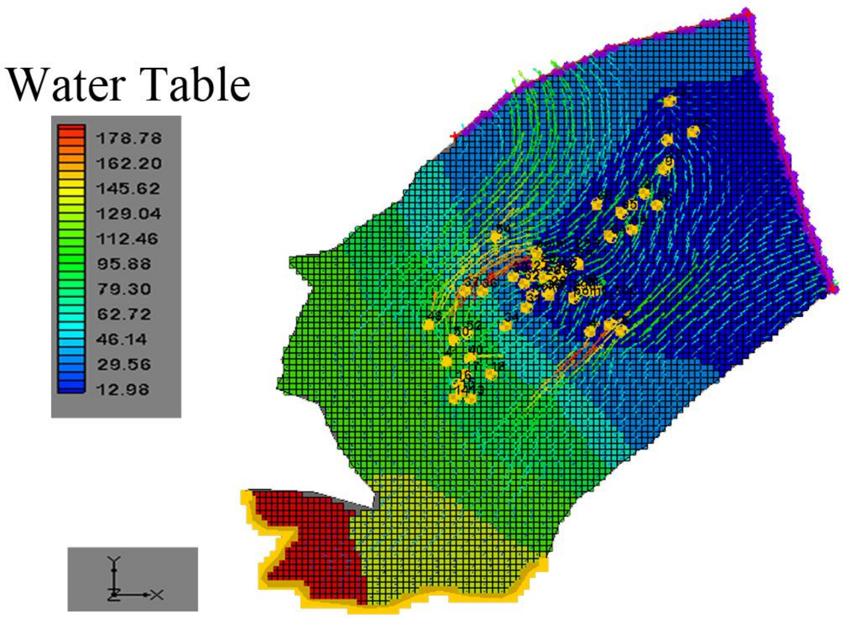

Figure 6.6: The Conceptual model of the study area for the Fourth scenario

The groundwater level will is 10 meters a.s.l in the northern part of the model, then it rises up to 50 m a.s.l in the middle part. Table (6.7) shows the water inflows and outflows.

Table 6.7: The water budget of conceptual water model for the Forth scenario

Budget Term	**Flow (MCM/year)**	
	Inflow	**Outflow**
Boundary flow	1.09	0.13
Direct recharge	2.53	0.00
Wells	1.36	4.85
Total	**4.98**	**4.98**

These results show that the amount of available water meets the farms' irrigation needs in the region and improves the crop and well productivity. The pumping rate from all these wells ranges between 13-45 m^3/h.

In the light of the groundwater outflow from the model of the north-eastern area, it is possible to dig another well has coordinate (176506/209985) in the area to take the utmost benefit from the available water in the aquifer, with a capacity up to 20 m^3/h. Figure (6.7) shows the model and the newly added well in the northeastern area.

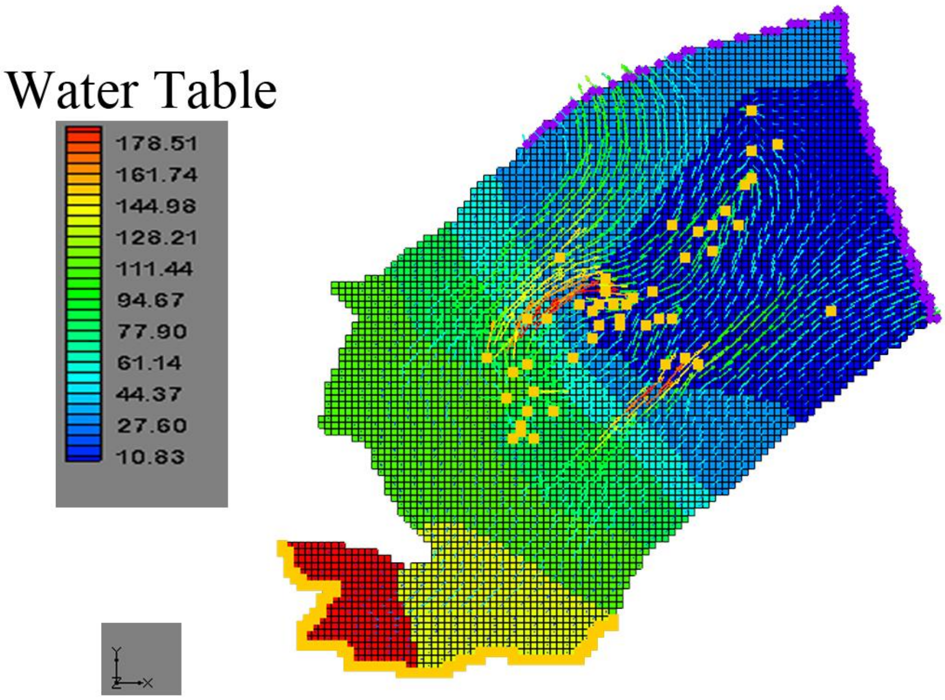

Figure 6.7: The Conceptual model of the study area for the Fourth scenario with the new well

The quantity of water pumped from the wells after the addition of a new well in the northeastern area reaches up to 5 MCM. Table (6.8) shows the groundwater inflows and outflows from the model.

Table 6.8: The water budget of conceptual water model for the Forth scenario with the new well

Budget Term	Flow (MCM/year)	
	Inflow	**Outflow**
Boundary flow	1.18	0.08
Direct recharge	2.53	0.00
Wells	1.36	5.00
Total	**5.08**	**5.08**

The amounts of groundwater inflow and outflow in the model are equal and reach up to 5.08 MCM. If the amount of groundwater in the model is fully utilized after proposing new well in the north-eastern region, the amount of water extracted from wells reaches up to 5 MCM, which is sufficient to meet the farms' needs in the area.

Chapter seven

Conclusions and Recommendations

7.1 Conclusions

Aquifer lithology and aquifer parameter have been determined. All aquifer parameters like hydraulic conductivity and transmissivity indicted the lithology of aquifer in Kufr-Dan area and water budget, modeling groundwater ware built in this investigation.

Eocene formation was identified in this investigation, which was made up of chalk with minor chart and limestone.

The model was divided into 100 columns and 100 rows. The number of active cells was 5,600 out of a total of 10,000 original cells.

Seven wells ware selected for model calibration. The difference between the simulated and observed wells was less than 8 meters. After adjusting the permeability value in the model for the study area, we found that there is an amount of 2,500 m^3/day that enters the northern part of the study area ager doing the calibration.

The groundwater table ranges from 50m a.s.l in the northern part to 170m a.s.l in the southern part, where the groundwater flow is towards the north eastern side.

The model has 73 wells taping the Eocene aquifer. Most of them are dry due to over pumping. The boundary of model is classified in to: flow boundary and non-flow boundary. The total input is 0.43 MCM/year from boundary of the model, the total output is 0.85 MCM/year from the boundary of the model.

The total quantity of recharge water for model is determined from rainfall (88%), leakage from network water (0.5%), the quantity of infiltration water from cesspits (1.4%), and the qouantity of residual water that passes through irrigation (10%) is 2.55 MCM. The total input and output from model was 2.98 MCM/year 2012/2013. The well abstraction from the model is 2.13 MCM/year which is about 70% of the aquifer budget.

Four scenarios have been applied based on the model. The climate change has been taken into account in which the rainfall has decreased by 30% composed with average amount of rainfall for the previous years. The total amount water input and output in the model is 1.86 MCM, and the amount of abstracted water is 13 MCM.

In another scenario, the rainfall has been increased by 10% based on the previous years. We did not notice any noticeable change in the input and output in the model, which is 3.19 MCM, and the amount of abstracted water was 2.34 MCM.

The third and fourth scenarios were based on abstraction.

The third scenario is based on addition of three new wells in the northern part of the study area each of them has a capacity of 40 m^3/h.

The fourth scenario is based on artificial recharge, where seven dry wells have been selected to be injected with 3,7500 m^3/day treated wastewater from nearby Jenin wastewater plant. The yield of the wells in the area has improved to 4.85 MCM, which is enough to meet the water demand of the farmers in the area. The water output and input of the model was 4.89 MCM.

It was concluded that another well could be digged in the northern part of the study area which can have a capacity of 20m^3/h, and the water input and output of a model well increase to 5.00 MCM/year.

7.2 Recommendations

- There should be an alternative plan if the situation does not change i.e. the fluctuations in the waterfall levels persist.
- The quantity of water in the area should be increased by digging three wells in the northeastern zone, with a capacity of $40m^3/h$ for each well, so the total quantity of the wells is estimated at 2.9 MCM.
- To meet farmers' needs, the artificial recharge should be addressed; besides, the pumped underground water should be processed as described in the fourth scenario.
- A new well in the northeastern zone should be drilled, and so the estimated water extracted from the wells might be about 5 MCM, which a sufficient quantity for the farmers' needs.

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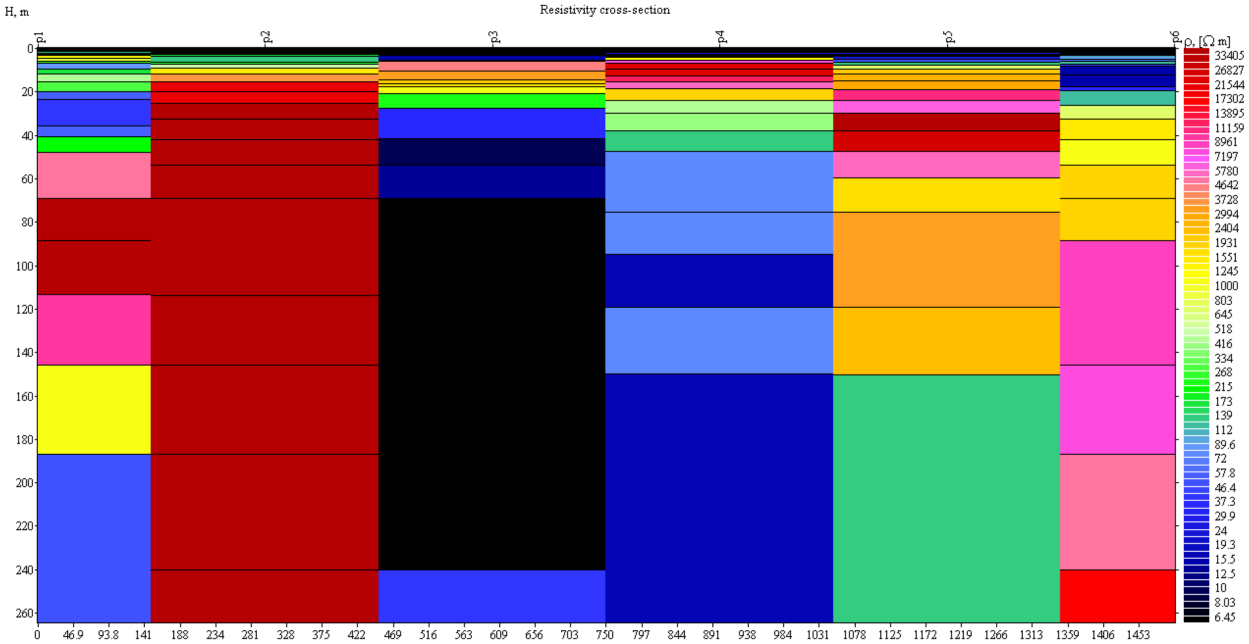
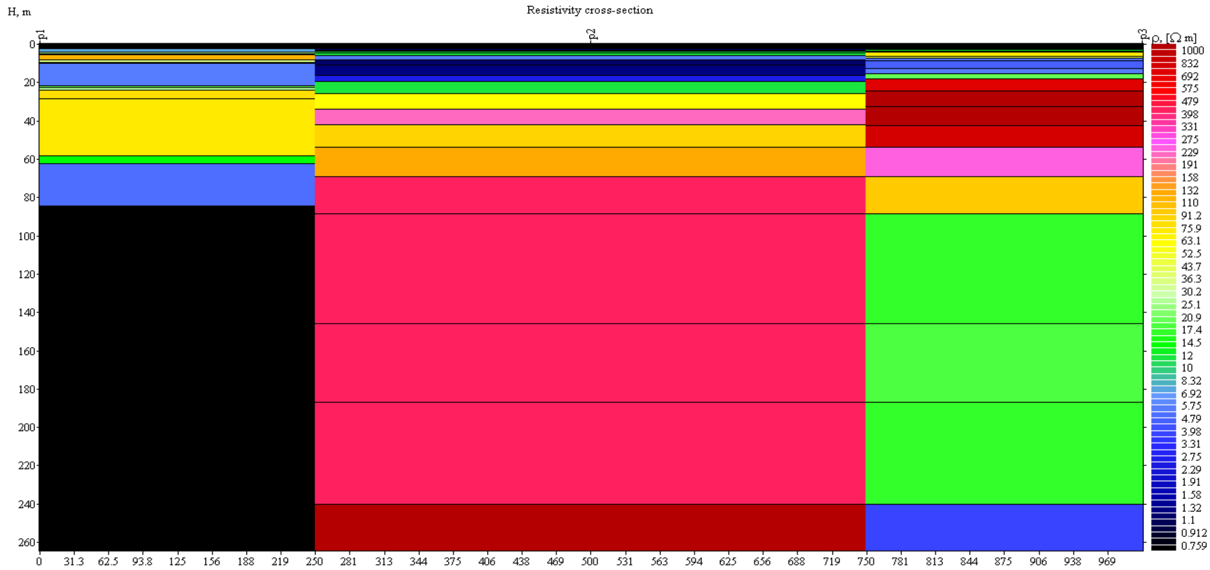
31- MoA (Ministry of Agriculture) , 2014, interview for crops which at Study area.

Appendices

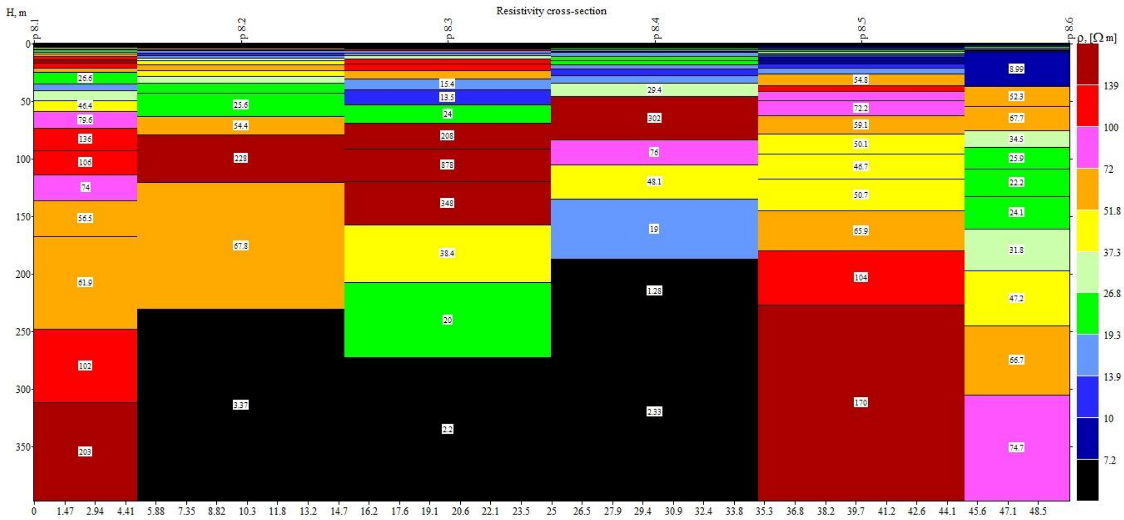
Appendix 1: Profile 1 of previous study



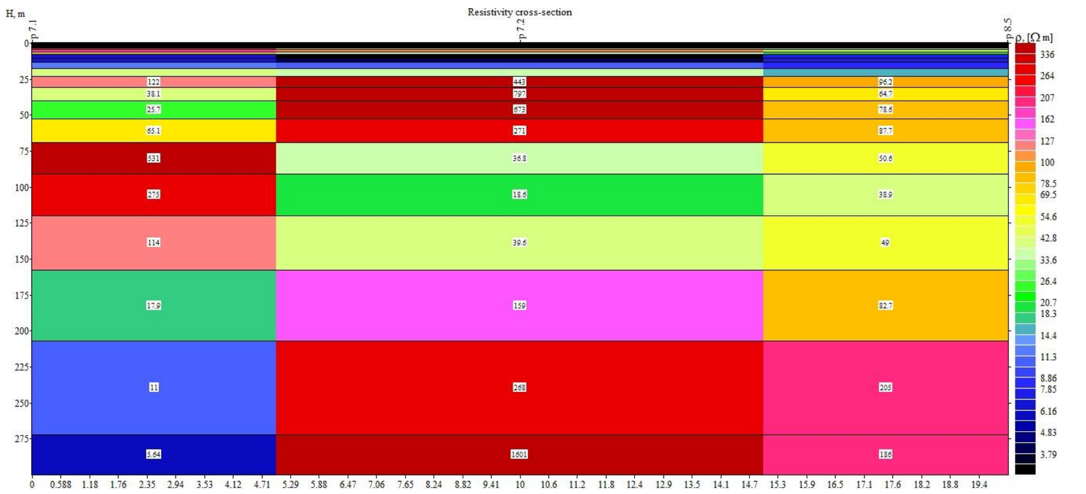
Appendix 2: Profile 2 of previous study



Appendix 3: Profile 1 of Geophysics of study



Appendix 4: Profile 2 of Geophysics of study



Appendix 5: Log of Jenin well 2

<table>
<tr><th>Period</th><th>Age</th><th>Typical lithology</th><th>Formation</th><th>Symbol</th><th colspan="2">Hdro-strtigraphy</th><th>Typical Thickness (m)</th></tr>
<tr><td>Tertiary</td><td>Eocene</td><td>Chalk, with nummulitic Limestone, cream, white, Soft</td><td>Jenin Subseries</td><td>J</td><td colspan="2">Jenin Aquifer (NE Basin)</td><td>100</td></tr>
<tr><td rowspan="3">Cretaceous</td><td>Senonian</td><td>Chalk with chert, massive, yellow and cream, chert, orange-brown</td><td>Abu Dis</td><td>AD</td><td colspan="2">Aquitard</td><td>250</td></tr>
<tr><td>Turonian</td><td>Limestone, Dolomitic, massive, thick, Porcellanous to Lithographic, Buff cream</td><td>Jerusalem</td><td>JEU</td><td rowspan="2">Upper Aquifer</td><td rowspan="2">Mountain Aquifer System</td><td>100</td></tr>
<tr><td>Cenomanian</td><td>Limestone, Dolomitic with calcite bonds, light brown, buff to cream, dense, crystalline</td><td>Bethlehem And Hebron</td><td>BL And HB</td><td>150</td></tr>
</table>

تقييم مصادر المياه الجوفية في كفر دان باستخدام نموذج للمياه الجوفية.

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الملخص

المياه الجوفية هي المصدر الرئيسي للشرب في فلسطين، وهي أيضاً تعد من أهم المصادر للزراعة. مع إزدياد عدد السكان وتأثير إزديادهم على مصادر المياه الجوفية أدى إلى خلق مشاكل على الأحواض الجوفية كإنخفاض مستوى المياه وعلى جودة المياه الجوفية. تواجه فلسطين مشكلة كبيرة في إدارة المياه الجوفية بسبب محدوديتها المتاحة، بالإضافة إلى الضخ الجائر لها. حيث أن الآثار السلبية التي تنجم عن النقص الحاد في المياه الجوفية تعمل على الحد من الإنتاج الزراعي مما يؤدي إلى تدهور الإقتصاد.

أجريت هذه الدراسة في قرية كفردان التي تهدف إلى دراسة الحوض السطحي في المنطقة الا وهو خزان الايوسين.

استخدم في الدراسة برنامج (GMS) من اجل بناء نموذج عن الحوض المائي في منطقة الدراسة للمياه الجوفية بالإعتماد على المعلومات في المقاطع الصخرية بالإضاف إلى المعلومات المتوفرة من الآبار الموجودة في منطقة الدراسة. وتم معايرة الموديل عن طريق هذا البرنامج.

تم إختيار سبعة آبار من أجل معايرة الموديل فإن فرق منسوب ارتفاع المياه الجوفية بين آبار المراقبة وآبار المحاكة في الموديل أقل من 8م وذلك بعد ضبط النفاذية لمنطقة الدراسة وأن هناك 2,500 م^3/يوم مياه جوفية تدخل إلى الموديل من الجزء الشمالي لمنطقة الدراسة.

يرتفع مستوى المياه الجوفية في منطقة الدراسة من 50م فوق مستوى سطح البحر في الجزء الشمالي ويرتفع حتى يصل إلى 170م فوق مستوى سطح البحر في جنوب منطقة الدراسة، بحيث إن إتجاه المياه الجوفية تتجه إلى الشمال الشرقي للموديل.

يحتوي الموديل على 73 بئر تضخ من الحوض السطحي (خزان الإيوسين)، معظمها جاف بسبب الضخ الجائر. مجموع المياه التي تدخل إلى الموديل من خلال حدود الموديل تقدر 043 مليون م^3 في العام والمياه الخارجة منه تقدر 0.85 مليون م^3 في العام.

مجموع المياه المغذية للموديل من خلال مياه الأمطار (88%)، والمياه المترشحة من شبكات المياه الداخلية(0.5%)، والمياه المترشحة من الحفر الإمتصالصية في منطقة الدراسة (1.4%)، بالإضافة إلى المياه المترشحة من المياه المروية للأراضي الزراعية(10%) تقدر ب 2.27 مليون م^3. كمية اليماه الداخلة والخارجة من الموديل تقدر 2.98 مليون م^3 في عام الدراسة 2013/2012. وكمية المياه المستخرجة في الموديل تقدر 2.13 مليون م^3 التي تقدر بـــ 70% من كمية المياه كاملة في الموديل.

أربع سياريوهات درسو في هذه الدراسة وطبقو على الموديل. أخذ بعين الإعتبار التغير المناخي من خلال السنوات السابقة بحيث أن مياه الأمطار تتناقص لتصل إلى 30%، وكان كمية المياه الداخلة والخارجة من الموديل تقدر 1.86 مليون م^3، وكمية المياه المستخرجة من الموديل تقدر 1.3 مليون م^3. وسيناريو آخر أخذ بعين الإعتبار إزدياد في هطول الامطار يزداد ليصل 10% نظرا للسيني السابقة، ولم نلاحظ أي تغير واضح في كمية المياه الداخلة والخارجة من الموديل التي تقدر 3.19 مليون م^3، وكمية المياهالمستخرجة من الويدل تقدر 2.34 مليون م^3.

السيناريو الثالث والرابع اعتمد على كمية الإستخارج. بحيث ان السيناريو الثالث اعتمد على إضافة ثلاث آبار جديد في الجزء الشمالي لمنطقة الدراسة بحيث أن تكون كفائة كل بئر 40 م^3 في الساعة.

السيناريو الرابع اعتمد على التغذية الإصطناعية، بحيث تم إختيار سبعة آبار جافة لحقن كمية 3,750 م^3 في اليوم من المياه المعالجة من محطة جنين المجاورة. فكانت إنتاجية الآبار تحسنت لتصل إلى 4.85 مليون م^3، وهي كمية كافية لتسد احتياج المزارعين من المياه في المنطقة. وإن كمية المياه الداخلة والخارجة من الموديل تقدر 4.89 مليون م^3.

وتم النظر على إمكانية حفر بئر جديد في الجزء الشمالي لمنطقة الدراسة بحيث أن تكون كفائته 20 م^3 في الساعة، وستكون كمية المياه الداخلة والخارجة تقدر ب 5 مليون م^3 في العام.