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Groundwater Pollution Assessment of the North Western Auja Tamaseeh Basin (Tulkarm Area)

By

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This Thesis is Submitted in Partial Fulfillment of the Requirements for the Master Degree in Water Engineering from the Faculty of Graduate Studies at Birzeit University-Palestine.

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The finding, interpretations and conclusions expressed in this study do not necessarily express the views of Birzeit University, the views of the individual members of the examination committee.

Abstract

A hydrogeological and hydrochemical studies were conducted for the north western of the Auja Tamaseeh basin (Tulkarm Area) which represents a highly sensitive area to pollution in the West Bank. Most of the groundwater wells are located within the upper aquifer with (Hebron, Bethlehem, Jerusalem) geological formations. The results act as assessment study to evaluate the effect of human activities on groundwater quality.

The hydrochemical study was conducted to define water types as well as water geneses of the aquifer system. A graphical representation of hydrochemical data and saturation indices analyses were interpreted to investigate whether the pollution is natural occurring or man-made. The dominant water type of most of the wells is of earth alkaline type with increased portion of alkalis and with prevailing bicarbonate. Water genesis of the groundwater wells in the study area is affected mainly by water rock interaction between water and the mineral phases of calcite, dolomite and aragonite, which are the main constituents of the lithological formations of the recharge area.

The state of pollution and trend analyses for groundwater in terms of nitrate and chloride concentrations were determined in Tulkarm Area. A spatial analyses was performed to interrelate the polluted groundwater wells with the natural and anthropological activities using the Geographical Information System (GIS) as a tool in performing such analysis and results presentation. The polluted wells are mostly located within high to moderate sensitive areas and within populated areas and close to agricultural activities.

Finally, a steady state flow and solute transport model for the western part of the Iskandaron drainage – north western Auja Tamaseeh basin - (a highly sensitive area of Tulkarm Area) was built using the visual Modflow software. A stress period of 10 years (2005-2015) was assigned to study the tendency of contamination. The aquifer system was represented by two layers. The model was simulated for the stress period and the results of the model showed that there is a pollution risk due to human activities and the situation will be harmful if there is no action done by the decision makers with the public to preserve the water resources from deterioration and contamination.

مستخلص

تم عمل دراسة هيدروجيولوجية وهيدرو كيميائية لمنطقة طولكرم الواقعة في شمال غرب الضفة الغربية جغرافيا و تقع في الجزء الشمالي الغربي لحوض (العوجا - تماسيح) هيدرولوجيا. معظم الآبار الجوفية تقع في الحوض العلوي والذي يتم تغذيته من التكوينات الجيولوجية (القدس – بيت لحم – الخليل). تمثل هذه الدراسة تقييما لمدى التأثير الناتج عن النشاطات البشرية على تلوث المياه الجوفية باعتبارها من المناطق الحساسة بيئيا للتلوث.

تتلخص الدراسة الهيدروكيميائية في معرفة سمة المياه وطبيعة الصخور التي تغذي الحوض الجوفي في تلك المنطقة. وتهدف الدراسة إلى تحديد السبب المباشر للتلوث إن كان طبيعيا أو بفعل النشاطات البشرية. وقد وجد من خلال الدراسة أن معظم الآبار تتمتع بسمة قلوية/ترابية مع زيادة في القلويات وسيطرة آيونات البايكربونات. وقد تبين أن أصل المياه في تلك المنطقة يتحدد من خلال التلامس بين الماء ومعادن صخور الكلس والدولومايت والأراجونايت التي تمثل المكونات الأساسية في مناطق التغذية المائية للآبار الجوفية في تلك المنطقة.

تمت دراسة حالة المياه وكذلك تمت دراسة تغير تراكيز آيونات النترات والكلوريد مع الزمن وتم تمثيل الآبار الملوثة حيزيا وربطها بعلاقات حيزية من خلال نظم المعلومات الجغرافية لربط التلوث بالآثار الطبيعية والبشرية وقد وجد أن الآبار الملوثة تقع ضمن المناطق الحساسة بيئيا وتقع ضمن مناطق التجمعات السكنية والقريبة من المناطق الزراعية.

تم عمل نموذج رياضي لتدفق المياه الجوفية وانتقال الملوثات في الحوض الجوفي لجزء من منطقة الدراسة (الجزء الغربي من حوض الإسكندرون الواقع شمال غرب حوض العوجا تماسيح) والذي يمثل المنطقة الأكثر حساسية للتلوث. تم تمثيل النموذج بطبقتين وتمت محاكاة النموذج خلال 10 سنوات (2005-2015) لدراسة كيفية تصرف الملوثات خلال تلك الفترة. وقد كانت النتيجة أن الوضع قد يسوء فيما يتعلق بتلوث المياه الجوفية في تلك المنطقة ما لم يكن هناك إجراءات يتم تنفيذها من قبل صناع القرار بالتعاون مع الناس للتقليل من الآثار الناتجة عن النشاطات الإنسانية المسببة لتلوث المياه الجوفية في تلك المنطقة.

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Abbreviations

ARIJ	Applied Research Institute – Jerusalem
BOD	Biological Oxygen Demand
COD	Chemical Oxygen Demand
DAR	Deutsche Abwasser Reinigungs – Gesellschaft
DEM	Digital Elevation Model
EIA	Environment Impact Assessment
GIS	Geographical Information Systems
MCM	Million Cubic Meter
MOPIC	Ministry of Planning and International Cooperation
PCBS	Palestinian Central Bureau of Statistics
PECDAR	Palestinian Economic Council for Development and Reconstruction
PHG	Palestinian Hydrology Group
PWA	Palestinian Water Authority
SUSMAQ	Sustainable Management of the West Bank and Gaza Aquifers
WAB	Western Aquifer Basin
WHO	World Health Organization

Chapter One

Introduction

1.1 Background

Palestine suffers from water scarcity and groundwater acts the main source of water in the West Bank. So, it is essential to preserve the quality of groundwater from deterioration and contamination especially when it is subjected to human activities may be harmful to its quality. It is very necessary to keep it as clean as possible and within the range of acceptable national standards in which it could be used without causing any harm for the users.

Actually, there is a little social awareness to the pollution of groundwater, mainly the pollution caused by an improper human activities and uncontrolled use of lands, especially in the areas sensitive to pollution. It seems that the contamination of some groundwater bodies with nitrate and other pollutants will continue and increase if no action is done to control such activities by publics. Hence, hydrochemical investigations for the groundwater system are needed and the extension of pollutants in the aquifer should be controlled.

The two main aquifers in historic Palestine are the Mountain and Gaza Aquifers. The Mountain Aquifer system, composed of three systems – the Western, Eastern and Northeastern Aquifer systems (Figure 1.1), and has a total annual recharge of about 679MCM (PHG, 2004). The Western Aquifer is flowing toward the Mediterranean with a replenishment capacity of approximately 362MCM per year, the Eastern Aquifer has a capacity of 170MCM per year (through nearly 50% of this is brackish) and the Northeastern Aquifer has the recharge capacity of 145MCM per year (PHG, 2004).

Groundwater in Tulkarm Area is being utilized through wells constructed to tap the groundwater aquifers. Groundwater wells are used to provide Palestinians with water for both domestic and irrigation purposes. There are 10 domestic wells and 53 irrigation wells with total available quantity of groundwater of 21.25MCM per year (MOPIC, 1998).

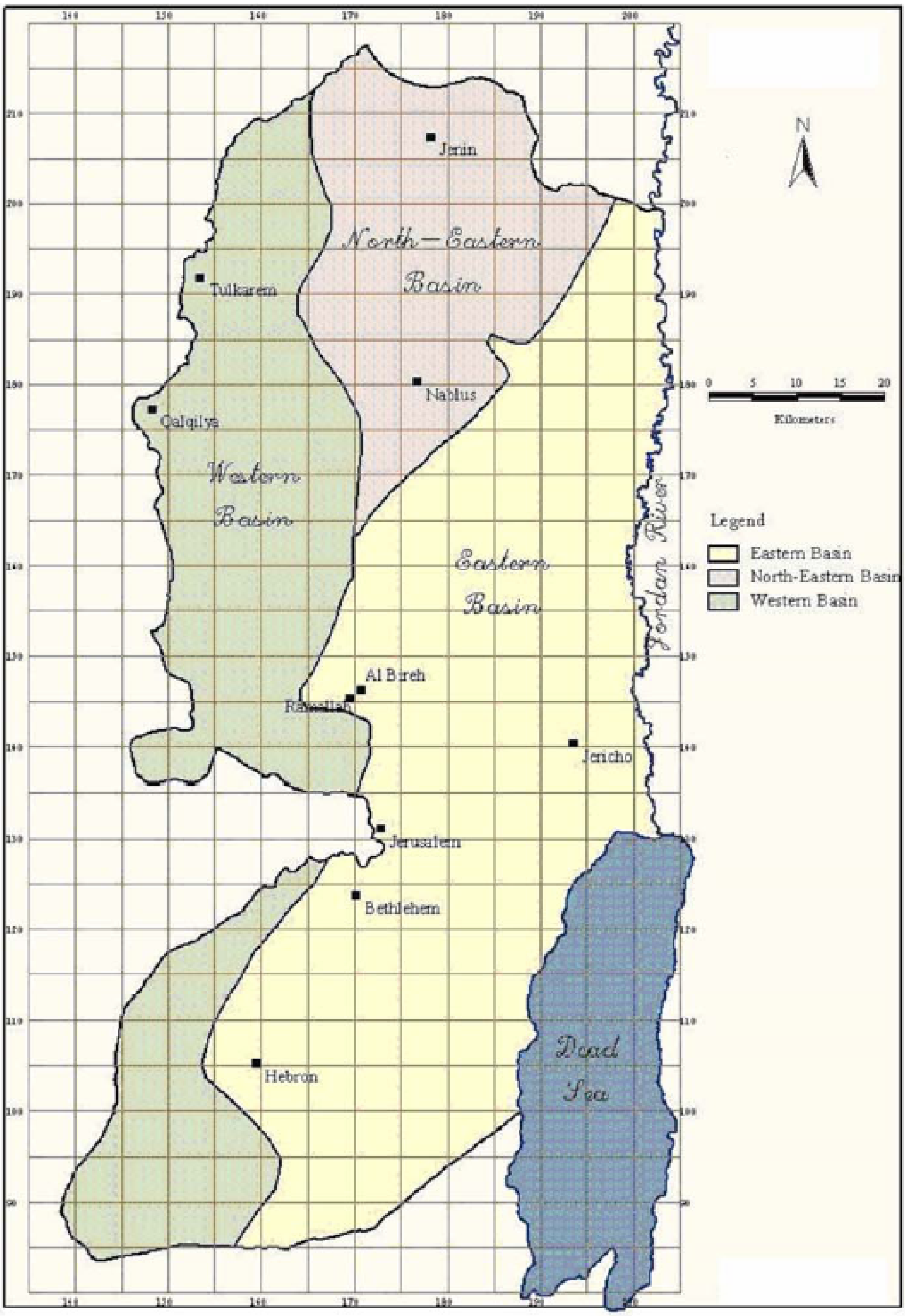


Figure 1.1: Groundwater Basins in the West Bank (Modified after PHG, 2004)

The West Bank has been classified into different sensitive areas based on the degree of sensitivity to pollution (Figure 1.2). Most of the sensitive areas are located in the north and the west of the West Bank while the south and the east is less sensitive and the area of Tulkarm is considered as highly sensitive area due to the shallow aquifer system where pollutants are being increasingly added to the groundwater system through various human activities and natural processes (MOPIC, 1998).

There are several activities that is harmful to the groundwater quality in Tulkarm Area. Approximately 58.5 tons of pesticide were used in Tulkarm Area in the years 1993/1994 growing season, about 25% of the total cultivated areas in the Area are treated with pesticides (ARIJ, 1996).

About 70% of houses dispose their wastewater using cesspits which is one of the main pollution source to groundwater (ARIJ, 1996). Most of these cesspits are emptied by vacuum tankers and disposed into wadis or to improper dumping sites.
There are approximately 12 known dumping sites in Tulkarm Area. These dumping sites are located in agricultural lands and their sites were selected randomly without any consideration to the soil characteristics, topography and climate as well as groundwater. As none of the existing dumping sites is designed to collect leachate from solid waste degradation, the leachate always finds its way through the soil to the groundwater, increasing nitrate concentration and other pollutants to the water. Other major pollutant is industrial waste that includes heavy metals, toxic compounds and radioactive materials.

The pollutants poses the aquifer system leads to increase the number of soluble chemicals from urban, agricultural and industrial activities. These chemicals are not completely removed by filtration as groundwater passes through the aquifer and some pose a threat to human health. The removal of pollutants from aquifers is an extremely costly and protracted operation and in some cases the aquifers may be irreversibly damaged.

Long term improvement of groundwater quality can be achieved by controlling inputs of pollutants in susceptible recharge areas and by gaining a better understanding of the movement and degradation of pollutants in aquifers.

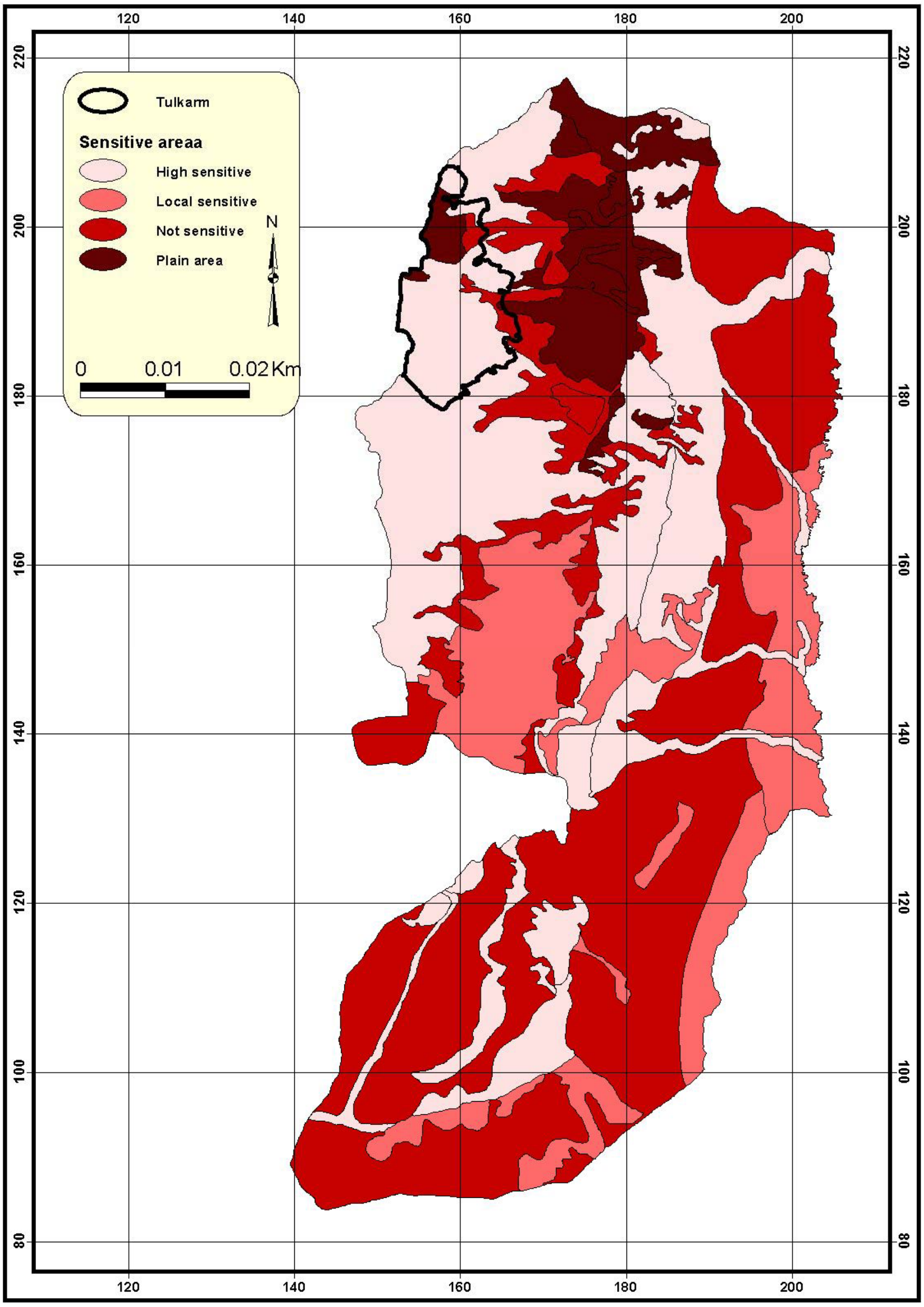


Figure 1.2: West Bank Sensitive Areas

1.2 Objectives

The main objectives of this thesis are:

- To study the effect of geomorphology on groundwater hydrochemistry to investigate whether the pollution is natural or man-made.
- To analyze and predict the groundwater contamination in the study area.

1.3 Methodology

The approach used for achieving the results and goals of the study is described as follows:

- **Data Collection:**

  The required data was collected and summarized as follows:
  - Hydrological and geological data for the study area.
  - Geometric shape and land cover data.
  - Historical and present states of pollution and pollution sources.
  - Historical water quality data for the specified wells in the study area.

- **Data Analysis and Mapping:**

  The collected data was analyzed, then a hydrogeochemical study was conducted for the study area to investigate whether the pollution is natural or man-made. Then, the trend analysis was performed for nitrate and chloride as pollution indicators. Moreover, the Geographical Information Systems (GIS) was used as a tool in performing spatial analysis to interact the recharge areas with the polluted wells.

- **Modeling :**

  A flow and solute transport model was developed to forecast the response of contamination after 10 years (in the period 2005-2015) for a specified parameter. The model was performed and simulated using Modflow package. Data was prepared and sorted according to the requirements of the program, where the required parameters for simulations are:

- Geometric parameters of the aquifers (boundary shape, thickness, elevations of the roof and the bottom).
- Initial distributions of hydraulic head and concentration.
- Location and intensity of pollution source.
- Estimations of various hydrogeological parameters, including porosity and hydraulic conductivity.

▪ **Interpretation:**

The output of the constructed model was discussed and the tendency of contamination was predicted with response to pollutant movement through model simulation time.

1.4 Thesis Structure

The thesis is divided into six chapters as follows:

▪ Chapter one is an introduction provides a general background about the subject of the thesis that describes the objective and the methodology used in it.

▪ Chapter two provides a brief description for Tulkarm Area as a case study in this thesis.

▪ Chapter three discusses the effect of geomorphology of Tulkarm Area and its effect on groundwater quality through hydrochemistry of groundwater for several wells in the study area.

▪ Chapter four discusses the groundwater pollution problem in Tulkarm Area basing on historical data for nitrate and chloride and conducting a spatial analysis using the GIS as a tool.

▪ Chapter five develops a groundwater flow and solute transport model for a specified parameter to study the tendency of contamination for groundwater in the study area.

▪ Chapter six summarizes conclusions and recommendations obtained from this thesis.

Chapter Two

Description of the Study Area

2.1 Location

Tulkarm Area is located in the north western part of the West Bank (Figure 2.1). It is bounded by the Jenin, Nablus and Qalqilia Areas in the north, east and south, respectively, and by the 1948 cease-fire line in the west.

Tulkarm lies at one of the most accessible gateways from the Tulkarm plain to the Nablus hills. It is located at the intersection of the north-south arteries of the Haifa-Lod railroad and motor road, both running along the western edge of the hills with the west-east highway leading from the coast to Nablus. The rich farmlands of the surrounding area have contributed to its development (ARIJ, 1996).

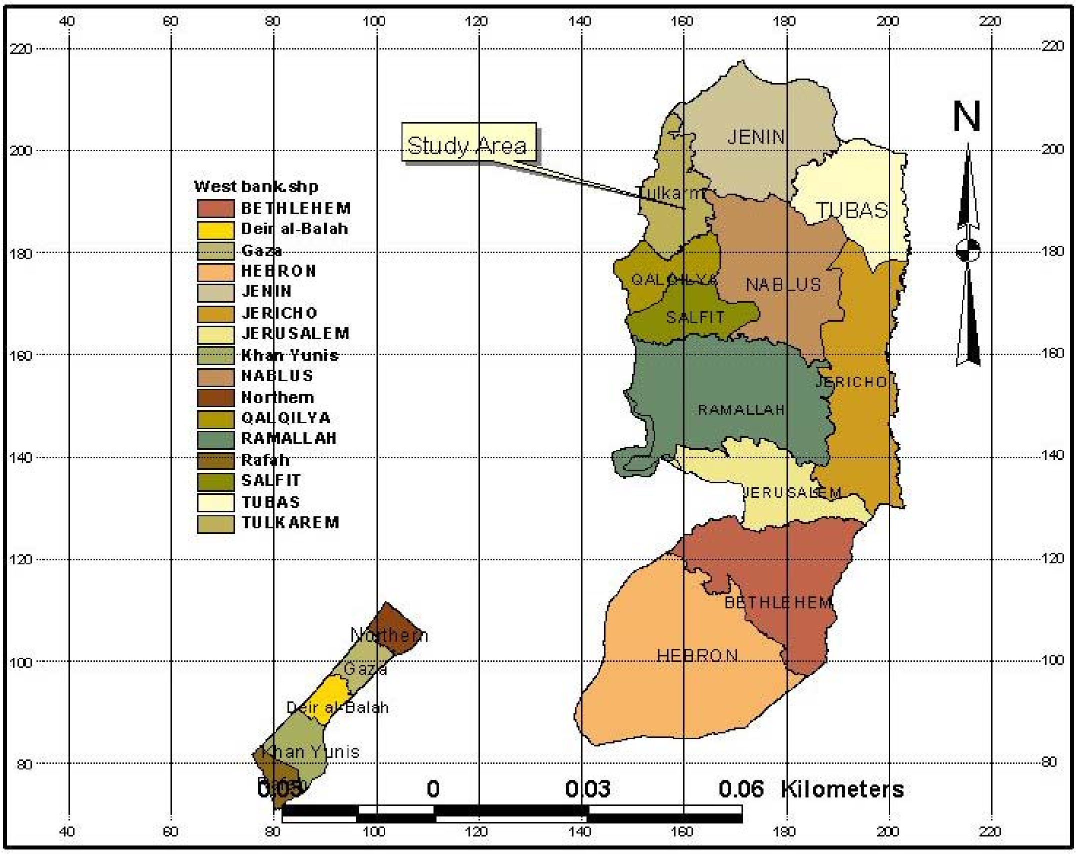


Figure 2.1: Tulkarm Location Map

2.2 Population

The total area of Tulkarm is about 246 km², the current population of the Tulkarm Area is estimated at 166,832 people including the two refugee camps, Tulkarm and Nur Shams, representing 12.4% of the total population of the West Bank. The number of people living in the rural areas is representing 55% of the total population of the Tulkarm Area. Approximately 20,778 people live in refugee camps, 54,281 live in urban areas and the population density in the Tulkarm Area is about 678.2 person/km² (PCBS, 1996).

2.3 Climate

The climate of Tulkarm is subtropical, with rainfall limited to the winter. The average temperature in the winter ranges from 8 to 16 °C, while the average temperature in the summer ranges from 17 to 30 °C.

1- Precipitation

The mean annual rainfall in the Tulkarm city is 642 mm for the period from 1952 to 1995 (Tulkarm Agricultural Department, 1996). The amount of mean annual rainfall in the Tulkarm Area varies from year to year and rain may fall with great intensity in wet years. The rainy season in the Tulkarm Area usually starts in October and continues through May. Between December and February, almost 70% of annual rainfall occurs, while 20% of annual rainfall occurs in October and November. December and January are normally the wettest months in the Tulkarm Area. Rain in June and September is rare and comes to negligible amounts. July and August have no rain at all, except for one rainfall of 1.5 mm on July 10, 1995 in Tulkarm City (Tulkarm Agricultural Department, 1996).

2- Dew

There is no available data on the amount of dew fall in the Tulkarm Area. It is known, however, that dew is greater in the west, closer to the sea especially on windless nights when the soil grows colder than the air that touches its surface. In general, the coastal plain of the Mediterranean has an average of 200 nights of dew per year and the total annual dew fall in the region is estimated at 30 mm (Orni and Efrat, 1980).

3- Temperature

The mean annual maximum temperature for the Tulkarm Area is 22.3°C and the mean annual minimum is 15.6°C. Exposure to marine influences mitigates the temperature in the summer months especially at midday. The mean temperature from June to August is 25°C. This value increases to an average of 26.2°C in August (the hottest month). From 1992 until 1996, the highest maximum temperature measured was 41.4 °C at 2 pm on May 12, 1996. In winter, the area is influenced by warm air from the sea. The average temperature from December to February is 11.8°C. The coldest days of the year come in January with an average of 11°C (ARIJ, 1996).

4- Winds

In Tulkarm Area, the wind direction mainly lies between the southwest and northwest with the mean annual wind speed of 3.4 km/h. In winter, the area is influenced by the depressions passing from west to east over the Mediterranean. These depressions bring westerly rain bearing winds. The average wind speed from December to February is 4.1 km/h. In summer, the area is influenced by the sea breeze that comes from the west. The incoming sea breeze usually begins to be felt in the Tulkarm Area in the morning. Towards noon, winds change their direction to southeast and later in the evening they turn to south and southwest. The average wind speed from June to August is 2.85 km/h. In September and October, winds are more northerly with an average wind speed of 2.78 km/h. In spring, Khamaseen winds may blow over the area full of sand and dust. These winds cause rising temperatures and drop in humidity. The mean daily wind speed from April to June is 3.2 km/h. (ARIJ, 1996)

2.4 Geology And Stratigraphy

The majority of Tulkarm Area rocks are composed of carbonate rocks such as limestone, dolomite, marl and chalk. The age of these rocks ranges from Cretaceous to Quaternary.

Jurassic rocks have no outcrops in the area but they are identified by bore holes in the area.

Rofe and Raffely (1965) reported the following lithological formations (ranging in age from older to younger) which can be shown in Figure 2.2 and described in Figure 2.3.

1. Bethlehem Formation (Upper Cenomanian):

   It is regarded as the Upper Cenomanian age and the outcrops are found mainly on the flank of the 'Anabta anticline. The lithology is characterized mainly by limestone and dolomite with chalk and marl. The dolomite and the limestone are well jointed, therefore, the formation is considered as moderate to good aquifer.

2. Jerusalem Formation (Upper Cenomanian-Turonian):

   It is considered as the Upper Cenomanian age and the alteration of thin bedded chalky and finely crystalline with occasional dolomite that is regarded as very good aquifer.

3. Abu-Dis Formation (Senonian):

   It consists mainly of chalks, chert and marls of Senonian age. The chalk is usually white, but in some parts of the formation it is dark due to the presence of bituminous materials. The thickness of this formation ranges between 0-450m. It is located almost in the northern parts of the study area.

4. Tertiary Rocks (Eocene):

   These rocks range in age from the Eocene to Pliocene in age. They are exposed in the 'Anabta area and in the Nablus-Beit Qad syncline. Lithology is marked mainly by chalk and limestone with some conglomerate. The chalk and limestone are represented by several covers including some chalk and chert. The presence of the limestone and the conglomerate lenses form a good aquifer while the chalk and marl act as a good aquiclude.

5. Quaternary Rocks (Alluvium & Nari):

   They are divided into the following formations:

   - Alluvium

     It is related to the Holocene age and it is distributed in both low and high lands. It consists mainly of unconsolidated and laminated marl with some siliceous sand. The Alluvium is characterized by the red color and fine texture which is due to its derivation from limestone. Sometimes it trends to be sandy and white which arise particularly in the area of sandstone exposures.

- Nari Formation

It forms the surface crust with variable thickness over all rocks. In the areas of the chalk and impure limestone, the thickness may exceed 10m but it becomes thin over the purer limestone. This formation consists of carbonate deposits mixed with rock or cement. It was formed as a result of bicarbonate water penetrating the exposed rocks. This water is drawn to the surface and evaporates leaving carbonate deposits mixed with insoluble residue.

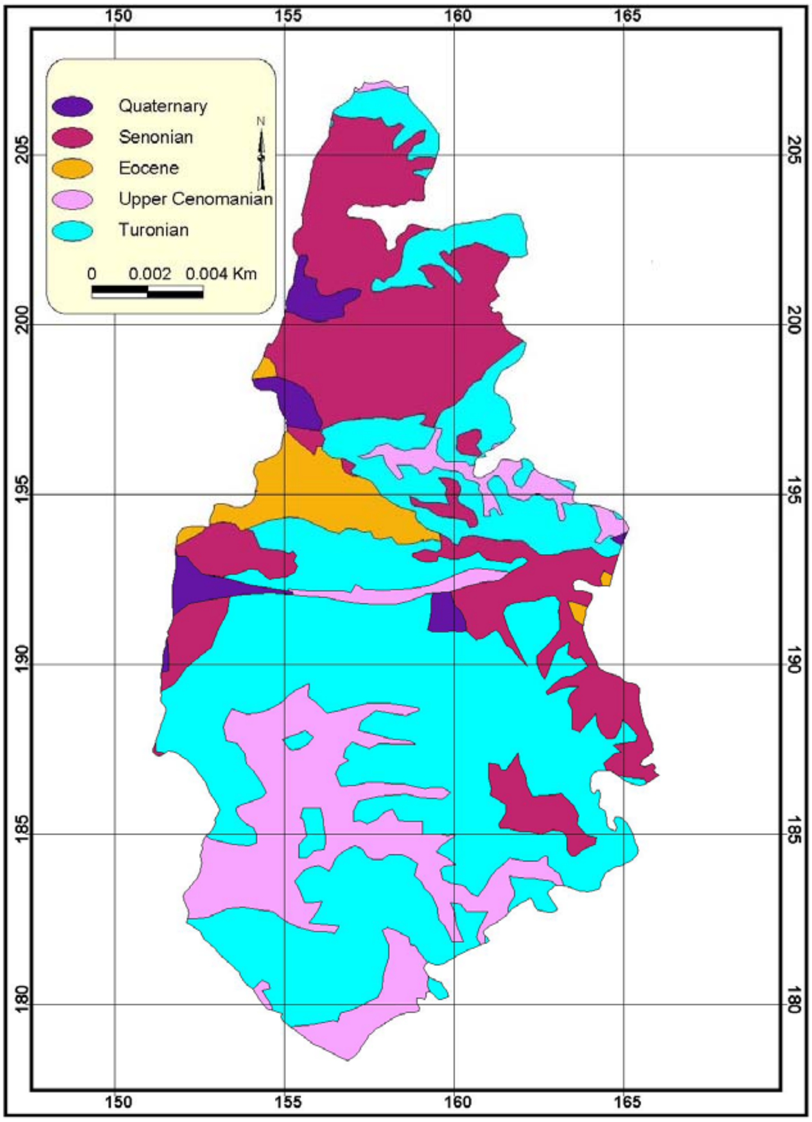
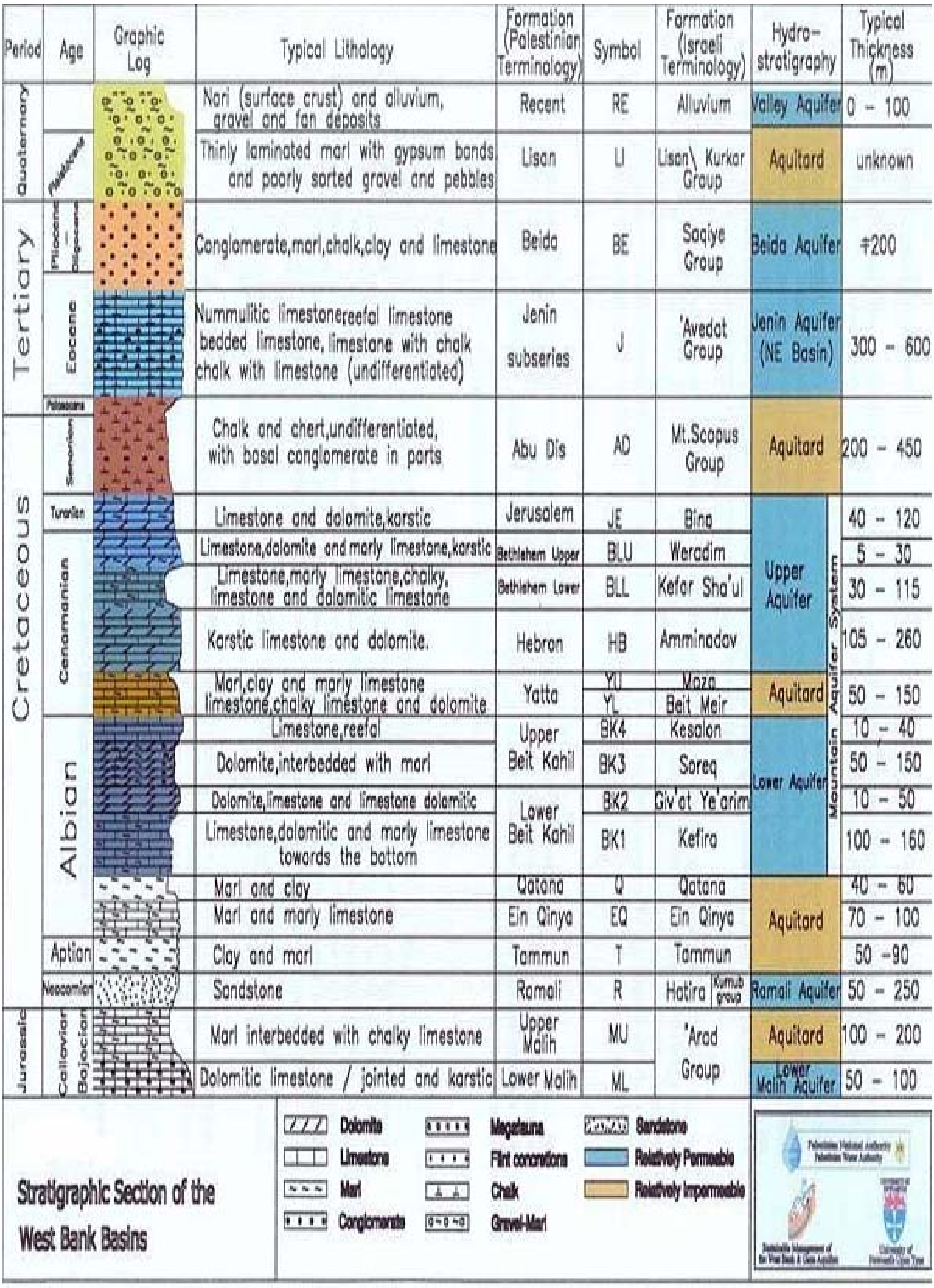


Figure 2.2: Geological Formation of Tulkarm

The stratigraphic cross section of the West Bank is shown in Figure 2.3 bellow:



Period	Age	Typical Lithology	Formation (Palestinian Terminology)	Symbol	Formation (Israeli Terminology)	Hydro-stratigraphy	Typical Thickness (m)
Quaternary		Marl (surface crust) and alluvium, gravel and fan deposits	Recent	RE	Alluvium	Valley Aquifer	0 - 100
	Pleistocene	Thinly laminated marl with gypsum bands and poorly sorted gravel and pebbles	Lisan	Li	Lisan\ Kurkar Group	Aquitard	unknown
Tertiary	Pliocene - Oligocene	Conglomerate,marl,chalk,clay and limestone	Beida	BE	Saqiye Group	Beida Aquifer	∓200
	Eocene	Nummulitic limestone,reefal limestone bedded limestone, limestone with chalk chalk with limestone (undifferentiated)	Jenin subseries	J	'Avedat Group	Jenin Aquifer (NE Basin)	300 - 600
Cretaceous	Paleocene / Senonian	Chalk and chert,undifferentiated, with basal conglomerate in parts	Abu Dis	AD	Mt.Scopus Group	Aquitard	200 - 450
	Turonian	Limestone and dolomite,karstic	Jerusalem	JE	Bina	Upper Aquifer (Mountain Aquifer System)	40 - 120
	Cenomanian	Limestone,dolomite and marly limestone,karstic	Bethlehem Upper	BLU	Weradim		5 - 30
		Limestone,marly limestone,chalky, limestone and dolomitic limestone	Bethlehem Lower	BLL	Kefar Sha'ul		30 - 115
		Karstic limestone and dolomite.	Hebron	HB	Amminadav		105 - 260
		Marl,clay and marly limestone limestone,chalky limestone and dolomite	Yatta	YU / YL	Moza / Beit Meir	Aquitard	50 - 150
	Albian	Limestone,reefal	Upper Beit Kahil	BK4	Kesalon	Lower Aquifer	10 - 40
		Dolomite,interbedded with marl		BK3	Soreq		50 - 150
		Dolomite,limestone and limestone dolomitic	Lower Beit Kahil	BK2	Giv'at Ye'arim		10 - 50
		Limestone,dolomitic and marly limestone towards the bottom		BK1	Kefira		100 - 160
		Marl and clay	Qatana	Q	Qatana	Aquitard	40 - 60
		Marl and marly limestone	Ein Qinya	EQ	Ein Qinya		70 - 100
	Aptian	Clay and marl	Tammun	T	Tammun		50 -90
	Neocomian	Sandstone	Ramali	R	Hatira (Kurnub group)	Ramali Aquifer	50 - 250
Jurassic	Callovian / Bajocian	Marl interbedded with chalky limestone	Upper Malih	MU	'Arad Group	Aquitard	100 - 200
		Dolomitic limestone / jointed and karstic	Lower Malih	ML		Lower Malih Aquifer	50 - 100

Figure 2.3: Stratigraphic Section of the West Bank (Source: PWA – SUSMAQ Project, 2003)

2.5 Geological Structure

The geological structure of Tulkarm area is described as follows:

1- Folds: Two main structural folds are dominant in the Tulkarm Area, the 'Anabta anticline and Nablus-Beit Qad syncline. The 'Anabta anticline is about 25km long, trends north-south from 'Anabta to Qalqilia, where it disappears. The southern part of the anticline is broken by a number of east-western faults whereas the northern part has gentle slopes. In general the anticline is considered as a symmetrical structure. The Nablus-Beit Qad syncline trends north-northeast and south-southwest and continues towards Biddya village, where it disappears. The western limb has gentle slopes while the eastern limb has sharp dipping. The western flank of syncline forms minor folds. One of these folds is the syncline located east of 'Anabta anticline. This small syncline extends one kilometer and is considered one of the important structures that affect channeling groundwater. One of the minor folds is the east-west anticline which is located between Kafr Qaddum and Jit villages. This anticline extends to about 15km (Rofe and Raffely, 1965).

2- Faults: Most of the faults trend east-west with some faults trending northwest-southeast. The normal faults are dominant in the area and have small throws. Long throw faults are rare in the area. Slopes of these faults are generally regular (Rofe and Raffely, 1965).

3- Joints: Joints and karsts caves are well developed in the Bethlehem, Hebron and Jerusalem formations. All of these formations consist mainly of weathered and caved limestone and dolomite. The high number of joints and channels in these formations are considered to be good aquifers (Rofe and Raffely, 1965).

2.6 Water Resources

2.6.1 Surface Water

The main drainage systems in Tulkarm Area are:

1- Wadi Abu Nar in the northern part of the Tulkarm Area with an annual discharge of 2.77 MCM.
2- Wadi Massin with an average annual discharge of 1.35 MCM.
3- Wadi Zeimar with an average annual discharge of 3.18 MCM.
4- Wadi et Tin with an average annual discharge of 0.73 MCM.

Very limited uncalculated water quantities are being utilized from these floods through cisterns and small catchment areas to harvest water in the form of agricultural ponds. Many Palestinians are using the roofs of their houses as well as plastic houses to collect water and store it in small reservoirs or cisterns (ARIJ, 1996).

3.6.2 Groundwater System

The main aquifer systems in the study area are:

1- Upper Cenomanian-Turonian Aquifer system, where the majority of Palestinian wells are tapped. It is composed of limestone, dolomite and marl with joints and krasts that give its aquifer properties. It has different aquifer formations including Hebron, Jerusalem and Bethlehem, which are exposed in the study area (Rofe & Raffety, 1965).

2- Lower Cenomanian Aquifer, which underlies the upper Cenomanian Aquifer. A small number of Palestinian wells are tapping this aquifer. This system is represented by Lower Beit Kahil and Upper Beit Kahil geological formations, which form good aquifers (Rofe & Raffety, 1965).

3- Eocene Aquifer of the Tertiary chert, which consists of limestone and sandstone. Few outcrops are found in the eastern part of the study area (Rofe & Raffety, 1965).

There are no springs in Tulkarm Area and the groundwater is utilized through groundwater wells constructed to tap the groundwater aquifers. The groundwater wells are used to cover the water needs for domestic and agricultural purposes.

2.7 Literature Review on the Study Area

A groundwater modeling study on the Yarkon-Taninim-Beer-Sheva Basin to identify their sources of salinity was done by Gutman and Zukerman in 1995. The study report was written in Hebrew and the results are not available for publics an can be reviewed in the library of the Hydrological Services of Israel (Gutman and Zukerman, 1995).

It was found by ARIJ through a conducted survey in 1996 that most of the cesspits in the Tulkarm Area are built without concrete linings in order to encourage sewage infiltration to the ground and thereby minimize emptying costs. However, this can also cause further groundwater pollution (ARIJ, 1996).

In 1998 it was found through a monitoring program that was conducted in Tulkarm Area that there is a bacterial pollution in approximately of 20% of samples taken by health department (DAR-UG, 1998). The groundwater wells near Wadi Zeimar show raised levels of chloride and nitrate concentrations with time (DAR-UG, 1999).

According to the ARIJ survey conducted in 1996, the sewerage network in Tulkarm city extends to 25 km, while that in Qalqiliya has a length of 40 km, covering 75 % of the population of urban areas. Only 50 % of the wastewater flows into the stabilization ponds operated by the municipalities; the other half flows into the green line where an emergency treatment facility has been constructed to prevent pollution of the Alexander stream., leakage of wastewater from the sewerage networks in both Tulkarm and Qalqiliya reaches 50 % (ARIJ, 1996). In that survey it was showed that 70 % of the population are depending on cesspits for their wastewater disposal and only 30 % benefit from connection to a sewerage system, and that these only exist within the borders of Tulkarm municipalities and refugee camps.

A groundwater modeling study for the Western Aquifer Basin was conducted through SUSMAQ project in the year of 2003. The study concentrated on the management of the (WAB). It was found that the sustainable yield of the basin about 443 MCM/yr which is considered the largest among the three aquifer basins (SUSMAQ, 2003).

Rumman (2003) developed steady state numerical flow and transport model for Wadi Zeimar as MSc thesis study. The study have demonstrated on the interaction between groundwater flow fields and pollution sources in areas of significant abstraction and help to emphasis that wadi development is one of the key elements of water resources planning (The quality of groundwater in Tulkarm Area indicates a gradual increase in chloride and nitrate with time) (Romman, 2003).

Chapter Three

Geomorphology and Hydrochemistry

3.1 Introduction

Geomorphology is the science that investigates the land forms of the earth. Included are the forms on the land surface, the mountains, valleys and slopes. Geomorphology describes the existing landforms, investigates the processes that create them, examines the relationships between landform and process and seeks to explain landform development. It is an earth science and is usually considered to be part of geography and geology. The genesis and evolution of features on the earth's surface erosion features, fluvial features, frost action, mass movements, shore features, solution features, and volcanic features are main parts of geomorphology. The following sections will discuss the geomorphology effects in terms of genesis and geological formations on hydrochemical parameters of groundwater in Tulkarm Area. This will be conducted by understanding the water type of groundwater wells, interpretation of hydrochemical parameters using the hydrogeochemical model (hydrowin software), grapgical representation for hydrochemical data and by understanding the water genesis of the groundwater wells and the possible water rock interaction.

3.2 Geomorphology of Tulkarm Area

From the contour map of the West Bank a clip was made for Tulkarm Area. Then, a surface model (Digital Elevation Model – DEM) for Tulkarm Area was constructed using the ArcView 3D analyst GIS software. From the DEM of Tulkarm (Figure 3.1), the area lies between 40m and 500m above sea level with gradual decrease from the east to the west. The general topography is sloppy to flat at the western parts of the area and mountainous at the eastern parts of the area. The most builtup areas is located in the flat area located in the downstream to the west.

The major drainage systems in Tulkarm Area flow westwards and the main catchment areas covering the area, are, from the north to the south, Alkhodera drainage basin, Iskandaron drainage basin and Auja Tamaseeh drainage basin based on the West Bank drainage basins. From the DEM of Tulkarm it can be shown that most of the groundwater wells in both drainage basins are located in the down stream, means that they are subjected to water flow from the east to the west.

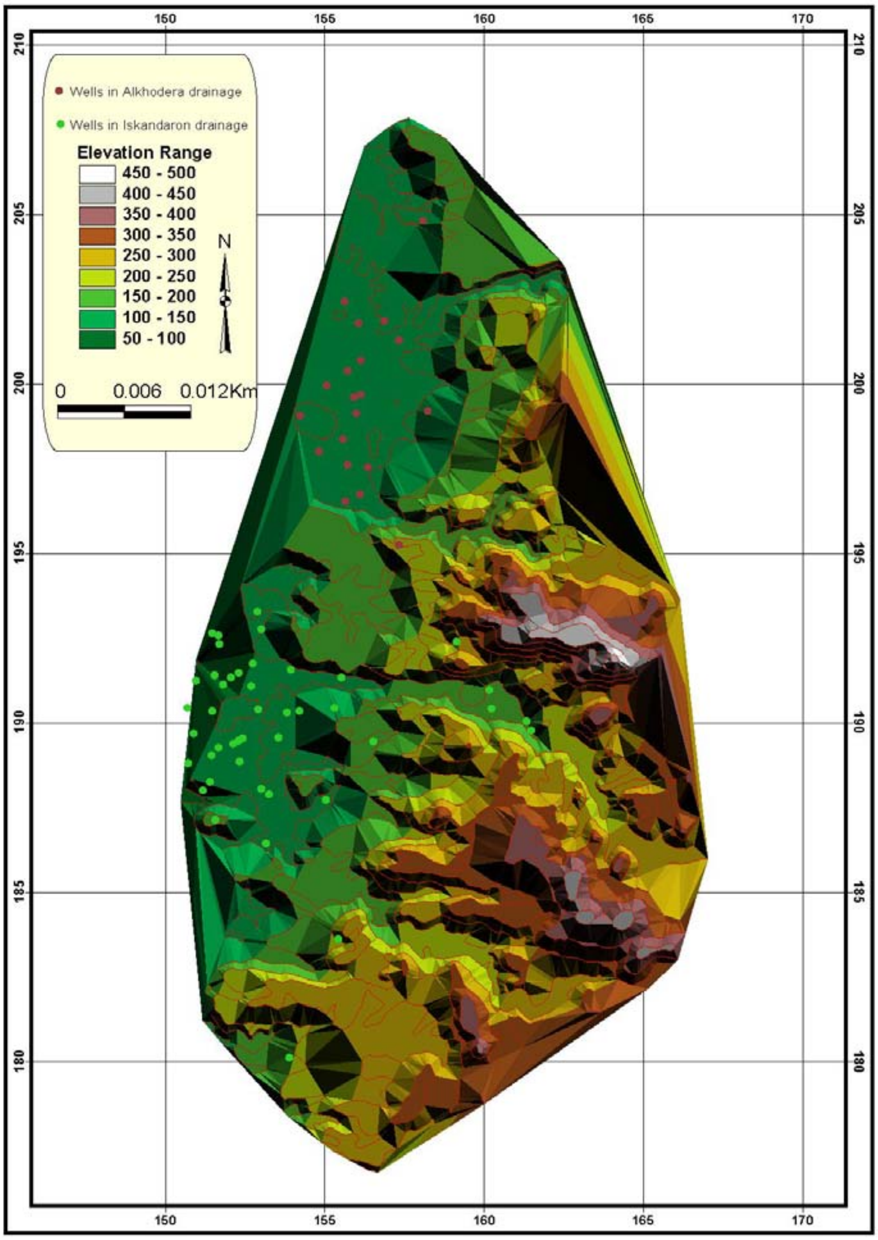


Figure 3.1: DEM for Tulkarm Area

3.3 Groundwater Quality Assessment

A wide range of natural processes determines groundwater composition. Groundwater is in close contact with the rock and soil material. The water composition is therefore likely to reflect the chemical rock or soil characteristics. Groundwater quality is furthermore affected by the composition of water infiltrating the soil and by the groundwater retention time. Groundwater often occurs in association with geological materials containing soluble materials. Therefore, higher concentrations of dissolved salts are normally expected relative to surface water. The type and concentration of salts depends on the geological environment and on the source and movement of water.

3.3.1 Groundwater Composition

The chemical composition of groundwater is highly dependent on the mineralogical composition of the aquifer systems and on the anthropological activities in the study area. When rainfall infiltrates soil and during its journey through flow paths to the groundwater, processes such as cation exchange with clay, dissolution and precipitation of minerals, oxidation reduction reactions and microbial activity will change the chemical composition of old groundwater.

The hydrochemistry of groundwater is affected by the dissolution reactions that occur when rain water containing carbon dioxide (CO_2) reacts with carbonaceous rocks which are composed mainly of limestone ($CaCO_3$) and dolomite ($CaMg(CO_3)_2$) according to the following equations:

$CO_{2\,(g)} + H_2O \rightarrow H_2CO_{3\,(aq)}$----------------------- (3.1)

$H_2CO_{3\,(aq)} + CaCO_{3\,(s)} \rightarrow Ca^{2+}_{(aq)} + 2\ HCO_{3\,(aq)}$------------- (3.2)

Equation (3.2) shows that massive limestone rocks are dissolved into soluble species, which means chemical weathering of limestone bedrocks and hence the formation of karstic systems, through which pollutants travel rapidly into groundwater Runoff water carries pollutants from landfill leachate, roads, cesspits and farms, which contribute in the increase of pollutants in spring's water and groundwater reservoirs.

3.3.2 Hydrochemical Data

The hydrochemical investigation of the groundwater in Tulkarm Area was based on the available data from the (PWA Master Data Bank, 2003 & 2004) for physical and chemical parameters for specified wells in Tulkarm Area. The main chemical and physical parameters were:

- Major anions in mg/L: HCO_3^- , Cl^- , SO_4^{2-} and NO_3^-
- Major cations in mg/L: Ca^{2+} , Mg^{2+} , Na^+ and K^+
- Physical parameters: pH and Temperature.

The specified wells were Eleven, 5 of them are located in Alkhodera drainage basin and the others in Iskandaron drainage basin. Tables 3.1 & 3.2 show the hydrochemical parameters for wells in both drainage basins.

Table 3.1: Water Quality For Selected Wells in Alkhodera Drainage Basin (PWA Master Data Bank, 2003 & 2004):

Well ID	Spring 2003									
	Ca^{2+} (mg/L)	Mg^{2+} (mg/L)	Na^+ (mg/L)	K^+ (mg/L)	HCO_3^- (mg/L)	Cl^- (mg/L)	SO_4^{2-} (mg/L)	NO_3^- (mg/L)	pH	T (°C)
15-19/041	122	16	49	1.3	241	101	28.39	92	7.36	23.5
15-19/021	139	22	69	2.32	246	139	31.6	215	7.6	--
15-19/035	90	11	39.4	2.6	278	71.7	25	72	7.29	--
15-19/036	84	10	51.4	5.7	282	45.6	21	72	7.32	24
15-19/031	77	36	51	2.4	280	97.8	19.5	29	7.32	--
Well ID	Spring – 2004									
	Ca^{2+} (mg/L)	Mg^{2+} (mg/L)	Na^+ (mg/L)	K^+ (mg/L)	HCO_3^- (mg/L)	Cl^- (mg/L)	SO_4^{2-} (mg/L)	NO_3^- (mg/L)	pH	T (°C)
15-19/041	86	26	46	3.8	205	132	21	63	7.52	24
15-19/021	116	25	61	6.6	250	113	28	149	7.2	24.5
15-19/035	89	24	38	2.8	250	82	20	61	7.36	24
15-19/036	83	11	35	2	265	59	21	46	7.5	23.5
15-19/031	80	28	44	4.8	261	75	17	32	7.56	25

Table 3.2: Water Quality For Selected Wells in Iskandaron Drainage (PWA Master Data Bank, 2003 & 2004):

Well ID	Spring – 2003									
	Ca^{2+} (mg/L)	Mg^{2+} (mg/L)	Na^+ (mg/L)	K^+ (mg/L)	HCO_3^- (mg/L)	Cl^- (mg/L)	SO_4^{2-} (mg/L)	NO_3^- (mg/L)	pH	T (°C)
15-19/030	71	24	21	1.4	185	71.7	17	43	7.46	24.5
15-19/017	103	35	49	22	311	137	27	80	7.25	23.5
15-19/018	80	28	55.7	23	291	124	35.4	53	7.17	23
15-19/028	66	26	15.39	1.71	198	45.6	18	23.6	7.52	24.5
15-19/046	85	26	48.6	8.1	298	97.8	35	57	7.4	23
15-19/019	135	56	277.5	5.4	318	454	170	21	7.25	--

Table 3.2: continued

Well ID	Spring – 2004									
	Ca^{2+} (mg/L)	Mg^{2+} (mg/L)	Na^{+} (mg/L)	K^{+} (mg/L)	HCO_3^- (mg/L)	Cl^- (mg/L)	SO_4^{2-} (mg/L)	NO_3^- (mg/L)	pH	T (°C)
15-19/030	61	20	24	1.8	157	34	19	52	7.42	23
15-19/017	94	36	49	22	239	121	31	66	6.99	22.5
15-19/018	91	34	63	22	253	117	31	60	7.01	23
15-19/028	53	26	20	0.8	161	35	18	28	7.52	22
15-19/046	87	39	64	9	272	95	32	59	7.4	22.5
15-19/019	89	69	254	4.6	350	489	90	23	7.17	24.5

3.3.3 Water Type Classification & Graphical Representation

Piper plot and Durov diagrams are both kinds of graphical representation of water quality data. The Piper plot (Figure 3.2) consists of two triangles , one for cations and one for anions, and one diamond shaped square. The Piper diagram (or plot) is used to show the relationship between rock composition and resulting groundwater quality. It can furthermore be used to illustrate the effect of chemical reactions on groundwater composition.

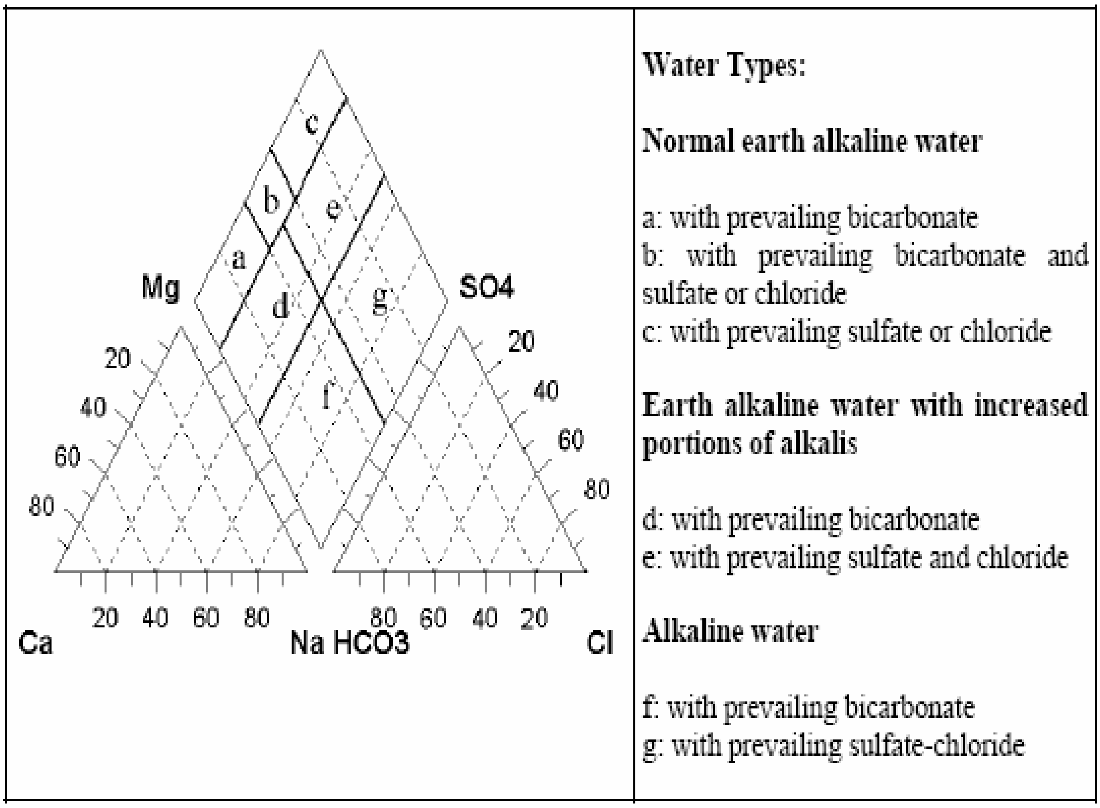
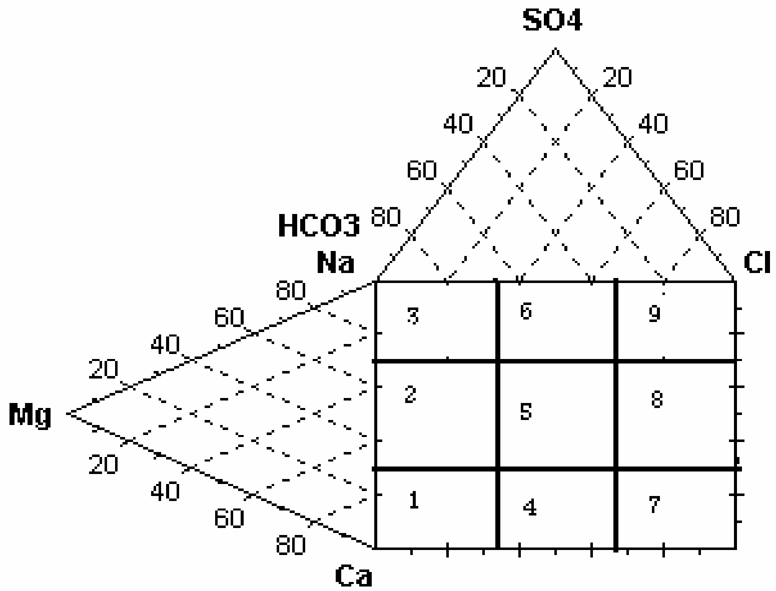


Figure 3.2: Water type classification on Piper Plot (Langguth, 1996)

The Durov diagram (Figure 3.3) is used to indicate recharge areas and interpretate of hydrochemical parameters. Also, Scholer diagram is used to indicate the main constituents of the groundwater samples and trends of pollution with time.



Field Symbol	Field Description
1-	HCO_3 and Ca dominant, frequently indicates recharging waters in limestone, sandstone and dolomite and may other aquifers.
2-	This water type is dominant by Ca and HCO_3 ions. Association with dolomite is presumed if Mg is significant. However, in those samples in which Na is significant, an important ion exchange is presumed.
3-	HCO_3 and Na are dominant, indicating ion-exchanged water, although under certain circumstances the generation of CO_2 at depth can produce HCO_3 where Na is dominant.
4-	SO_4 dominant, or anion descriminant and Ca dominant, Ca and SO_4, dominant frequently indicates a recharge water in lava and gypsiferous deposits, otherwise a mixed water or water exhibiting simple dissolution may indicated.
5-	No dominant cation or anion, indicates water exhibiting simple dissolution or mixing.
6-	SO_4 dominant, or anion descriminant and Na dominant is a water type not frequently encountered and indicates mixing influence.
7-	Cl and Na are frequently encountered unless cement pollution is present. Otherwise the watermay result from reverse ion exchange with of Na-Cl.
8-	Cl dominant anion and Na dominant cation indicate that the water may be related to reverse ion exchange of Na-Cl waters.
9-	Cl and Na dominant frequently indicates end point waters.

Figure 3.3: Durov Diagram with water type classification according to Lloyd and Heathcoat, 1985

1- Water Type and Graphical Representation for Alkhodera Wells:

The software of hydrowin was used to perform chemical analysis and graphical representation of the hydrochemical parameters of the groundwater samples for the specified wells in Alkhodera drainage basin (Figures 3.4 & 3.5).

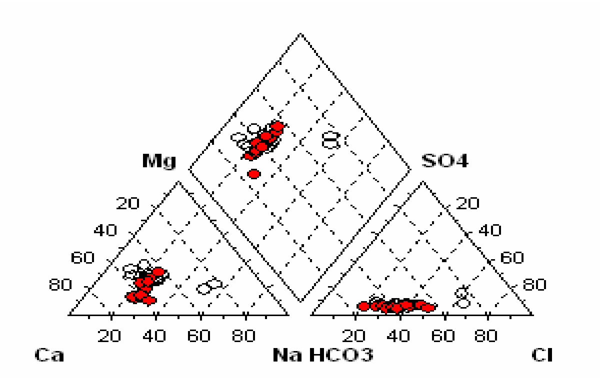


Figure 3.4: Piper Plot for Alkhodera Wells

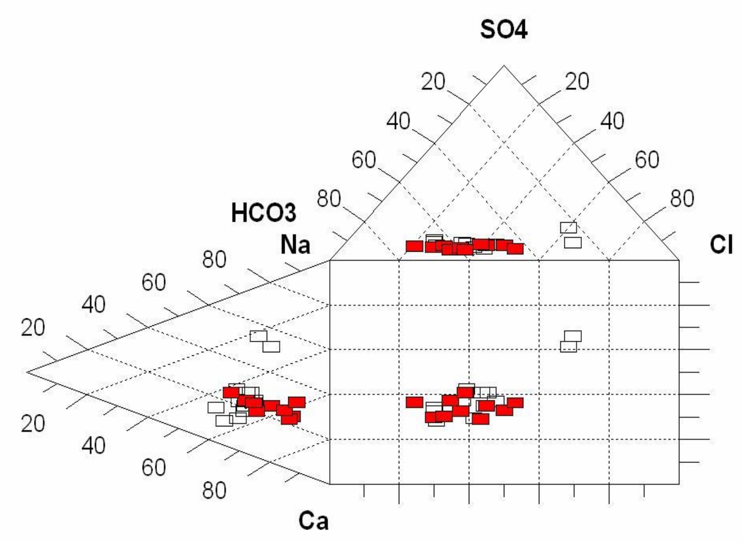


Figure 3.5: Durov Diagram for Alkhodera Wells

Figure 3.4 indicates that most of the wells have the water type of earth alkaline water with increased alkalis and with prevailing bicarbonate with no observable change between the years of 2003 and 2004. Durov diagram (Figure 3.5) indicates that some of groundwater samples are located in fields 2 means that HCO_3^- and Ca^{2+} are dominant aions, in association with dolomite which is presumed if Mg is significant. The other samples located in field 5 means that no dominant cation or anion, indicates water exhibiting simple dissolution or mixing. This agrees with Piper classification and water type. Scholer diagram (Figure 3.6) indicates that dominant ions for the samples are (Ca^{2+} & HCO_3^-) for the year of 2003 and 2004 originating from recharging water in limestone aquifer that is interrelated to aquifer type and its lithology, also, it can be shown that there is a variable trend of chloride concentration from the year of 2003 to 2004.

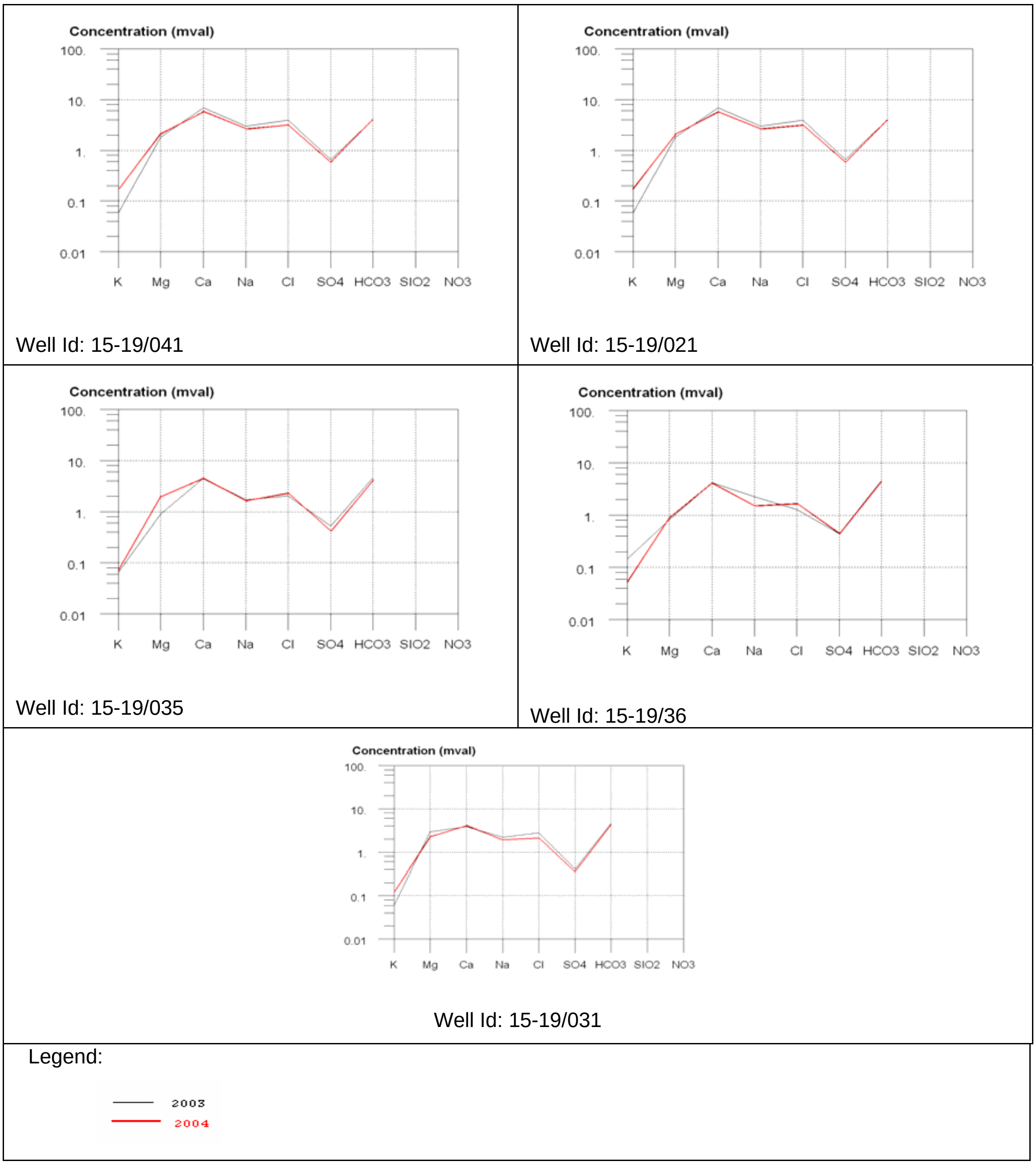


Figure 3.6: Scholer Diagram for Alkhodera Wells

2- Water Type and Graphical Representation for Iskandaron Wells:

The graphical representation of the hydrochemical parameters of the selected groundwater wells in the Iskandaron drainage basin is shown in Figures 3.7 and 3.8. Most of the samples have the water type of earth alkaline water with increased alkalis and with prevailing bicarbonate according to Piper classification.

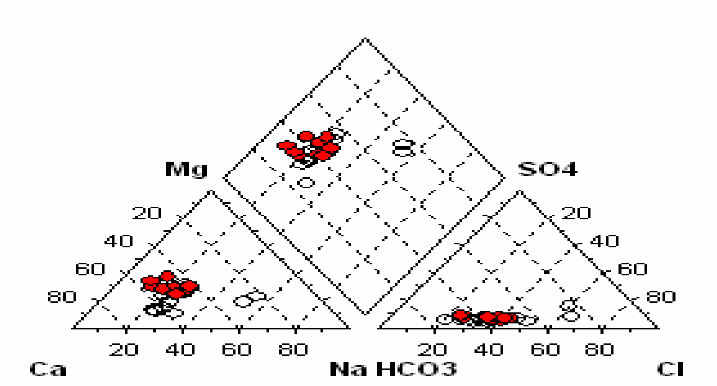


Figure 3.7: Piper Plot For Iskandaron wells

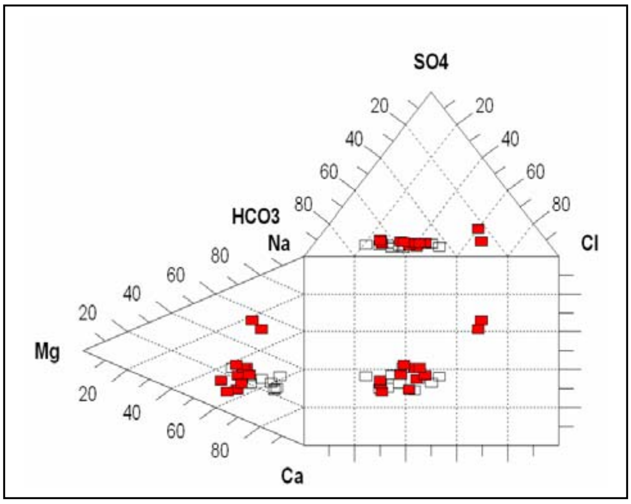


Figure 3.8: Durov Diagram for Iskandaron Wells

Also, Durov diagram (Figure 3.8) indicates that some of groundwater samples are located in fields 2 means that HCO_3^- and Ca^{2+} dominant aions, association with dolomite is presumed if Mg is significant. The other samples are located in field 5 means that no dominant cation or ion, indicates water exhibiting simple dissolution or mixing. This agrees with Piper classification and water type and one sample is located in field 8, which means that Cl^- dominant anion and Na^+ dominant cation indicate that the water may be related to reverse ion exchange of Na-Cl waters. Scholer diagram (Figure 3.9) indicates that dominant ions for the samples are (Ca^{2+} & HCO_3^-) for the year of 2003 and 2004 originating from recharging water in limestone aquifer that is interrelated to aquifer type and its lithology. It is shown that there is a variable trend of chloride concentration from the year of 2003 to 2004.

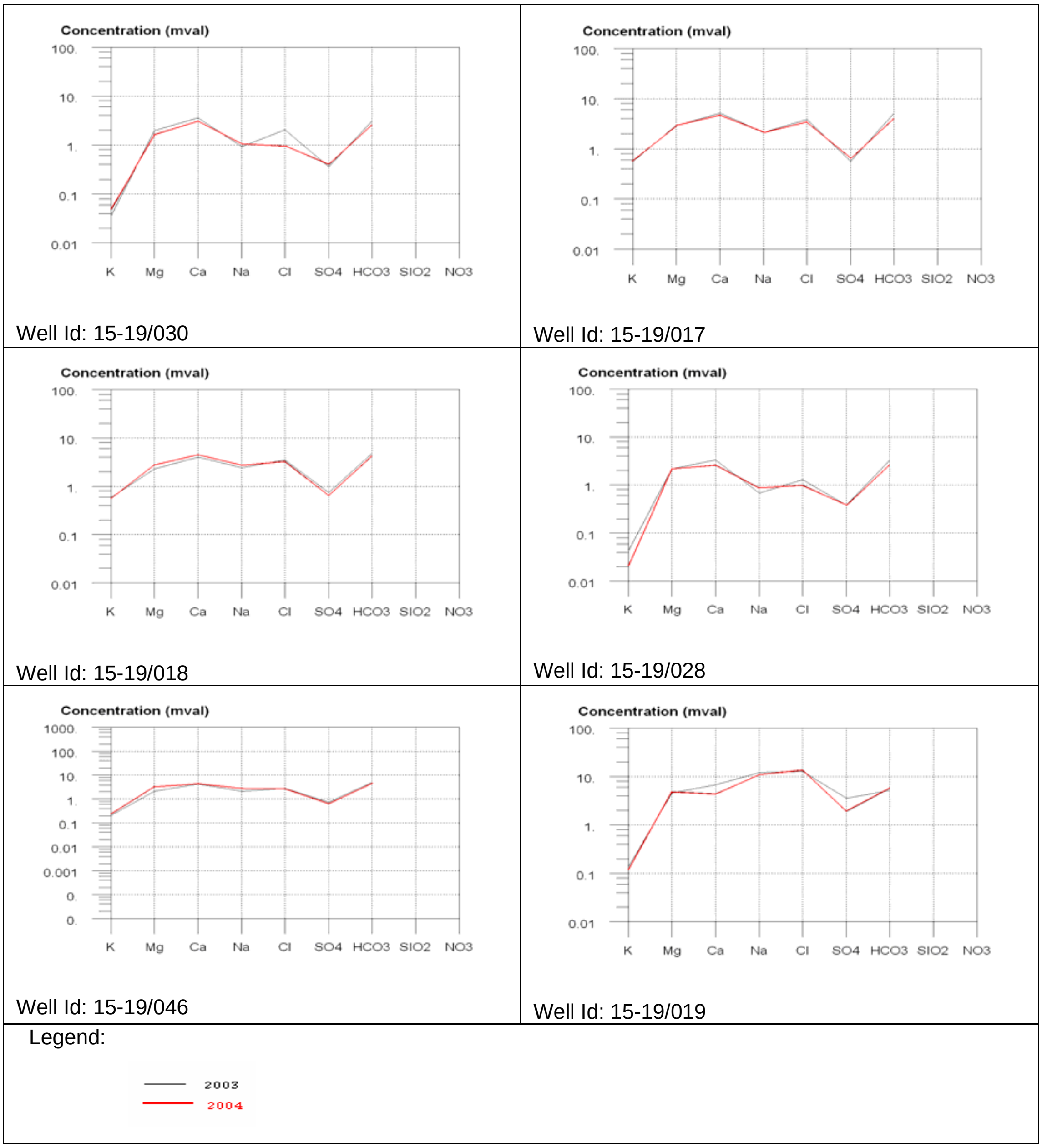


Figure 3.9: Scholer Diagram for Iskandaron Wells

The water type is interrelated to the geological formation and lithology of each well in both drainage basins using the arcview GIS software in conducting such analysis. The water type classification is described in Tables 3.3 & 3.4.

Table 3.3: Water Type for Selected Wells in Alkhodeera Drainage Basin:

Well ID	Geological Formation	Lithology	Year	Water Type (Piper Plot)	Piper classification	Dominant Constituents (Scholar Diagram)	State of Pollution (2005)
15-19/41	Senonian	Chalk & chert, undifferentiated with basalt conglomerate in parts.	2003	Ca-Na-HCO_3-Cl-NO_3	Earth alkaline water with increased portion of alkalis and with prevailing bicarbonate.	Ca, HCO_3	Cl=100 mg/L NO_3=93 mg/L (nitrate pollution)
			2004	Ca-Mg-Na-Cl-HCO_3	Earth alkaline water with increased portion of alkalis and with prevailing chloride & sulfate.	Ca, HCO_3	
15-19/21	Senonian	Chalk & chert, undifferentiated with basal conglomerate in parts.	2003	Ca-Na- NO_3-HCO_3-Cl	Earth alkaline water with increased portion of alkalis and with prevailing bicarbonate.	Ca, HCO_3	Cl=140 mg/L NO_3=189 mg/L (nitrate pollution)
			2004	Ca-Na- HCO_3 – NO_3-Cl	Earth alkaline water with increased portion of alkalis and with prevailing bicarbonate.	Ca, HCO_3	
15-20/35	Turronian	Limestone & dolomite karstic (Jerusalem)	2003	Ca-Na-HCO_3-Cl- NO_3	Earth alkaline water with increased portion of alkalis and with prevailing bicarbonate.	Ca, HCO_3	Cl=109 mg/L NO_3=69 mg/L (nitrate pollution)
			2004	Ca-Mg-HCO_3-Cl	Earth alkaline water and with prevailing bicarbonate.	Ca, HCO_3	

Table 3.3: continued

Well ID	Geological Formation	Lithology	year	Water Type (Piper Plot)	Piper classification	Dominant Constituents (Scholar Diagram)	State of Pollution (2005)
15-20/36	Quaternary	Nari (surface crust) & alluvium, gravel and fan deposit	2003	Ca-Na-HCO_3-NO_3	Earth alkaline water with increased portion of alkalis and with prevailing bicarbonate.	Ca, HCO_3	Cl=95 mg/L NO_3=44 mg/L (not polluted)
			2004	Ca-Na-HCO_3-Cl	Earth alkaline water with increased portion of alkalis and with prevailing bicarbonate.	Ca, HCO_3	
15-19/31	Senonian	Chalk & chert, undifferentiated with basal conglomerate in parts.	2003	Ca-Mg-Na-HCO_3-Cl	Earth alkaline water with increased portion of alkalis and with prevailing bicarbonate.	Ca, HCO_3	Cl=97 mg/L NO_3=29 mg/L (not polluted)
			2004	Ca-Mg-Na-HCO_3-Cl	Earth alkaline water with increased portion of alkalis and with prevailing bicarbonate.	Ca, HCO_3	

Table 3.4: Water Type for Selected Wells in Alkhodera Drainage Basin:

Well ID	Geological Formation	Lithology	Year	Water Type (Piper Plot)	Piper Classification	Dominant Constituents (Sholar Diagram)	State of Pollution (2005)
15-19/030	Turronian	Limestone & dolomite karstic (Jerusalem)	2003	Ca-Mg-HCO_3-Cl	Normal earth alkaline water and with prevailing bicarbonate.	Ca, HCO_3	Cl=58 mg/L NO_3=53 mg/L (nitrate pollution)
			2004	Ca-Mg-HCO_3- NO_3	Normal earth alkaline water and with prevailing bicarbonate.	Ca, HCO_3	
15-19/017	Senonian	Chalk & chert, undifferentiated with basal conglomerate in parts.	2003	Ca-Mg-HCO3-Cl	Normal earth alkaline water and with prevailing bicarbonate.	Ca, HCO3	Cl=145 mg/L NO3=62 mg/L (nitrate pollution)
			2004	Ca-Mg-Na-HCO_3-Cl	Earth alkaline water with increased portion of alkalis and with prevailing bicarbonate.	Ca, HCO_3	
15-19/018	Quaternary	Nari (surface crust) & alluvium, gravel and fan deposit	2003	Ca-Na-Mg-HCO_3- Cl	Earth alkaline water with increased portion of alkalis and with prevailing bicarbonate.	Ca, HCO_3	Cl=130 mg/L NO3=61 mg/L (nitrate pollution)
			2004	Ca-Mg-Na-HCO_3- Cl	Earth alkaline water with increased portion of alkalis and with prevailing bicarbonate.	Ca, HCO_3	

Table 3.4: continued

Well ID	Geological Formation	Lithology	Year	Water Type (Piper Plot)	Piper Classification	Dominant Constituents (Sholar Diagram)	State of Pollution (2005)
15-19/028	Turronian	Limestone & dolomite karstic (Jerusalem)	2003	Ca-Mg-HCO_3-Cl	Normal earth alkaline water and with prevailing bicarbonate.	Ca, HCO_3	Cl=45mg/L NO_3=32mg/L (not polluted)
			2004	Ca-Mg-HCO_3	Earth alkaline water and with prevailing bicarbonate.	Ca, HCO_3	
15-19/046	Senonian	Chalk & chert, undifferentiated with basal conglomerate in parts.	2003	Ca-Mg-Na-HCO_3-Cl	Earth alkaline water with increased portion of alkalis and with prevailing bicarbonate.	Ca, HCO_3	----
			2004	Ca-Mg-Na-HCO_3-Cl	Earth alkaline water with increased portion of alkalis and with prevailing bicarbonate.	Ca, HCO_3	
15-19/019	Quaternary	Nari (surface crust) & alluvium, gravel and fan deposit	2003	Na-Ca-Mg-Cl-HCO_3	Alkaline water with prevailing sulfate	Ca, HCO_3	Cl=450 mg/L NO_3=21 mg/L (chloride pollution)
			2004	Na-Mg-Ca-Cl-HCO_3	Alkaline water with prevailing sulfate	Ca, HCO_3	

3.3.4 Water Genesis & Saturation Indices

The saturation index indicates whether a water is saturated or not saturated regarding to a certain material. It is calculated using this equation: SI = Log (IAP/K_{sp}) where:
IAP is the Ion Activity Product, K_{sp} is the solubility of the product.
The solution is considered to be in equilibrium regarding particular SI equals zero. It is considered to be unsaturated if the SI < 0 and oversaturated (precipitated) if SI > 0. Saturation index is used to define the amounts of an assemblage of pure phases that can react reversibly with the aqueous phase. As groundwater moves underground it tends to develop a chemical equilibrium by chemical reactions with its environment.
Average values of SI for anhydrite ($CaSO_4$), aragonite ($CaCO_3$), calcite ($CaCO_3$), dolomite ($CaMg\ (CO_3)_2$) and gypsum ($CaSO_4.2H2O$) and magnesite ($Mg\ CO_3$) (Tables 3.5 & 3.6), were calculated for the samples of both drainage basins (Alkhodera & Iskandaron) using the Hydrowin software. The results indicate that no significant variance was observed between the year of 2003 and 2004. Also the results show that SI < 0 for anhydrite, gypsum and magnesite. On the other hand, the SI > 0 for calcite, dolomite and aragonite. The saturation indices indicate that the groundwater is over saturated with aragonite, calcite and dolomite which are three dominant mineral phases affecting the water composition through its transformation from rainwater to well water in the recharge area of the watershed.
Referring to the water type classification, most of the samples have a water type of earth alkaline water with increased alkalis and with prevailing bicarbonate according to Piper plot, and located in the field where calcium and bicarbonate are dominant according to Durov diagram, which indicates that water type of those wells recharges in limestone. It is shown that dominant ions for the samples are (Ca & HCO3) for the years of 2003 and 2004 and they are originating from recharging water in limestone aquifer which is interrelated to the aquifer type as well as its lithology.

Table 3.5: Saturation Indices for the Specified Wells in Iskandaron Drainage:

Well Id	Saturation Index (2003)						Saturatin Index (2004)					
	Calcite	Aragonite	Dolomite	Magnesite	Gypsum	Anhydrite	Calcite	Aragonite	Dolomite	Magnesite	Gypsum	Anhydrite
15-19/041	0.374	0.23	0.215	-0.727	-1.96	-2.181	0.324	0.18	0.478	-0.414	-2.215	-2.436
15-19/021	0.05	-0.094	-0.352	-0.969	-1.919	-2.14	0.194	0.051	0.071	-0.69	-2.016	-2.237
15-20/035	-0.037	-0.181	-0.638	-1.168	-2.095	-2.316	0.269	0.126	0.319	-0.518	-2.214	-2.435
15-20/036	0.262	0.12	-0.049	-0.879	-2.19	-2.41	0.418	0.274	0.308	-0.678	-2.183	-2.404
15-19/031	-0.106	-0.25	-0.193	-0.655	-2.297	-2.518	0/448	0.304	0.789	-0.227	-2.321	-2.541

Table 3.6: Saturation Indices for the Specified Wells in Iskandaron Drainage:

Well Id	Saturation Index (2003)						Saturatin Index (2004)					
	Calcite	Aragonite	Dolomite	Magnesite	Gypsum	Anhydrite	Calcite	Aragonite	Dolomite	Magnesite	Gypsum	Anhydrite
15-19/030	0.159	0.015	0.196	-0.53	-2.343	-2.563	-0.009	-0.153	-0.153	-0.712	-2.333	-2.554
15-19/017	0.292	0.149	0.465	-0.395	-2.079	-2.299	-0.114	-0.258	-0.296	-0.75	-2.042	-2.263
15-19/018	0.086	-0.057	0.065	-0.588	-2.032	-2.252	-0.083	-0.227	-0.244	-0.729	-2.052	-2.273
15-19/028	0.224	0.08	0.392	-0.399	-2.336	-2.557	0.056	-0.088	0.152	-0.471	-2.411	-2.632
15-19/046	0.356	0.212	0.546	-0.377	-2.006	-2.226	0.319	0.176	0.639	-0.248	-2.06	-2.28
15-19/019	0.090	-0.054	0.144	-0.514	-1.31	-1.53	0.143	-0.001	0.455	-0.255	-1.722	-1.943

Chapter Four

Groundwater Pollution in Tulkarm Area

4.1 Introduction

The term of groundwater quality refers to its physical, chemical, and biological characteristics as they relate to the intended use of water. Groundwater quality is threatened mainly by human activities, although harmful substances are sometimes introduced by natural processes. Sustainable groundwater management must be based not only on prevention of the overexploitation of groundwater resources but also on prevention of contamination, because unlike treatment at the point of use, prevention protects all of the resource.

Contaminants can be transformed by geochemical, radiological, and microbiological processes as they are transported through various environments within the ground-water system. Some chemical transformations can change harmful contaminants into less harmful chemical species, while other processes can produce compounds that are more harmful to ecosystems or human health than the parent compound. The natural decay of some radio nuclides can produce daughter products with different transport properties and health effects than the parent product (Focazio et al., 2000). In some cases, transformation products are found in the environment more often than parent compounds (Kolpin et al., 1997). Similarly, some chemical transformations can change relatively immobile compounds into highly mobile compounds, and change parent compounds to transformation products. Knowledge of the path and timing of groundwater movement as well as the chemistry and biology relevant for the contaminant present is important in determining the fate and transport of a contaminant and its associated transformation products. This is important for contaminants that rapidly change to other chemicals in the environment particularly when transformation or daughter products are more persistent than the parent compound. In addition, the vulnerability of a groundwater supply to many contaminants is dependent on the solubility and subsequent mobility of the contaminant as influenced by the specific mineralogy and associated geochemical conditions within the aquifer and pumped well. For example, naturally occurring arsenic can be tightly bound to aquifer materials in certain geochemical conditions but can be subsequently released to the pore waters of the aquifer if those conditions are changed, (Welch et al., 2000). The chemical properties of a contaminant are important in the unsaturated zone as well as the aquifer itself. For example, some (hydrophobic) compounds strongly attach to soils in the unsaturated zone (as well as the saturated zone) before reaching the water table, and these compounds are attached until released by geochemical or other changes such as when the binding capacity of the soil is exceeded.

Groundwater quality is influenced considerably by the quality of the recharge source. Variations in natural and human activities reflect spatial variations as well as the petrological aspects of the aquifer and the hydro chemical parameters of the groundwater. Municipal, industrial and agricultural wastes resulted by human activities entering an aquifer are major sources of organic and inorganic pollution. Irregular dumping sites, flow of wastewater and cesspits put threats to what extent of pollution is, in the most important aquifer in the West Bank (Western Aquifer Basin). The following sections will discuss the mechanism of groundwater pollution, some of groundwater pollutants and some of pollution sources resulted by human activities in Tulkarm Area through an assessment study for nitrate and chloride parameters as pollution indicators of the groundwater.

4.2 Theoretical Background on Groundwater Pollution

4.2.1 Mechanism of Groundwater Pollution

The contaminant introduced into the soil-rock-groundwater system will spread within the system only if a transport mechanism is available, for example, a flowing liquid. As soon as the contaminant reaches the subsurface water in the unsaturated or saturated zone, various processes determine its fate (Jackson, R.E. ,1980) :

- Physical processes: advection, dispersion, evaporation, filtration, and degassing.
- Geochemical processes: acid-base reactions, adsorption-desorption, ion exchange, oxidation-reduction, precipitation-dissolution, retardation, and complexation.

- Biochemical processes: transpiration, bacterial respiration, decay, and cell synthesis.

Many of these processes are related to each other or interact. Some of them may attenuate the contaminants, some have a reverse effect. The soil zone is the most reactive part of the system due to the soil-water-air environment, the soil-plant behavior, and the microbiological activity. Short-circuiting of this zone makes the soil-rock-groundwater system much more vulnerable.

Contaminants are carried by moving groundwater (advection) and travel at the same rate as the average linear velocity of groundwater. The process of dispersion acts to dilute the contaminant and lower its concentration. For example, because of hydrodynamic dispersion, the concentration of a waste plume will decrease with distance from the source. Dispersion increases with increasing groundwater velocity and aquifer heterogeneity. However, for removal of bacteria and viruses by filtration, a fine-grained and homogeneous material is needed. Volatile bacterial products, such as carbon dioxide, nitrogen, or methane, and volatile organic compounds may be removed by degassing.

Chemical reactions, such as adsorption-desorption and ion exchange can retard the rate of contaminant movement. Adsorption and desorption are characterized by the distribution coefficient, which expresses the ratio of the amount of contaminant adsorbed per gram of soil material to the amount of contaminant remaining in groundwater per milliliter. The distribution coefficient can be used to compute the retardation of the movement of the contamination front (Fetter, C. W., 1994).

Bacteria use the reaction energy of oxidation-reduction (redox) reactions for their metabolism. After free oxygen is used up, anaerobic bacterial respiration may successfully reduce nitrate, sulfate, and even carbon dioxide and decompose organic compounds. Recent research has given strong evidence that many toxic organic chemicals can undergo microbial decay to more simple compounds. The mechanisms mentioned above are illustrated here with an example of nitrogen (nitrate and ammonium) contamination by fertilizers. Some of the nitrogen released from the fertilizers will be taken up by crops. Evaporation concentrates the leachate. Further, a part of the dissolved nitrogen will be removed, and another amount will be added to the soil water. Removal takes place by bacterial cell synthesis and further by nitrate respiration under anaerobic conditions, when bacteria break nitrate down to molecular nitrogen. Decay (mineralization) of litter by bacteria will add nitrate and ammonium to the system. Ammonium ions will be adsorbed on clay particles, but are under aerobic conditions subsequently oxidized to nitrate, which is very mobile. The nitrate moves with the infiltrating water to the saturated zone (advective transport) and is diluted by dispersion. The dispersive capacity of the porous medium is directly proportional to the pore-water velocity and the heterogeneity of the aquifer materials. During residence in an anaerobic saturated zone, nitrate may be reduced by pyrite according to: $2FeS_2\ (s) + 6NO_3^- + 4H_2O = 2Fe(OH)_3\ (s) + 3N_2\ (g) + 4SO_4^{2-} + 2H^+$, where s = solid and g = gas. During oxidation, pyrite may release heavy metals, e.g. bivalent Cd, Ni, or Zn, which become mobile under acidic conditions or by complexation with organic substances and may contaminate the groundwater.

4.2.2 Groundwater Pollutants

Groundwater pollutants consist of (micro)biological substances (bacteria, viruses), inorganic substances (anions, cations and heavy metals) and organic substances (synthetic or natural substances, pesticides and sewage sludge , respectively). Some of groundwater pollutants and their behavior in soil and groundwater are briefly addressed in the following sections.

1- Bacteria and viruses:

Two main factors control the elimination of bacteria and viruses from the soil and groundwater: their persistence under the chemical and biological groundwater conditions and the physical process controlling their transport in groundwater.

The elimination rate of bacteria and viruses depends on physical and biological parameters. Temperature and soil moisture seem to be dominant factors determining survival of bacteria in soil and groundwater. The environmental factors affecting bacterial survival in the unsaturated zone are:

- Soil moisture content (higher content means better survival)
- Temperature (longer survival at lower temperature)

- pH (shorter survival time at lower pH values)
- Presence of organic matter (the more organic matter, the higher the survival rate)
- The presence of predating organisms.

Cesspits can cause severe groundwater contamination by pathogenic microorganisms (bacteria and viruses).

2- Nitrate (NO_3^-):

Nitrates are soluble species and can percolate with infiltrate water down to groundwater reservoirs. Water analysts in terms of nitrogen, i.e. mg/L N, usually express nitrite (NO_2^-) and nitrate (NO_3^-): the total oxidized nitrogen is the sum of nitrite and nitrate nitrogen. Nitrite is an intermediate oxidation state of nitrogen in the biochemical oxidation of ammonia to nitrate and in the reduction of nitrates under conditions where there is a deficit of oxygen. The presence of nitrites in a groundwater may be a sign of sewage pollution, it may have no hygienic significance. Nitrate sources in groundwater originate from mineralization of nitrogen from atmosphere, fertilizers and from agricultural activities, where animal manure contributes to the rise of nitrate levels (Widory et al., 2004). The presence of nitrates in groundwater in concentrations above the WHO guidelines of 45mg/L makes water toxic for humans, poultry and cattle .

Nitrates in groundwater can be reduced to nitrite, especially in areas of ferruginous sands, and new brickwork in the wells is also known to produce a similar effect. Nitrate is the final stage of oxidation of ammonia and mineralization of nitrogen from organic matter. Most of this oxidation in soil and water is achieved by nitrifying bacteria and can be only in a well-oxygenated environment.

3- Chloride (Cl^-):

Chlorides, compounds of chlorine with another element or radical are present in nearly all natural waters and the range of concentrations can very wide, but the most concentrations are with sodium (NaCl, “common salt”) and, to a lesser extent, with calcium and magnesium. They are one of the most stable components in water, with concentrations being unaffected by most of natural physiochemical or biological processes. The presence of chloride in natural waters in general can be attributed to dissolution of salt deposits, discharges of effluents for chemical industries, oil-well operations, sewage discharges, irrigation drainage, contamination from refuse leachates, and seawater intrusion in coastal areas.

Chloride levels are an indication of salinity in groundwater. It is measured in mg/L. Wastewater adds considerable amounts of chloride into groundwater, for example, human excreta, particularly the urine, contain an average amount of 6g/person/day (Sawyer et al., 1994). Anthropogenic activities such as agricultural and industrial sources contribute in the increase of chloride levels in groundwater. Many pesticides containing chloride, such as poly-chlorinated biphenyls PCB's contribute in pollution of groundwater with chloride through biodegradation processes. Chloride at concentrations above 250mg/L gives salty taste to water, which is objectionable to many people (Sawyer et al., 1994).

4- Phosphate:

Phosphate can easily be retained in the soil due to chemical changes and adsorption. Phosphate ions become chemisorbed on the surfaces of Fe and Al minerals in strongly acid to neutral systems.

5- Metals:

Four major reactions with metals take place in the soil: adsorption, ion exchange, chemical precipitation and complexation with organic substances. The type of clay mineral is important, as metals adsorb onto the surface of iron and aluminum hydroxides and hydroxy oxides. The aluminum and iron content of the soils are the essential factor governing the ability of a soil for heavy metal immobilization. The soil pH is the determining factor in all adsorption-desorption and precipitation-solubilization reactions. The cation exchange capacity of soils generally increase with an increase in pH. Heavy metal in groundwater is originated from dumping sites, industrial sources….etc.

4.3 Pollution Sources in Tulkarm Area

Pollution sources are classified as point sources and diffuse sources. Point sources are sources that can be clearly identified and pinpointed (such as landfill leachate). Diffuse sources cannot be pinpointed and are distributed over a large surface area (application of fertilizers and pesticides in agriculture: (nitrates and pesticides infiltrate into the soil over an extensive surface area). Cesspits in built-up areas, with a high tank density , can also be considered as a diffuse groundwater pollution source. Through each individual cesspit is a point source, all cesspits together form a widely distributed pollution source. By its very nature, a pollution source is easier to control than a diffuse source. Some of groundwater pollution sources in Tulkarm are listed in the following sections.

4.3.1 Cesspits

Tulkarm Area is in the same situation as other parts of the West Bank in wastewater collection and disposal. Wastewater is either collected and discharged into wadis or temporarily stored in cesspits prior to dumping. A survey carried out by ARIJ in 1996 showed that 70 % of the population depend on cesspits for wastewater disposal and only 30 % benefit from connection to a sewerage system, and that these only exist within the borders of Tulkarm municipality and refugee camps (Tulkarm camp, Nour Shams camp) and ‘Anabta, while the other villages are not covered by the sewage network (ARIJ, 1996).

Cesspits operate as percolation or leach pits, so the infiltration capacity via the soil is high and pollutants are allowed to penetrate to underground strata. Septage characteristics show high variation depending on the wastewater retention time inside the system, design and construction of the system and type of wastewater source (industrial, commercial, agricultural or domestic).

Cesspits are considered to be the most widespread disposal method in the Tulkarm Area, similar to all West Bank Areas. Cesspits are designed to serve single or multiple apartment buildings. Most of the cesspits in the Tulkarm Area are built without concrete basement in order to encourage sewage infiltration to the ground and thus minimize the cost of emptying (ARIJ, 1996). Sewage infiltration from cesspits into the ground layers may reach the groundwater aquifer, constituting a major source of groundwater pollution.

Most of the cesspits are emptied by vacuum tankers and wastewater is discharged in the roads. Also the dumping sites act the best places for tankers drivers to empty their tanks without any care to health and environmental aspects. A'ttil village is suffering from such problems caused by vacuum tankers used dumping sites to empty tanks contents at the dumping sites.

4.3.2 Wastewater Pollution

Pollution from discharge of wastewater is considered as main source of pollution of the groundwater. Mixing the recharge water with sewage is the main pollution factor prevailing in the study area. Raw sewage from the western pipeline of Nablus and Tulkarm sewage is discharged into Wadi Zeimar. In addition the wastewater from the Israeli settlements is discharged into valleys and Wadi Zeimar (Photo 4.1) is a good evidence for that practice as none of the Israeli settlements have a developed sewage treatment plants. Furthermore, the sewerage network in Tulkarm city extends to 25 km, covering 75 % of the population. Only 50 % of the wastewater flows into the stabilization ponds operated by the municipalities; the other half flows into Israel where an emergency treatment facility has been constructed to prevent pollution of the Alexander stream. Consequently, the leakage and flooding of the existing systems is therefore common. Table 4.1 shows the characteristics of raw wastewater for Tulkarm city.

Table 4.1: Characteristics of Raw Wastewater for Tulkarm City:

Parameter	**BOD**	**COD**	**NO3**	**PO4**	**P**	**Cl**	**Na**	**pH**	**TSS**
Value (mg/L)	250	540	27.9	6	17.9	801	252	6.5	398
Source: (PECDAR, 1994)									

The groundwater quality for the wells located near the Wadi Zeimar is extremely poor. The Nitrate concentration exceeding WHO standard (45mg/L) and the chloride concentration is increasing with time. Wadi Zeimar catchment area is considered one of the serious potential pollution sources over the highly permeable area in the Western Basin.

Photo 4.1: Wastewater in Wadi Ziemar (May 2006)

4.3.3 Solid Waste

Tulkarm Area as well as other West Bank Areas are facing similar problems in solid waste collection and disposal. Currently, dumping in open areas and burning in the open are the most common methods of disposal. Evidence also shows that much of the solid waste generated by settlers is being disposed of on Palestinian land, in addition to the illegally transferring of toxic waste generated inside Israel into the West Bank.

Appraisal of waste from Palestinian communities has shown that the majority of waste is organic material, mostly in the form of food waste. Also, plastic bags are used and disposed frequently. Paper makes up a relatively small portion, much of which is cardboard and newspaper. Most disposal sites are unplanned and unmanaged open dumps with little consideration being given to their proximity to people, agriculture, or water resources. Often, the solid waste is burned at these sites causing serious air pollution.
Collection Services of solid waste collection in Tulkarm Area is considered better than other Areas in the West Bank, where 87% of the population are privileged with solid waste collection services. All urban areas, refugee camps, most of the villages have solid waste collection services. The quantities of domestic solid waste is estimated at 0.9-1kg/capita/day (Al-Hamidi et al., 1995).

Open and uncontrolled dumping of solid waste is practiced widely in Tulkarm Area (Photo 4.2). There are more than 12 dumping sites in the area. None of them were chosen according to hydro geological or environmental considerations. None of them are lined, fenced or monitored. The leachate produced from the solid waste degradation finds its way through the soil to the groundwater, as most of the dumping sites are located near the groundwater wells in Tulkarm Area.

Photo 4.2: Tulkarm Dumping Site (May 2006)

4.4 State of Groundwater Pollution in Tulkarm Area

According to the samples collected by PWA in the spring of 2005 the current state of groundwater quality in terms of nitrate and chloride for both drainage basins is tabulated in Tables 4.2 & 4.3 as follows:

Table 4.2: Nitrate & Chloride Concentration - Iskandaron Drainage (PWA Master Data Bank, 2005):

Well Id	Name	Locality	Water Use	Nitrate Concentration (mg/L)	Chloride Concentration (mg/L)
15-18/006	MUHAMMAD 'ABED AL HALEEM	FAR'UN	Agricultural	27	45
15-18/007	MUHAMMAD YUSEF 'OMAR	FAR'UN	Agricultural	28	39
15-18/008	ISMA'EEL I'TAIR	FAR'UN	Agricultural	66	88
15-18/009	AHMAD ABU SHANAB & PARTNERS	IRTAH	Agricultural	33	78
15-18/010	HASAN 'ISA & PARTNERS	IRTAH	Agricultural	28	85
15-18/017	'ABDALLAH SHRAIM & PARTNERS	TULKARM	Agricultural	82	140
15-18/019	RASHEED HANNUN & PARTNERS	TULKARM	Agricultural	45	80
15-18/022	MUHAMMAD AHMAD ABU SHANAB	IRTAH	Agricultural	75	95
15-18/024	SHUFA WATER COOPERATIVE COMMITT	SHUFAH	Domestic	23	89
15-19/002	KHALED SALEEM HANNUN	TULKARM	Agricultural	54	59
15-19/003	I'QAB FRAIJ & PARTNERS	SHWAIKAH	Agricultural	59	219
15-19/012	ZUBAYDAH AL SA'EED	DHINNABAH	Agricultural	45	55
15-19/013	HAFEDH ALHAMDALLAH	TULKARM	Agricultural	63	130
15-19/017	TULKARM MUNICIPALITY	TULKARM	Domestic	62	145
15-19/018	TULKARM MUNICIPALITY	TULKARM	Domestic	61	130
15-19/019	MUSTAFA AL SA'EED	TULKARM	Agricultural	21	450
15-19/028	HASAN MAHMUD KHALEEL	KUFUR AL LABAD	Agricultural	32	45
15-19/030	SADEEQ JAMUS	DHINNABAH	Agricultural	53	58
15-19/034	SA'EED JABER	SHWAIKAH	Agricultural	38	70
15-19/043	RAFEEQ HAMDALLAH	IKTABAH	Agricultural	57	97
15-19/044	SHAKER SAMARAH	SHWAIKAH	Agricultural	51	110
15-19/048	BAL'A VILLAGE COUNCIL	BAL'A	Domestic	16	35
16-19/001	'ANABTA MUNICIPALITY	'ANABTA	Domestic	65	135
16-19/002	'ANABTA MUNICIPALITY	'ANABTA	Domestic	55	120
16-19/011	JAMEEL 'AWARTANI	'ANABTA	Agricultural	62	155

Figure 4.1 shows the nitrate and chloride concentration for the groundwater wells in the Iskandaron drainage basin in the spring of 2005.

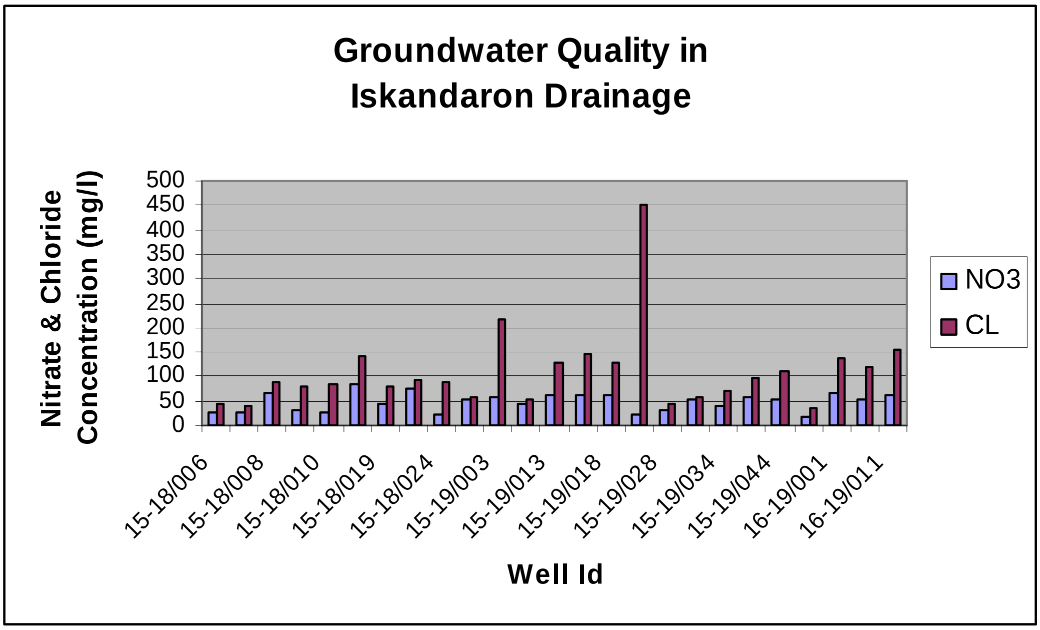


Figure 4.1: Nitrate & Chloride Concentration in Iskandaron Drainage Basin

From the mentioned information in Table 4.2 and Figure 4.1, with reference to the WHO standard limits for drinking water quality of 250mg/L and 45mg/L for chloride and nitrate concentrations respectively, it can be concluded that:

- The percentage of polluted wells by nitrate in this drainage basin is (14/25) *100% = 56%, while the percentage of polluted well by chloride is (1/25)*100% = 4%.
- The concentrations of nitrate reach a level up to 82 mg/L, with typical values in the range of 20-80 mg/L.
- The concentrations of chloride reach a level up to 450 mg/L, with typical values in the range of 35-219 mg/L, this range of concentrations is less than the WHO standards for drinking water quality of 250 mg/L.
- 4 wells of 6 domestic wells in the Iskandaron drainage basin are polluted by nitrate, while the other polluted wells with nitrate are agricultural wells, with values exceeding WHO standards for drinking water.

Table 4.3: Nitrate & Chloride Concentration - Alkhodera Drainage (PWA Master Data Bank, 2005):

Well Id	Name	Locality	Water Use	Nitrate Concentration (mg/L)	Chloride Concentration (mg/L)
15-19/010	ZAITA VILLAGE COUNCIL	ZAITA	Domestic	48	92
15-19/011	'ABED AL JABBAR SAMARAH	ZAITA	Agricultural	55	155
15-19/021	HASEEB I'MUS	'ATTEEL	Agricultural	189	140
15-19/022	MUHAMMAD MEKKAWI	'ALLAR	Agricultural	21	67
15-19/023	RASHEED SAMARAH & TAHSEEN SHADE	'ALLAR	Agricultural	76	150
15-19/029	'ABED AL MAJEED QASEM	DAIR AL GHSUN	Agricultural	89	125
15-19/031	FARIS & RUSHDEE ABU SABHAH	ZAITA	Agricultural	29	97
15-19/035	AS'AD RABEE' & PARTNERS	'ATTEEL	Agricultural	69	109
15-19/036	'ATTEEL COOPERATIVE SOCIETY	'ATTEEL	Agricultural	44	95
b15-19/041	MUHAMMAD NEMER BARAKAT	'ATTEEL	Agricultural	93	100
15-19/042	MUHAMMAD 'ABED AL RAZEQ & PARTN	'ALLAR	Agricultural	24	60
15-20/002A	MUHAMMAD ABU SHAMS	BAQAH AL SHARQ	Agricultural	30	75
15-20/003	MUHAMMAD AL TAHER & PARTNERS	NAZLET 'ISA	Agricultural	27	79
15-20/004	FADEL KITTANAH & PARTNERS	AL NAZLAH AL G	Agricultural	33	82
15-20/006	SAQER AL SA'ED	BAQAH AL SHARQ	Agricultural	50	88

Figure 4.2 shows the nitrate and chloride concentrations for the groundwater wells in the Alkhodera drainage basin.

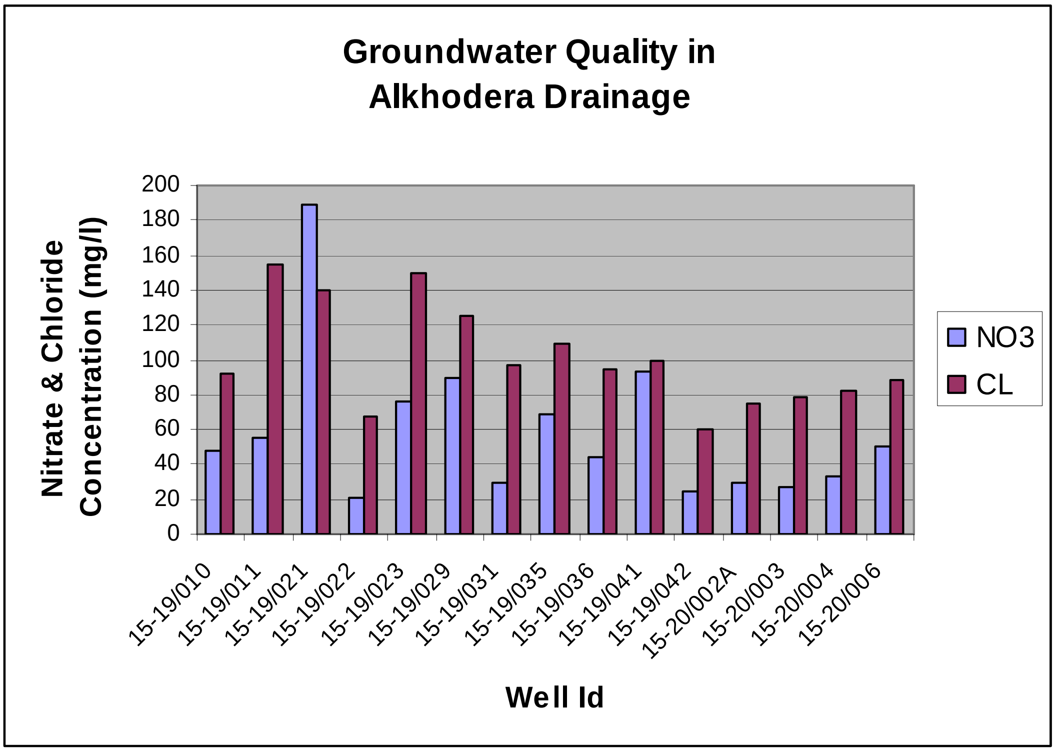


Figure 4.2: Nitrate & Chloride Concentration in Alkhodera Drainage Basin

From the mentioned information in Table 4.2 and Figure 4.1, basing on the WHO standards for chloride concentration of 250mg/L and for nitrate concentration 45mg/L for drinking water. It can be concluded that:

- The percentage of polluted wells by nitrate in this drainage basin is (8/15)*100% = 53%, while no well in the Alkhodera drainage basin is polluted by chloride.
- The concentrations of nitrate reach a high level up to 189 mg/L, with typical values in the range of 21-93 mg/L.
- The concentrations of chloride reach a level up to 150 mg/L, with typical values in the range of 60-155 mg/L, this range of concentrations is less than the WHO standards for drinking water quality of 250 mg/L.
- The only domestic well in the Alkhodera drainage basin is polluted by nitrate, while the other polluted wells with nitrate are agricultural wells, with values exceeding WHO standards for drinking water.

It is shown that there is no pollution risk with respect to chloride in both drainage basins (Iskandaro and Alkhodera), while, it is clear that the high level of nitrate concentrations exceed the WHO standards of 45 mg/L, in both drainage basins in agricultural and domestic wells and the over all percentage of polluted wells in both drainage basins is (22/40) * 100% = 55%.

Figure 4.3 shows the nitrate concentration for the groundwater wells distributed spatially in both drainage basins (Iskandaron & Alkhodera) using the arcview GIS software.

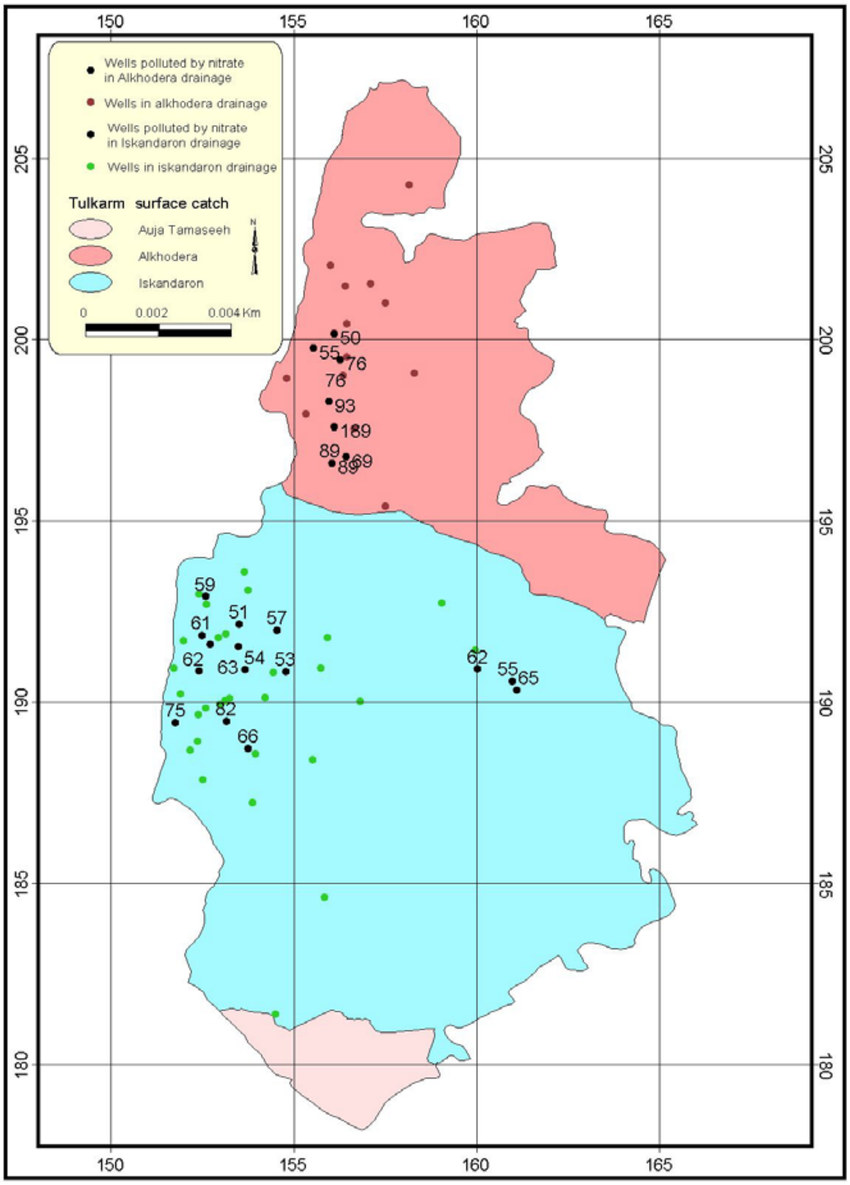


Figure 4.3: Nitrate Concentration for Groundwater Wells in Tulkarm

This can be explained by many anthropogenic activities and agricultural practices that pose a great probability of nitrate pollution of groundwater in Tulkarm. These practices and activities include the lack or inadequate sewage disposal methods. Furthermore, the heavy cultivation of the agricultural land and the need to increase the production lead to excessive use of fertilizers, pesticides, herbicides, and soil fumigants, which have drastic effects on the water quality in the Area. Solid wastes (including manure) disposal practices, which mainly include crude dumping in any available open areas without controlling, monitoring, and studies also increase the severity of the water quality problems.

4.5 Trend Analysis

The ground water quality in Tulkarm Area with respect to the nitrate and chloride concentrations is not constant depending on many factors, like the pollution sources and the intensity of pollutant, soil type and sensitivity of the aquifer. Increasing trends may be caused either by the accumulation of nitrates or chloride in the groundwater from continued land use practices or by changes in land use, such as changes to more intensive agricultural activities or increased rates of wastewater effluent application. Decreasing trends may also be caused by changes in land use, such as changes to less intensive agriculture or reduced waste disposal rates. In case of deep aquifer, decreasing trends could also be caused by increased abstraction rates, which would increase the hydraulic gradients around the well and could cause more water to be drawn from areas with lower concentrations.

A graphical representation of historical data (PWA Master Data Bank, 2005) of nitrate and chloride concentration was conducted for 20 groundwater wells in Tulkarm Area (Appendix A). Twelve of them were selected in the Iskandaron drainage basin and the others were selected in the Alkhodera drainage basin. The selected wells were polluted and unpolluted and long term trends in the data from individual wells were investigated.

It is recorded from the graphs in Appendix A that there are two types of trends, steady state trend and significant increase trend. The steady state trend defined for wells with small or no variation of nitrate and chloride concentrations with time series. The significant increase trend defined for wells with increasing variations of concentrations with time. Table 4.4 summarizes the trend for the selected groundwater wells as follows:

4.4: Trend Analysis for Groundwater Wells in Tulkarm:

Drainage Basin	Well Id	State of Pollution	Steady state trend		Significant increase trend	
			NO_3^-	Cl^-	NO_3^-	Cl^-
Iskandaron	15-19/003	Polluted	--	--	1	1
	15-18/008	Polluted	--	--	1	1
	15-19/002	Polluted	--	--	1	1
	15-19/030	Polluted	--	--	1	1
	15-19/043	Polluted	--	--	1	1
	15-19/013	Polluted	--	--	1	1
	15-19/038	Unpolluted	--	1	1	--
	15-19/012	Unpolluted	--	--	1	1
	15-19/020	Polluted	1	1	--	--
	15-19/033	Unpolluted	1	--	--	1
	15-19/039	Unpolluted	1	1	--	--
	15-19/046	Unpolluted	1	1	--	--
Total	**12**		**4**	**4**	**8**	**8**
Alkhodera	15-19/023	Polluted	--	--	1	1
	15-19/035	Polluted	--	--	1	1
	15-20/006	Polluted	--	--	1	1
	15-19/047	Unpolluted	--	--	1	1
	15-20/004	Unpolluted	--	--	1	1
	15-19/010	Unpolluted	--	--	1	1
	15-19/42	Unpolluted	--	1	1	--
	15-19/29	polluted	1	1	--	--
Total	**8**		**1**	**2**	**7**	**6**

According to Table 4.4 it is concluded that:

Total # of selected wells = 20

% of wells with steady state increase trend of nitrate = (5/20)*100% = 25%

% of wells with significant increase trend of nitrate = (15/20)*100% = 75%

% of wells with steady state trend of chloride = (6/20)*100% = 30%

% of wells with significant increase trend of chloride = (14/20)*100% = 70%

From these results it is concluded that both the polluted and unpolluted wells have a significant increase in nitrate and chloride concentrations. The wells with increasing trends are distributed in both drainage basins (Iskandaron and Alkhodera) but are primarily at the centre of the residential areas and population centers. Also they are affected by agricultural practices. This means that, these wells are subjected to manmade pollution due to uncontrolled human activities in the study area that will be studied spatially through spatial analysis.

4.6 Spatial Analysis Relations Using Arcview

The Arcview GIS software was used as a tool and multi-layers were generated. In other words, spatial related layers were created in order to investigate and interpretate the spatial distribution of the polluted wells in Tulkarm Area with respect to aquifer sensitivity, geological formation of the aquifer system, soil description, land use pattern and built up areas in Tulkarm Area. These relations are shown in Figures 4.4, 4.5, 4.6, 4.7 & 4.8. The spatial relations is shown as follows:

1- Polluted groundwater wells/ Sensitive areas

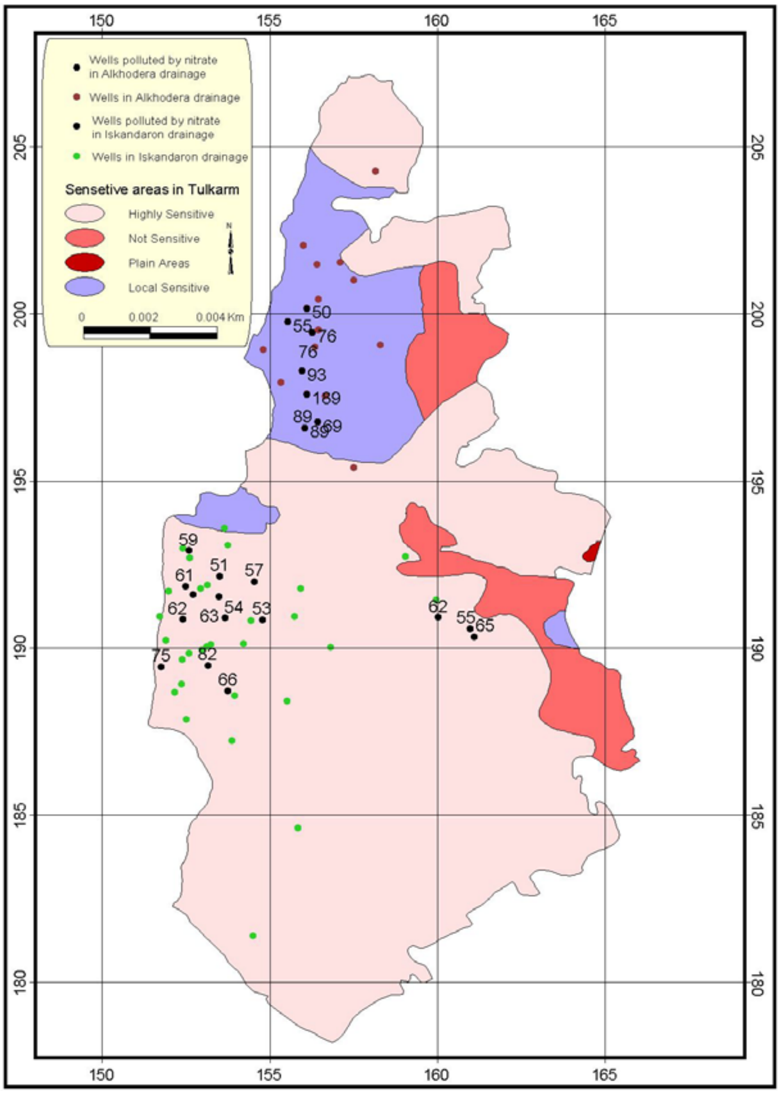


Figure 4.4: Polluted Wells and Tulkarm Sensitive Areas

Figure 4.4 shows that all the polluted wells within the Iskandaron drainage basin are located in the highly sensitive areas. Furthermore, the polluted wells located in the Alkhodera drainage basin are located in the moderate sensitive areas.

2- Polluted wells/ Geological formation for aquifer system.

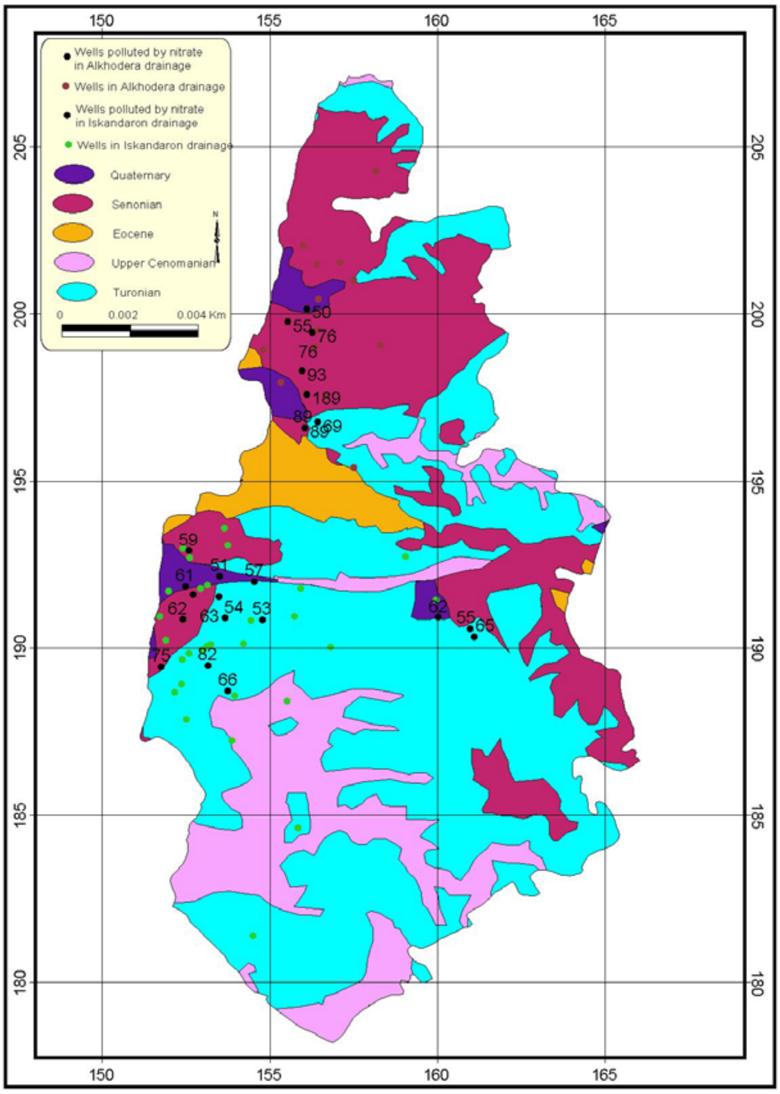


Figure 4.5: Polluted Wells and Tulkarm Geology

Figure 4.5 shows that all the polluted wells in the Alkhodera drainage basin are located in the Aquitard aquifer with Senonian geological formation (Abu Dies terminology) with a lithology of chalk and chert, undifferentiated with basal conglomerate in parts. Furtermore, most of the polluted wells located in the Iskandaron drainage basin are located in the Upper aquifer with Turanian geological formation (Jerusalem) having a typical lithology of limestone and dolomite karstic, marly limestone, karstic. The thickness of the Aquittard aquifer ranges between 200-450m, while, the thickness of the Upper Turanian aquifer thickness ranges between 40-150m. Furthermore, the nature of karstic aquifer explains the easily movement of pollutants to the groundwater system in both drainage basins, especially when subjected to human activities and uncontrolled use of lands with respect to wastewater discharge, leakage from cesspits and agricultural fertilizers.

3- Polluted groundwater wells/ Soil description

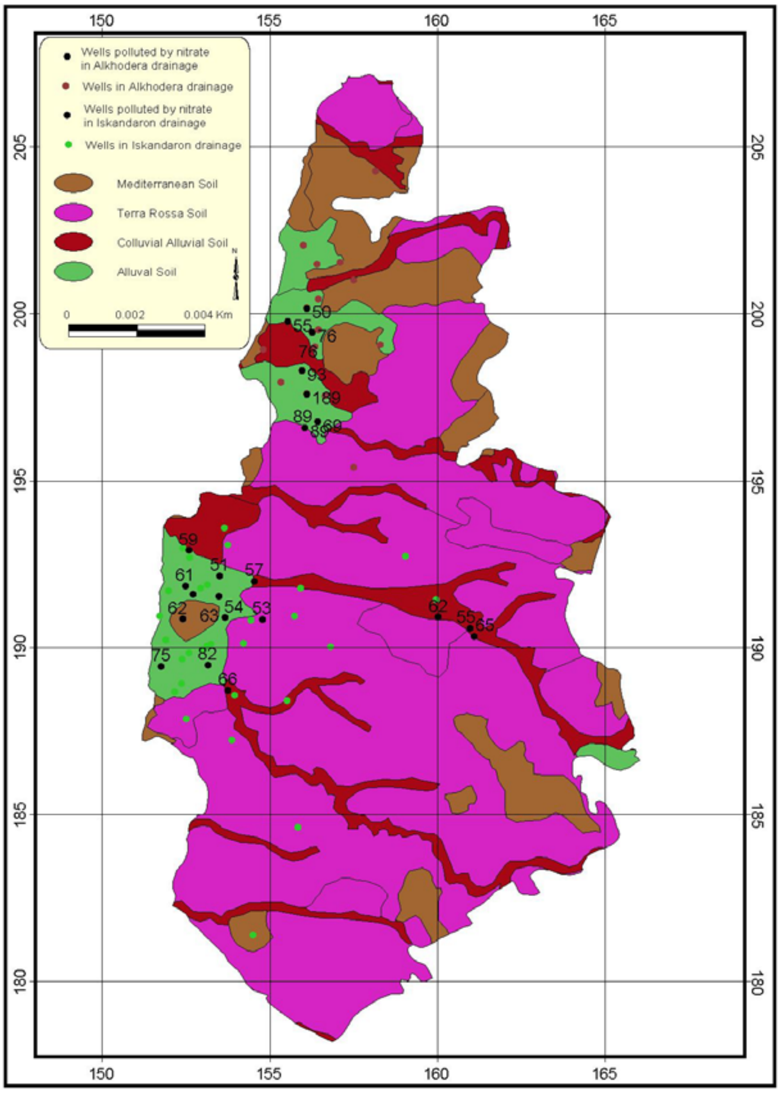


Figure 4.6: Polluted Wells and Soil Cover in Tulkarm

Figure 4.6 shows that the polluted wells in both Alkhodera and Iskandaron drainage basins are located in the regions covered by Alluvial soil which is characterized by fine textural or aeolien sediments, where the usage of this soil type for productions currently limited to cultivate wheat.

From the arcview the percentage of each type of soil was calculated and tabulated as follows:

Table 4.5: Soil Cover in Tulkarm:

Soil Description	Area (km)	% from the Tulkarm Area
Terra Rossa	160	65.8
Colluvial-Alluvial	31	12.8
Mediterranian Brown Forest	32	13.2
Alluvial	20	8.2

The Terra Rossa soil acts the main soil cover in the area which is fertile and the cultivation of field crops mainly wheat, bareley, vineyards, olive and fruit trees, particularly on valley shoulders, are the dominant land use pattern on these soils. It can be concluded that these fertile soils are subjected to excess use of fertilizer acts as a non point source of pollution for the groundwater because of the agricultural runoff especially when the polluted groundwater are located in the downstream of the area.

4- Polluted groundwater wells/ Land use.

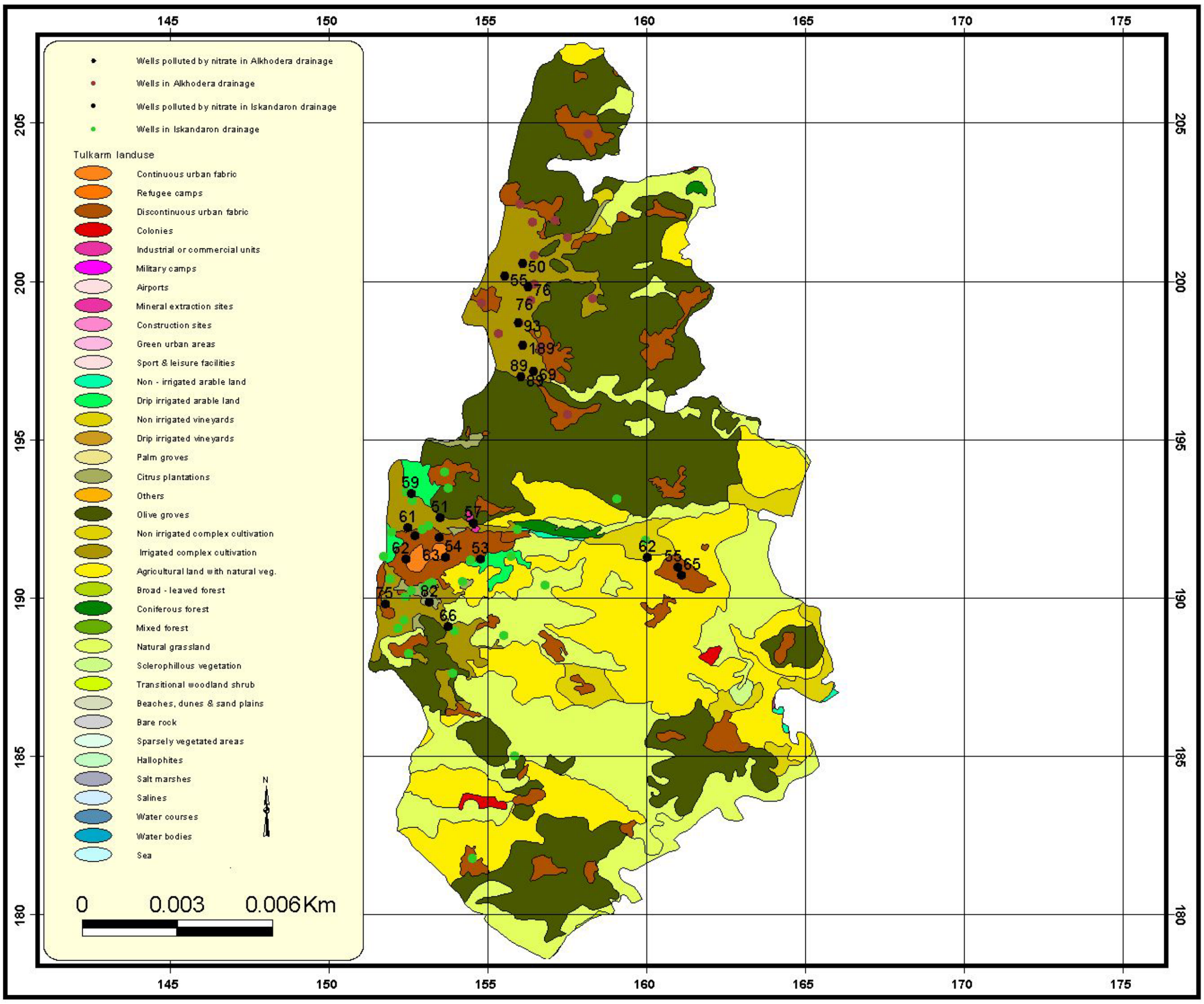


Figure 4.7: Polluted Wells and Landuse in Tulkarm

The area of land use pattern was calculated using the arcview and tabulated in Table 4.6.

Table 4.6: Landuse Pattern in Tulkarm:

Land Use Pattern	Area(km2)	%
Continuous Urban Fabrics	0.63	0.26
Discontinuous Urban Fabrics	19.53	8.04
Colonies	0.66	0.27
Miniral Extraction Sites	0.12	0.05
Non-Irrigated Arable Land	1.37	0.56
Drip Irrigated Arable Land	2.33	0.96
Citrus Plantations	1.28	0.53
Olive Groves	81.99	33.76
Non-Irrigated Complex Cultivation	8.33	3.43
Irrigated Complex Cultivation	17.99	7.41
Agricultural Land With Natural	51.94	21.38
Coniferous Forest	1.01	0.42
Natural Grass Land	54.25	22.34
Sclerophillous Vegitation	1.37	0.56
Traditional Wood Land Shurb	0.08	0.03
Total	**243**	**100.00**

From Table 4.6 it is obvious that the agricultural lands act the main land use pattern in the Tulkarm in term of (olive grove/ agricultural land with natural vegetation/natural grass land/ irrigated and non-irrigated complex cultivation) covering about (88 %) of the area and the builtup areas in term of (continuous and discontinuous urban fabrics) is covering about (8%) of the area.

From Figure 4.7, the polluted wells are located with in the irrigated complex cultivation land and with in discontinuous urban fabrics. This can explain the tendency of nitrate pollution in the specified wells resulted by excess use of fertilizers and cesspits from the discontinuous urban fabrics not connected to sewerage network, knowing that the Wadi Zeimar passing the ‘Anabta village toward Tulkarm city to the west, which is considered as the main pollutant for groundwater contamination in Tulkarm besides other pollution sources.

5- Polluted groundwater wells/ Builtup areas

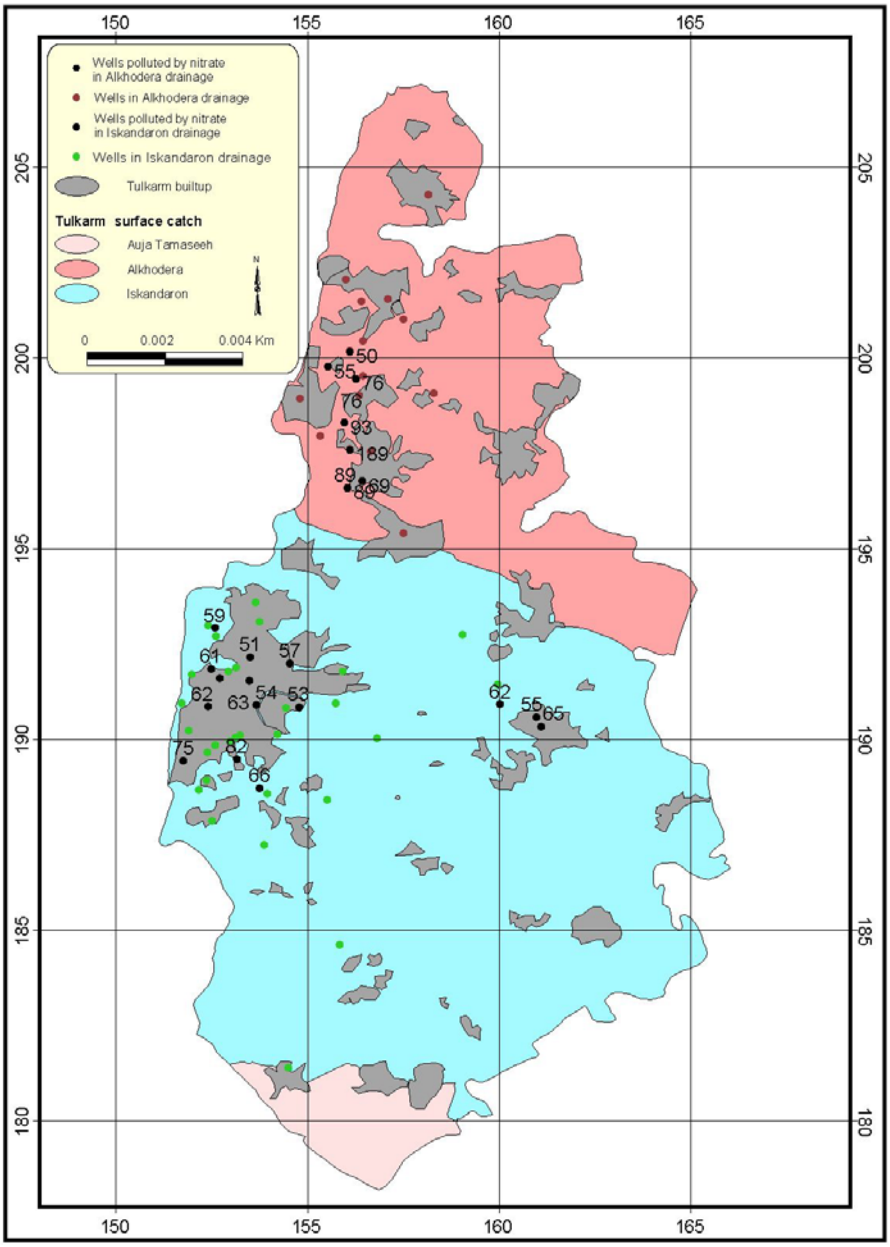


Figure 4.8: Polluted Wells and Builtup Areas in Tulkarm

Figure 4.8 shows that most of the polluted wells are located within built up areas and villages boundaries. This means, the polluted wells are subjected to human activities such as wastewater, cesspits, fertilizer, ….etc, especially in the absence of regulations to control these actions which is harmful to the groundwater quality. In addition, the wells located in populated areas have higher values of nitrate, which reveals the possibility of wastewater intrusion from sewer system and cesspits.

Chapter Five

Groundwater Model Development

5.1 Introduction

The Western Aquifer Basin (WAB) covers an area of 9155km^2 (SUSMAQ, 2002) within Israel and Palestine and is therefore the largest of all groundwater basins in historical Palestine. The geology of the Western Aquifer Basin (WAB) consists mainly of a group karstified limestone and dolomite of late Albian to Turanian. It is recharged mainly from precipitation falling on the mauntains of the West Bank. There are several modeling studies was undertaken for the Western Aquifer Basin (WAB) such as a study conducted by Sabbah (2004) and SUSMAQ (2003).

The model study area is located within the Western Aquifer Basin (WAB) and is a part of the hydrogeological system of the Western Aquifer Basin (WAB). It has an area of 214km^2. The model domain is located in the western portion of the Iskandaron drainage – north west of Auja Tamaseeh Basin- (highly sensitive area of Tulkarm Area). Figure 5.1 shows the location map of the model study area.

The model development was based on previous studies conducted by the SUSMAQ model (2003), and Sabbah model (2004), who developed a ground water flow model of the Western Aquifer Basin. A three dimensional grid with 500 meters X 500 meters cell size was used. The metric system of units was used in this model; meters per day for the hydraulic conductivity, meters for head, cubic meters (m3) for volume, and days for time.

Firstly, the conceptual model with emphasis on the boundary conditions, geometry, recharge and other important conceptual details about the model domain was built and then developed into a numerical model using the Modflow software. The anticipated outcome of the model is to simulate the groundwater flow and to study the hydraulic response of the aquifers.

The steady state flow model is firstly simulated, then, the solute and transport model is developed using the MT3D package under the visual Modflow software. A stress period of 10 years was assumed to perform the model by assuming a contaminated area within the model domain with specified initial concentration, and then, several runs and animations were conducted to study the the response of the aquifer system to a contamination event.

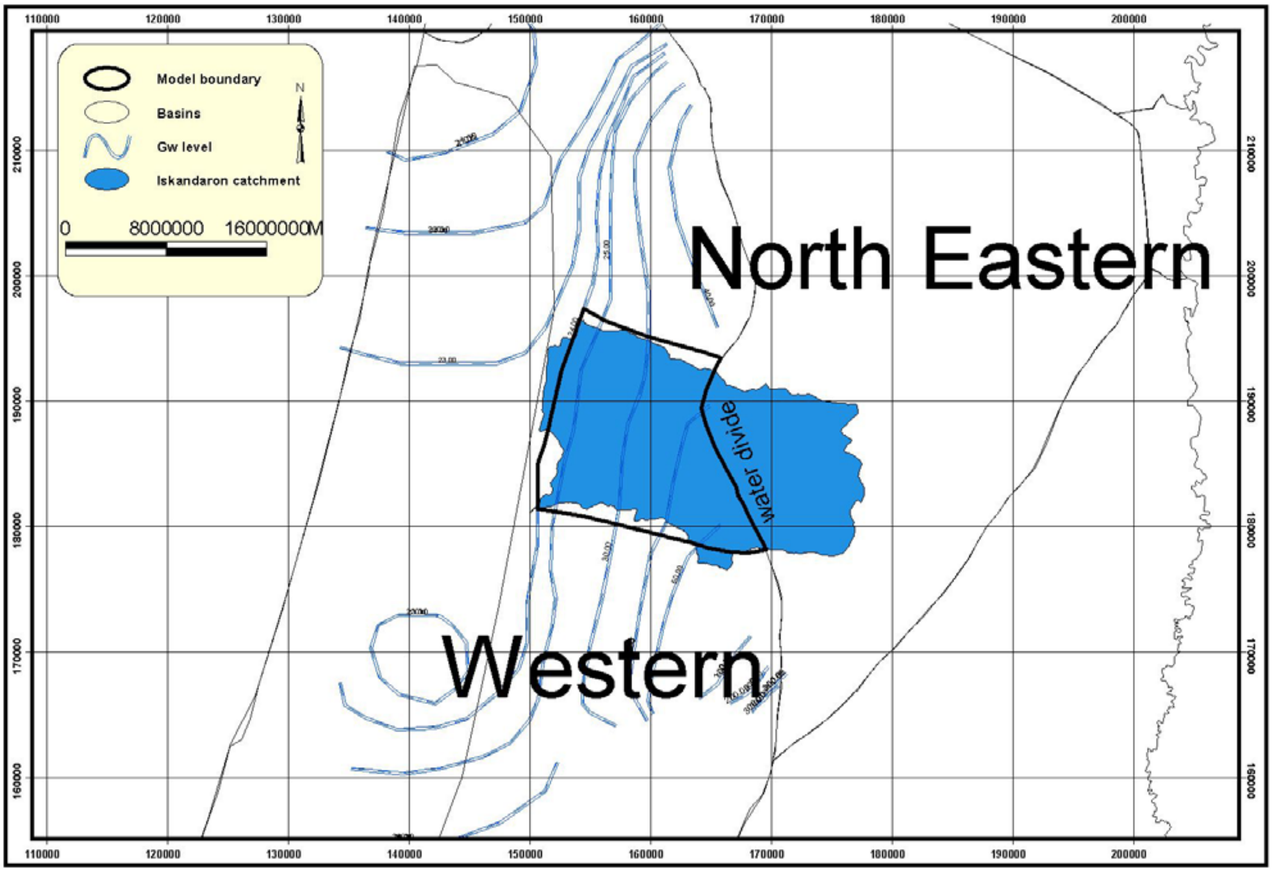


Figure 5.1: Location Map for the Model Study Area

5.2 Theoretical Background of Groundwater Modeling

5.2.1 General

Groundwater models are usually applied for predicting the consequences of a proposed actions such as groundwater development scenarios or tendency of contamination. Models can be used for analyzing groundwater flow system by assembling and organizing field data and formulating ideas about dynamics of flow systems. Models can be also used for studying processes in generic geologic settings like river-aquifer systems. It is essential to identify clearly the purpose of modeling so that the needs of modeling efforts and accuracy are determined. The purpose of modeling also decides on the dimensionality and time dependency of a model.

Groundwater models are used to predict the migration pathway and concentrations of contaminants in groundwater. The accuracy of model predictions depends upon successful calibration and verification of the model in determining groundwater flow directions, transport of contaminants and chemical reactions, and the applicability of the groundwater flow and solute transport equations to the problem being simulated. Errors in the predictive model, even though small, can result in gross errors in solutions projected forward in time. Among other things, performance monitoring is required to compare future field conditions with model predictions to assess model error.

A conceptual model is firstly built and then a mathematical model is developed. A computer code is used after that to solve the mathematical model of groundwater flow or contaminant transport numerically. The selection of a suitable code depends on the complexity of the conceptual model and the purpose of study. The main considerations are:

- Types of model: flow model, particle tracking or solute transport model.
- Time dependency: steady or transient model.
- Dimensionality: one-, two-, quasi-three, or fully three dimensional model.
- Ability to describe the aquifer properties: homogeneous or heterogeneous; isotropic or anisotropic media.
- Ability to include various hydrological stresses.
- Requirements on the computer facility.

The design of numerical model includes the design of model grids, selection of stress periods and time steps and setting model boundaries. The conceptual model will be the bases for the design of the numerical model. The purpose of the modeling will dictate the sizes of grids and time steps. The memory and computing time of computers and the computer code may have limitations on total number of grids and time steps.

The inputs to the model include initial and boundary conditions, hydrogeological parameters, and hydrological stresses. The data for all these inputs have to be entered to all grid points for all stress periods.

After that, the model is calibrated to establish that the model can reproduce the field measured groundwater heads or concentrations. The calibration forces the model calculations approximate the field measured values through the adjustment of aquifer parameters or stresses by trial-and-error method or automated parameter estimation method. Sensitivity analysis is followed to evaluate the influences of uncertainties of model parameters and boundary conditions on the model results.

To check whether the calibrated model has the predictive power, the calibrated model is applied to another period of time where a second set of field data are available. The model should also be able to reproduce the field measured values of groundwater heads or concentrations with hydrological stresses in this period.

The calibrated model is used to predict the response of the aquifer system to future events. In the prediction the model is run with calibrated aquifer parameters and future hydrological stresses. Some hydrological stresses are the proposed actions (such as abstraction). Others are natural uncontrolled stresses (such as recharge from precipitation).

5.2.2 Flow Model

Groundwater flow models are used to calculate the rate and direction of movement of groundwater through aquifers and confining units in the subsurface. These calculations are referred to as simulations. The simulation of groundwater flow requires a thorough understanding of the hydrogeologic characteristics of the site. The hydrogeologic investigation should include a complete characterization of the following:

- Subsurface extent and thickness of aquifers and confining units (hydrogeologic framework).
- Hydrologic boundaries (also referred to as boundary conditions), which control the rate and direction of movement of groundwater.
- Hydraulic properties of the aquifers and confining units.
- A description of the horizontal and vertical distribution of hydraulic head throughout the modeled area for both beginning (initial conditions), equilibrium

(steady-state conditions) and transitional conditions when hydraulic head may vary with time (transient conditions).

- Distribution and magnitude of groundwater recharge, pumping or injection of groundwater, leakage to or from surface-water bodies, etc. (sources or sinks, also referred to as stresses). These stresses may be constant (unvarying with time) or may change with time (transient).

The general partial differential equation to be solved in the case is:

$$\boxed{K_x \frac{\delta^2 h}{\delta x^2} + K_y \frac{\delta^2 h}{\delta y^2} + K_z \frac{\delta^2 h}{\delta z^2} = S_s \frac{\delta h}{\delta t} - R} \quad \text{..................................}\mathbf{(5.1)}$$

(Anderson and Woessner, 1992).

Where;

K_x, K_y, and K_z =	Hydraulic conductivities in x, y, and z directions, respectively.
h =	head
t =	time
S_s =	specific storage which represents the water volume stored in a unit volume of the aquifer per unit change in head
R =	source/sink term which could represent injection wells, extraction wells, rainfall/recharge, or evaporation

The term $(S_s \frac{\delta h}{\delta t} - R)$ is equal to zero for steady state i.e. the equation (5.1) becomes:

$$\boxed{K_x \frac{\delta^2 h}{\delta x^2} + K_y \frac{\delta^2 h}{\delta y^2} + K_z \frac{\delta^2 h}{\delta z^2} = 0} \quad \text{...}\mathbf{(5.2)}$$

Equation (5.2) can only be applicable under the following assumptions:

1. The aquifer is saturated.
2. Darcy's law is valid, since it is laminar flow.
3. Mass is conserved i.e. inflow-outflow = change in storage + sources and sinks.

The outputs from the model simulations are the hydraulic heads and groundwater flow rates which are in equilibrium with the hydrogeologic conditions (hydrogeologic framework, hydrologic boundaries, initial and transient conditions, hydraulic properties, and sources or sinks) defined for the modeled area. Figure 1 shows the simulated flow field for a hypothetical site at which pumping from a well (lower left side of figure) creates changes in the groundwater flow field.

5.2.3 Solute and Transport Model

Solute and transport models simulate the movement and chemical alteration of contaminants as they move with groundwater through the subsurface. These models require the development of a calibrated groundwater flow model or, at a minimum, an accurate determination of the velocity and direction of groundwater flow, which has been based on field data. Fate and transport models are used to simulate the following processes:

- Movement of contaminants by advection and diffusion.
- Spread and dilution of contaminants by dispersion.
- Removal or release of contaminants by sorption, or desorption, of contaminants onto, or from, subsurface sediment or rock.
- Chemical alteration of the contaminant by chemical reactions which may be controlled by biological processes or physical chemical reactions.

In addition to a thorough hydrogeological investigation, the simulation of fate and transport processes requires a complete characterization of the following:

- Horizontal and vertical distribution of average linear groundwater velocity (direction and magnitude) determined by a calibrated groundwater flow model or through accurate determination of direction and rate of groundwater flow from field data.
- Boundary conditions for the solute.
- Initial distribution of solute (initial conditions).
- Location, history and mass loading rate of chemical sources or sinks.

- Effective porosity.
- Soil bulk density.
- Fraction of organic carbon in soils.
- Octanol-water partition coefficient for chemical of concern.
- Density of fluid.
- Viscosity of fluid.
- Longitudinal and transverse dispersivity.
- Diffusion coefficient.
- Chemical decay rate or degradation constant.
- Equations describing chemical transformation processes, if applicable.
- Initial distribution of electron acceptors, if applicable.

The movement of contaminants, is largely dependent on the hydrogeologic environment. the effectiveness of the various methods that represent the contaminant transporting will vary with different geologic settings. Designing a programme for containment or control of ground water contamination is further complicated by the fact that not all the contaminants behave in the same manner in the subsurface. Many contaminants move at different rates in the groundwater system and may occupy different levels in aquifers according to their solubility in water, their density, and other physical properties to the contaminants. All of the processes of migration and alterations present in groundwater are also present in the unsaturated zone. However the flow of water through the unsaturated zone is considerably more complex due to the presence of the air water vapor phases.

The dispersion equation in a two dimensional horizontal flow field can be written as follows (Anderson & Woessner, 1992):

$$\boxed{\begin{aligned}&\partial(mC)/\partial t = \partial/\partial x\,[m\,(D_{xx}\,(\partial C/\partial x) + D_{xy}(\partial C/\partial y) - CV]\\ &+ \partial/\partial x\,[m\,(D_{xy}\,(\partial C/\partial x)\\ &+ D_{yy}\,(\partial C/\partial y) - CV] + I\end{aligned}} \qquad \text{..............................(5.3)}$$

Where m is the saturation thickness of the aquifer. The dimensions of (I) in the two dimensional dispersion equation [M/L^2T]. Where $I = C_oR/n$ if R denotes water injection

While I = - C_oR/n if R denotes water extraction. Where $C_o$is the tracer concentration contained in the injected water.

The MT3D transport model uses a mixed Eulerian-Lagrangian approach to the solution of the three-dimensional advective-dispersive-reactive transport equation. MT3D is based on the assumption that changes in the concentration field will not affect the flow field significantly. This allows the user to construct and calibrate a flow model independently. After a flow simulation is complete, MT3D simulates solute transport by using the calculated hydraulic heads and various flow terms saved by MODFLOW. MT3D can be used to simulate changes in concentration of single species miscible contaminants in groundwater considering advection, dispersion and some simple chemical reactions. The chemical reactions included in the model are limited to equilibrium-controlled linear or non-linear sorption and first-order irreversible decay or biodegradation.

The outputs from the model simulations are the contaminant concentrations, which are in equilibrium with the groundwater flow system, and the geochemical conditions (described above) defined for the modeled area. Figure 2 shows the simulated migration of a contaminant (red contours) at a hypothetical site.

As with groundwater flow models, fate and transport models should be calibrated and verified by adjusting values of the different hydrogeologic or geochemical conditions to reduce any disparity between the model simulations and field data. This process may result in a re-evaluation of the model used for simulating groundwater flow if the adjustment of values of geochemical data does not result in an acceptable model simulation. Predictive simulations may be made with a fate and transport model to predict the expected concentrations of contaminants in groundwater as a result of implementation of a remedial action. Monitoring of hydraulic heads and groundwater chemistry will be required to support predictive simulations.

5.3 Conceptual Model

Conceptual model is a quantitative representation of groundwater systems in terms of aquifer-aquitard layers, boundary conditions, hydrogeological parameters, hydrological stresses, flow patterns, and water balance components. Field visits are necessary to gain the modeler first impression about the area to be modeled.

The purpose of building a conceptual model is to simplify the field problem and organize the associated field data so that the system can be analyzed more readily. The conceptual model is a valid representation of the important hydrogeological conditions. The aim of the conceptual model is to define the requirements for the numerical model to be able to simulate water flow and with some restrictions transport phenomena for the region under steady state and transient conditions.

The conceptual model deals mainly with the layers representing the aquifer geology, the lateral extent of the region to be modeled, the boundary conditions, the head and flow observations, etc.

The best representation of the aquifer system of the study area is by a three-dimensional two layer models since the groundwater wells is located in the upper aquifer in the study area. The upper aquifer layer has a variable thickness ranging from (494) meters in the north western part of the model study area to (249) meters (Appendix B) in different places of the model study area. The second layer acts a confining layer (Aquitard-Yatta formation) separating the upper and lower aquifer and behaves as an aquifer in some other places which merges the upper and lower aquifers into a single layer aquifer. The aquifer system is highly affected by geological faults and folded structures which make the possibility of a hydraulic connection between the different aquifers very high.

5.4 Boundary Conditions

The horizontal boundaries of the model domain are shown in Figure 5.2. The northern and southern boundaries of the study area are all of the no-flow boundary type. The eastern boundary is no flow boundary (water divide boundary). The western boundary is a specified head boundary of 24 m. The boundary conditions for the model were defined based on the static groundwater levels performed by (SUSMAQ, 2003) as shown in Figure 5.1.

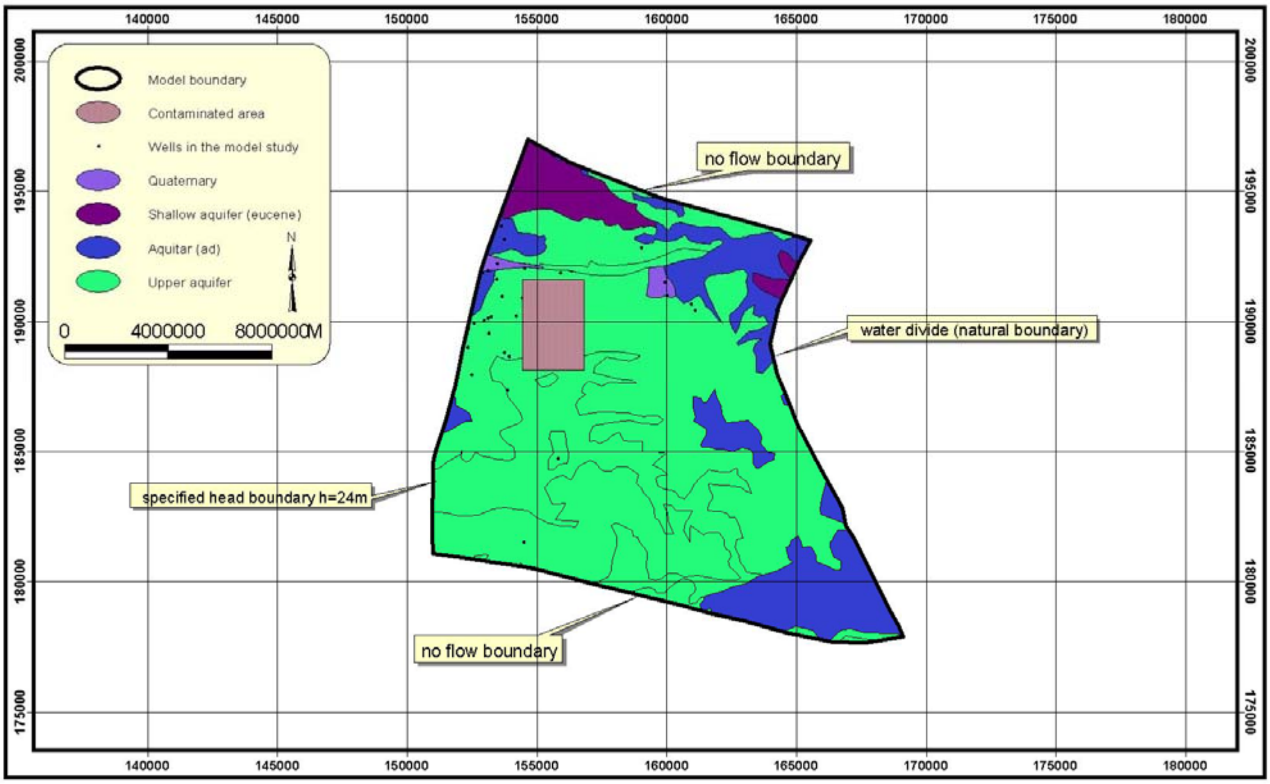


Figure 5.2: Description of the Model Study Area

From Figure 5.2, it is shown that the model of the study area is located within the upper aquifer hydrogeology with (Hebron, Jerusalem, Bethlehem) geological formation for over 77% of the model area. So, the aquifer properties were assumed the same for all the model study area ignoring the properties of other geological formations.

A base map was constructed by the arcview GIS software, representing the model domain, its boundaries, positions of the wells. This map was exported as DXF-format (vector file) to be used by the Modflow software. The model boundary conditions were defined in the program and the surrounding cells were represented as inactive cells as shown in Figure 5.3.

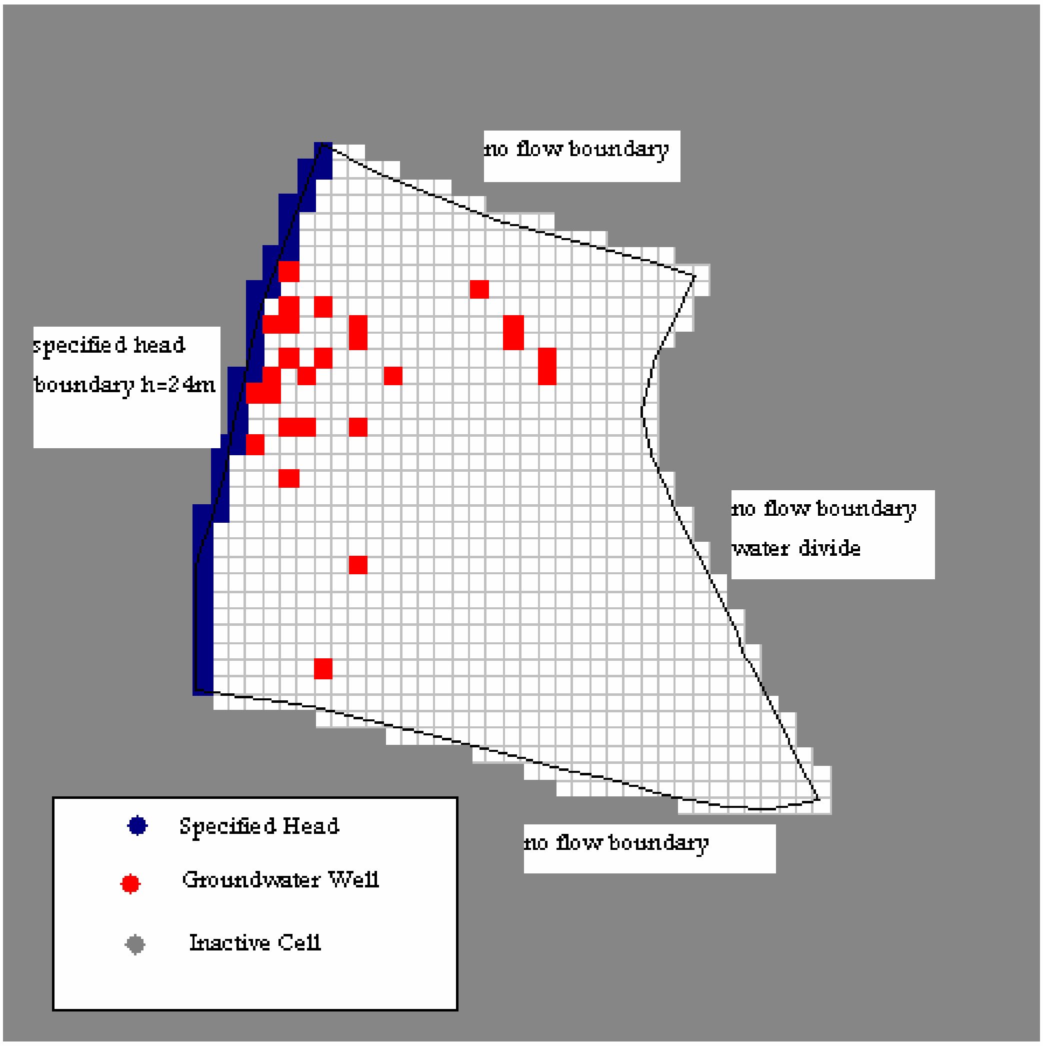


Figure 5.3: Model Boundary Conditions

5.5 Aquifer Geometry

Getting the accurate geometry of the aquifer system represented by the top and bottom of the model layers was the most difficult and challenging effort required to complete the model setup. The x, y, z coordinates for the upper aquifer and aquitard (Yatta Formation) layers were converted to (*.dat format) to be convenient with the modflow software. In other words, this technique is mainly based on interpolating grids from coordinates using the field interpolator package under the Modflow software. Figure 5.4 shows the hydro-geological cross section which represents the northern portion of the WAB.

Appendix B shows the elevations of the top and bottom of both layers representing the model geometry as reported by (SUSMAQ, 2003).

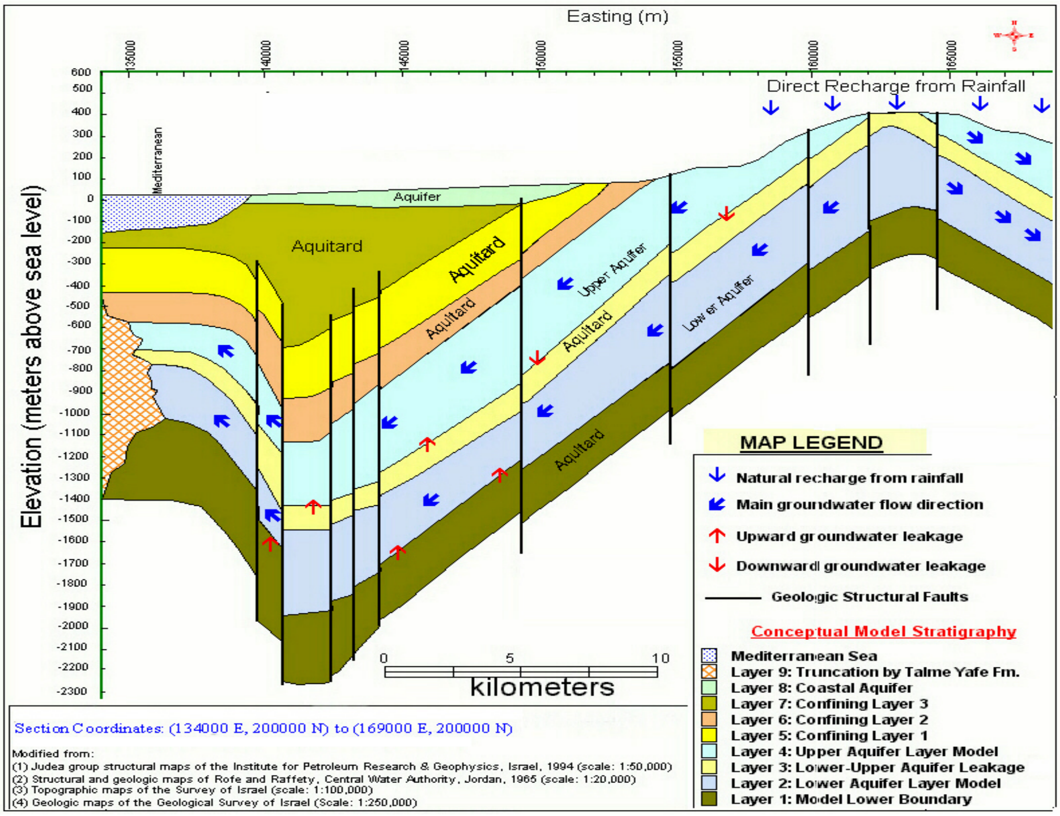


Figure 5.4: East West Hydro-geological Cross Section of WAB (northern area)
(Source: Sabbah, 2004)

5.6 Aquifer Properties

The Upper Aquifer is mainly composed of fractured limestone and dolomite which gave it relatively higher hydraulic conductivity. The Aquitard layer (Yatta Formation) is mainly composed of crystalline limestone and massive dolomite which gave it much lower hydraulic conductivity relative to upper layers. The average initial value of the horizontal hydraulic conductivity of the upper layer used in this model was 20 meters per day. The average initial value of the horizontal hydraulic conductivity of the aquitard layer used in this model was 0.1 meters per day and the vertical hydraulic conductivities assumed 1/10 of the horizontal conductivities for both layers. These values were based on the spatial distribution of the calibrated hydraulic conductivities done by SUSMAQ-2003, as shown in Figures 5.5.

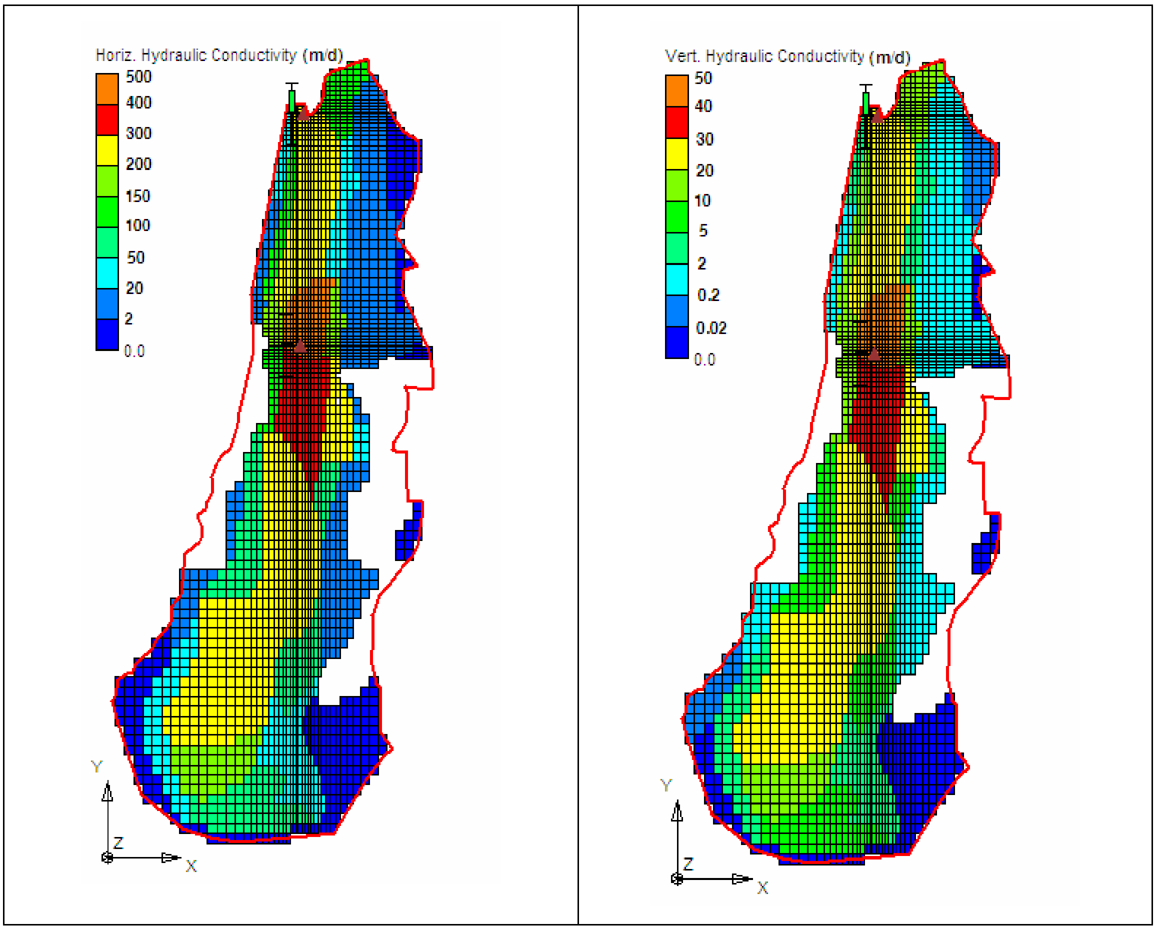


Figure 5.5: Calibrated Horizontal and Vertical Conductivities for the Upper Aquifer-WAB, Respectively, (SUSMAQ-2003)

5.7 Recharge Estimation & Wells Abstraction

Goldschmidt and Jacoub (1958) derived a relationship between recharge and runoff based on the long-term average rainfall over the catchment's area. The empirical equation developed was based on the annual rainfall quantities during the period 1943\44 to 1953\54. This equation was first developed for Jordan and Litani catchments then it was applied to the Yarkon-Nahal Hatteninim catchments (WAB). The equation relates to the long term average total run off from a catchment (R_{red}) to the long term average precipittion over it (P_{red}).

$$\boxed{\mathbf{R_{red} = 0.9 * (P_{red} - 360) \text{ in mm\textbackslash yr}}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \mathbf{(5.4)}$$

(R_{red}) in the above equation was approximated to equal the annual recharge R. This recharge value was later on divided into three segments to develop linear relationship between rainfall and recharge by Guttman and Zukerman (1995). The final equations developed read as follows:

R = 0.8 * (P – 360)	**P>650mm\yr**
R = 0.534 * (P - 216)	**650 > P>300mm\yr**
R = 0.15 * (P)	**P<300mm\yr**

R = Recharge from rainfall in mm\yr

P = Annual rainfall in mm\yr ……………………………………**(5.5)**

Equations (5.5) was modified by SUSMAQ (2005) as follows:

R = 0.6 * (P – 285)	**P > 700mm\yr**
R = 0.46 * (P -159)	**700 > P > 456mm\yr**
R = 0.3 * (P)	**P < 456mm\yr**

R = Recharge from rainfall in mm\yr

P = Annual rainfall in mm\yr ………………………………………..**(5.6)**

Equation (5.5) which was developed by Guttman and Zukerman (1995) is applicable for the model study area. It was used by the Israelis in such studies for the (WAB), also the

SUSMAQ modification was based on the same equation. The use of this equation to calculate the recharge value for the model domain is justified for the following:

- The model area is small, so we have one measurement for the recharge (one zone).
- The model domain has the same geology and strategraphy with the same metrological and climatic properties.
- The conceptual model was based on the recharge to the upper aquifer layer (one layer), so one measurement was assigned to the model study area.

Based on the mentioned justification, equation (5.5) was used to calculate the recharge value of the model domain. Knowing that the average precipitation for the study area is (642mm\yr), the estimated recharge is:

R = 0.534 (642 – 216) = 227.48mm\yr = 0.0006 m\day

By applying equation (5.6) – the modified equation by SUSMAQ – the calculated recharge is:

R = 0.46 * (642 - 159) = 222.18mm/yr = 0.0006 m/day (the same value as equation 5.5)

The pumpage of groundwater wells located with in the model study area, was assumed to be (0.07 – 1)MCM\year for each well in the model study area and checked with the average wells abstraction from the municipalities in the study area.

5.8 Model Simulation and Presentation

The model is informative in terms of the conceptual model and the overall setup of the numerical model. In order to run the model, values of hydraulic conductivities and recharge were assigned to each of the active cells in the model domain. Starting with the mentioned values in sections 5.6 & 5.7 for hydraulic conductivities and recharge values.

The result of the static groundwater level is shown in Figure 5.6.

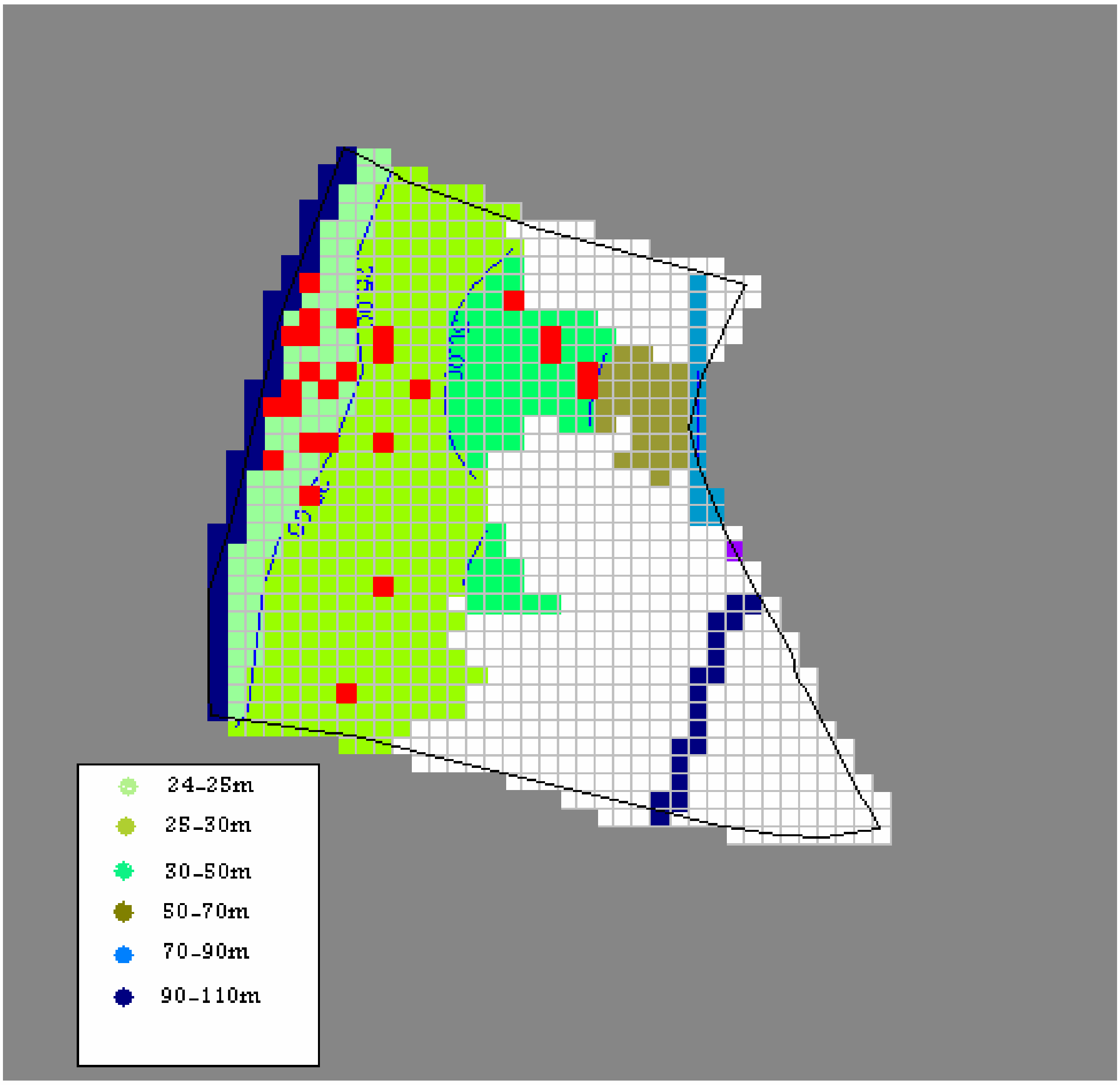


Figure 5.6: Static Water Level for the Model Domain

Several trials were conducted by assigning values of hydraulic conductivities spatially over the model domain and no change was observed through simulation.

The results of the groundwater flow model can be listed as follows:

1- The groundwater head starts at an elevation of 110 meters above sea level in the south east of the area, 70 meters above sea level in the north east of the model and then it decreased gradually to a value of 24 meters above sea level in the western boundary of the model domain.

2- The model cells in the eastern part of the model area were dry which means that the computed head is lower than the bottom of the aquifer at these cells. That could be attributed to the fact that the model layers there are outcropped and to the absence of observation heads at that area. Also it may refer to the geometrical mistake within the model domain. In order to better account for that area with dry cells, the model could be updated later on by looking for more observations and by installing more pilot points of hydraulic conductivity there. The presence of dry cells may be justified by the recharge zone of the water divide boundary (no flow boundary).

3- Considering the simulated calculations of the aquifer system, the in-out flows from the groundwater reservoir can be defined as follows: The recharge to the aquifer in this model was calculated to be 25.15 MCM/year and the recharge through constant head was found to be 5.07 MCM/year. The discharge of groundwater wells was considered as outflow from the whole aquifer system and was calculated to be 21.5 MCM/year and the discharge through constant head was found to be 8.72 MCM/year. Table 5.1 shows the water flow budget of the whole model calculated on a yearly basis. inflow – out flow = 0.

Table 5.1: Water Flow Budget of the Whole Model Domain.

Flow Term	**In (MCM/year)**	**Out (MCM/year)**	**In – Out (MCM/year)**
Constant Head	5.07	8.72	-3.65
Wells	0	21.50	-21.5
Recharge	25.15	0	25.15
Sum	**30.22**	**30.22**	**0**

DISCREPANCY [%] 0.0

The calibration of the model was based on the comparison between the observed heads and the calculated heads. It can be shown obviously in Figure 5.7.

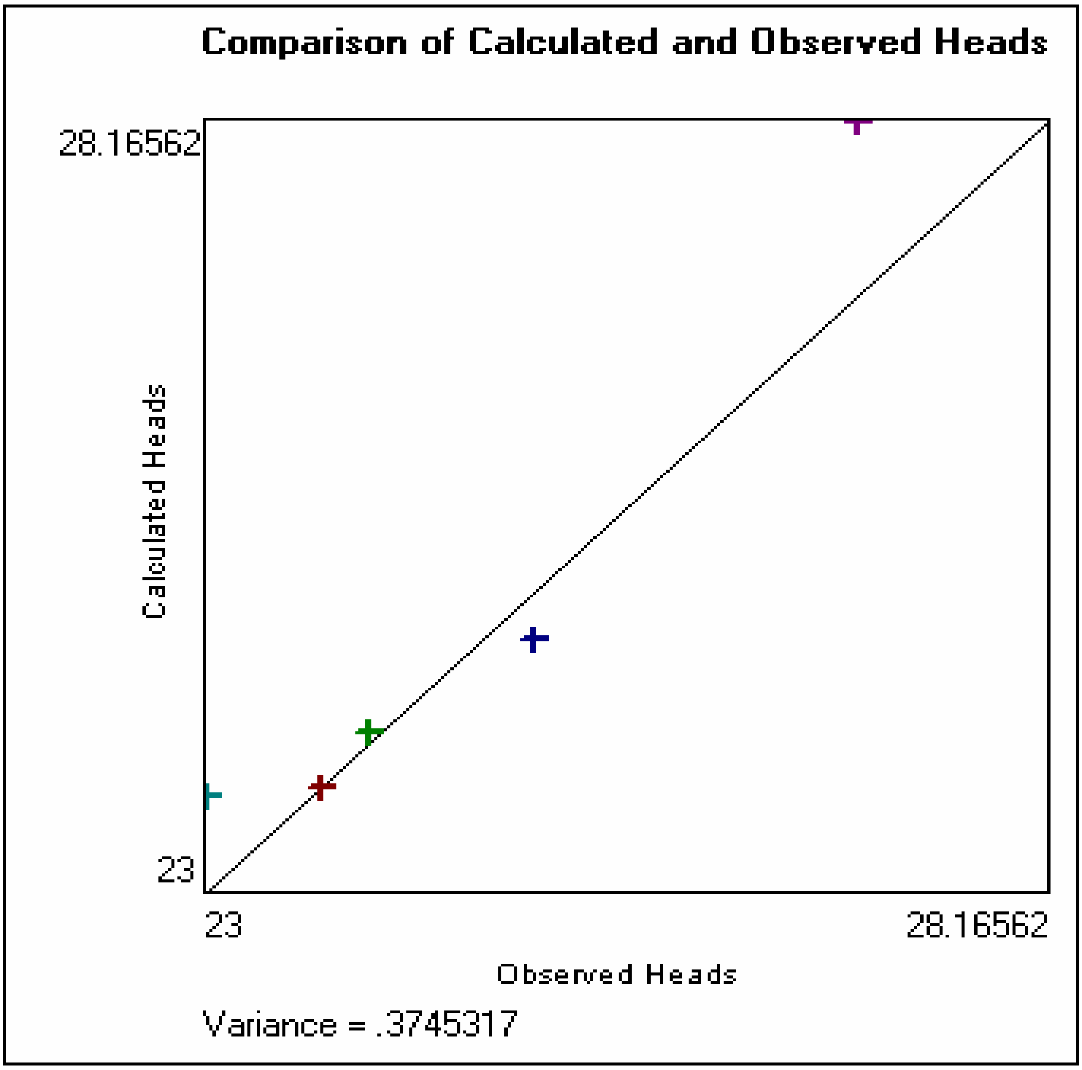


Figure 5.7: A Plot of Observed Versus Calculated Head Values

The calibration of the first layer (upper aquifer) shows that the observed data match the calculated data with variance (≅0.4).

The solute and transport model was simulated to investigate the movement of conservative pollutant and long term pollutant distributions for continuing source input using MT3D model. In this study a pollutant source of 2000mg/L represented by built up areas (contaminated area in Figure 5.2) was assigned in the model.

The input parameters affecting the movement of pollutant such as effective porosity was assumed of 0.1 (SUSMAQ, 2003) and a dispersivity value of 50m, which is typical of karstic aquifer system.

The results of simulation of pollutant movement can be presented by Figure 5.8. The response of pollution occurs due to dispersion. Also the chloride concentration indicates a gradual increase with time up to high level after long term simulation for the model study area.

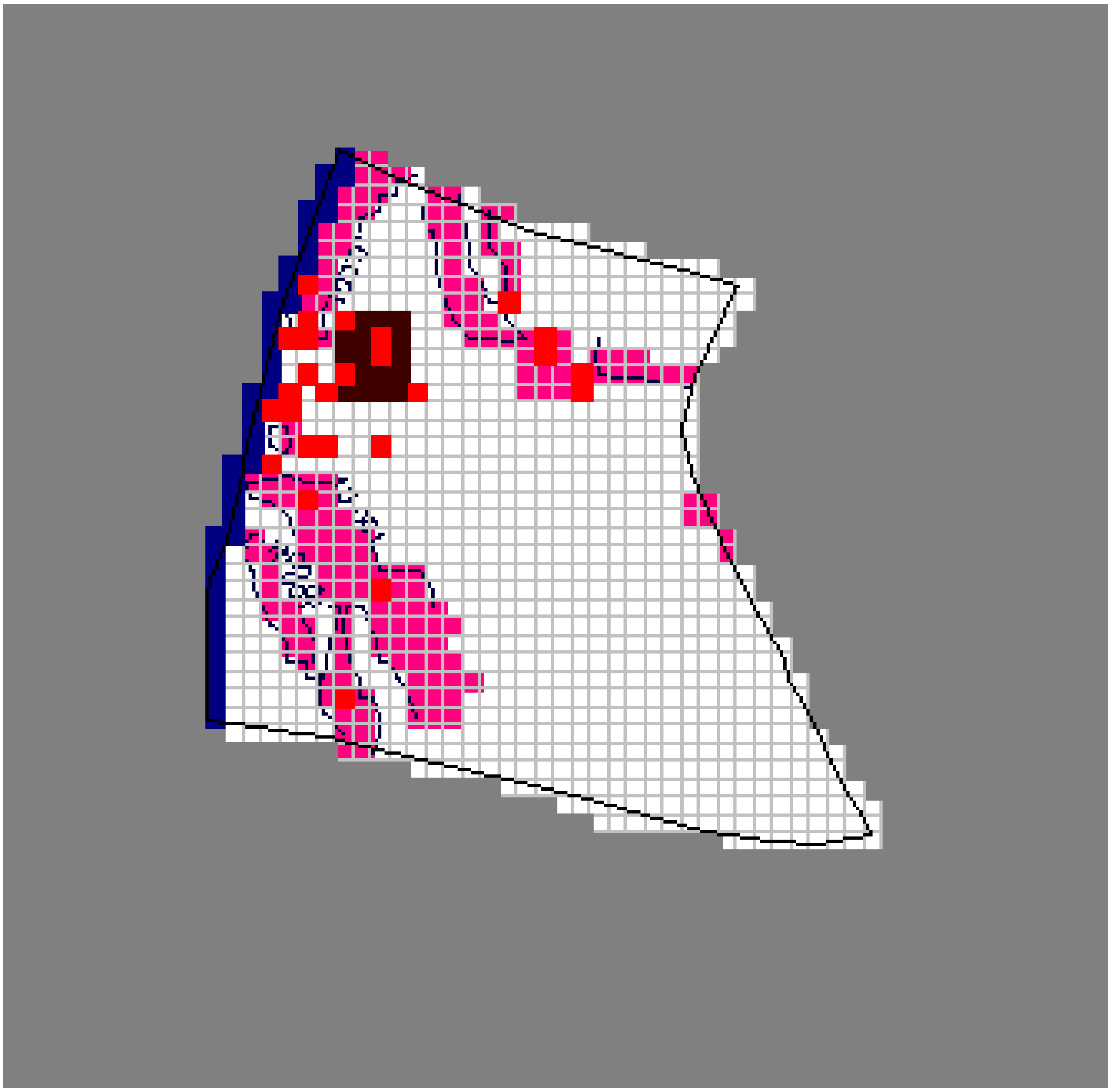


Figure 5.8: Chloride Concentration at the End of Simulation

Chapter Six

Conclusions and Recommendations

6.1 Conclusions

The hydrochemical study was conducted to define water types and water geneses of the aquifer system based on the available data from (PWA Master Data Bank, spring of 2003 & spring of 2004) for eleven groundwater wells in Tulkarm Area. The water type according to Piper plot for most of the wells is earth alkaline water with increased alkalis and with prevailing bicarbonate. The scholer diagram indicates that a pollution trend with respect to chloride was observed from the year of 2003 to 2004. Furthermore, Durov diagram indicates that most of the samples are located in field where Ca^{2+} , HCO_3^- dominant aions, association with dolomite if Mg^{2+} is significant. These ions are originated from recharging water in limestone and dolomitic aquifer that is interrelated to aquifer type and its lithology.

The saturation indices analyses revealed that water genesis originates from the recharge area of limestone and dolomitic limestone. The results showed that aragonite, calcite & dolomite are three dominant mineral phases affecting the water composition through its transformation from rain water to well water in the recharge area watershed. Most of the wells are oversaturated with respect to aragonite, calcite & dolomite and thus allows their precipitation. And no change was noticed through comparison between the two sets of data in 2003 and 2004.

The hydrochemical analysis and graphical representation indicates that, the ions of Cl^- & NO_3^- is mainly coming from pollution causing activities such as (intensive irrigation, sewage percolation & excessive land fertilization).

The pollution indicators of nitrate and chloride concentrations were used to investigate the state of pollution with respect to WHO standards for drinking water. Basing on the available data from PWA Master Data Bank, spring 2005. Fourty groundwater wells in Tulkarm Area were investigated in terms of nitrate and chloride concentrations and represented spatially and interrelated to geological and anthropological factors.

The results of pollution investigation for domestic and agricultural wells in Tulkarm Area indicates that there are high levels of nitrate concentrations exceeds the WHO standards of 45mg/L for drinking water of 55%. On the other hand there is no pollution risk with respect to chloride. The spatial analysis and representation conducted by the arcview indicates that:

- The polluted wells in Tulkarm area are located in high sensitive & moderate sensitive areas and most of them are located in the upper aquifer with Turanian geological formation (Jerusalem) having typical lithology of limestone and dolomite karstic, marly limestone, karstic. The karstic nature in the recharge area for the aquifer brings the risk of pollution from runoff over industrial zones, farms and uncontrolled dumping sites and wastewater percolation.
- The polluted wells are located within the irrigated complex cultivation and within the built up areas and village boundaries means that they are subjected to human activities which is harmful to groundwater quality .
- The polluted wells are mostly located in unsewered areas where direct contamination from septage take place.

The long term trend analysis through historical data was conducted for 20 groundwater wells in Tulkarm for nitrate and chloride concentrations, for polluted and unpolluted wells. The results revealed that there is a gradual increase in nitrate and chloride concentration with time.

A 3-dimentional model of 2 layers system in the western portion of the Iskandaron drainage (representing a highly sensitive area of Tulkarm) was built using the Modflow software backage. After completing the flow model, the pollution model was built using the MT3D package under Modflow. The model output indicates that the response of pollution due to contaminant area chosen within the built-up areas shows that the tendency of contamination and pollutant spreading occurs due to dispersion. The results show that there is a gradual increase in chloride concentration with time during the period of simulation.

6.2 Recommendations

The main recommendations of this thesis could be summarized as follows:

- Increasing the public awareness of the issue of groundwater scarcity and pollution sources which is harmful to groundwater quality. Besides that, Pollution mitigation measures besides public awareness should be taken with action on the ground to protect groundwater from increasingly generated pollution loads in the surrounding of the water resources. Also, the awareness among different water users and stakeholders should be raised to ensure public contribution in water quality protection and conservation.
- Construction of on site sanitary treatment options for sewage disposal and sewer treatment plants in residential areas.
- The use of fertilizer and pesticide must be applied to the plants and crops by the value not exceeding the plant nutrients requirements through farmers awareness.
- The construction of protection zones is recommended which will help in restoring the water quality to its initial state and could protect groundwater wells with low nitrate pollution.
- The polluted wells with nitrate concentration > 50mg/l should be abanded from domestic use. Their use should be transformed to irrigation where possible and after comparing their salinity levels with WHO standards.
- A GIS base: geological, hydrogeological, hydrochemical and landuse data base is highly recommended to be build. It is recommended to establish and develop a quality monitoring program which could be conducted through cooperation between the decision makers and the public.
- The EIA studies should be applied for new developments in order to avoid and mitigate the negative impacts which is to groundwater resources.
- The initial concentration of the contaminated areas and the intensities of such pollution sources was assumed through the historical data of the conservative parameter (Cl^-) in the groundwater samples. So, it is recommended to get a real data from the pollution sources through conducting studies and tests.

- It is recommended to develop a solute transport model for a reactive parameter (NO_3^-), also it is recommended to simulate a transport model after simulating a transient flow instead of steady state model.

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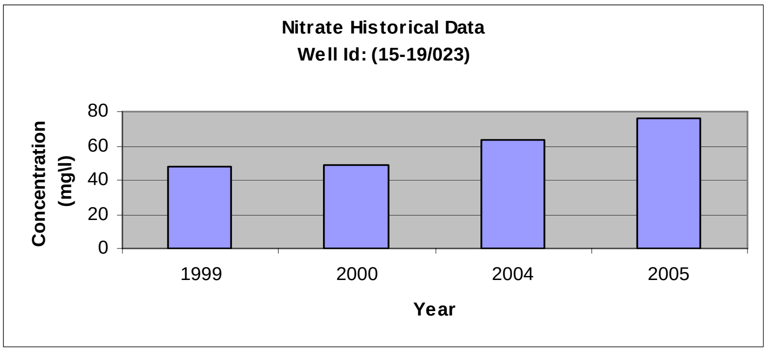
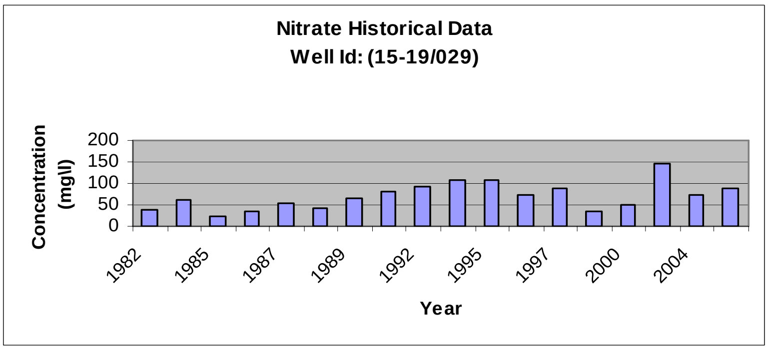
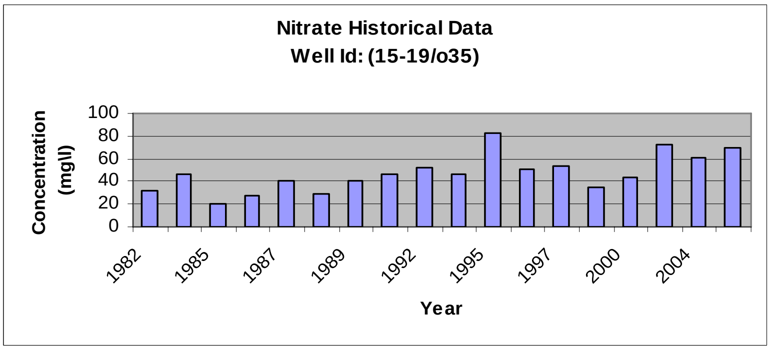
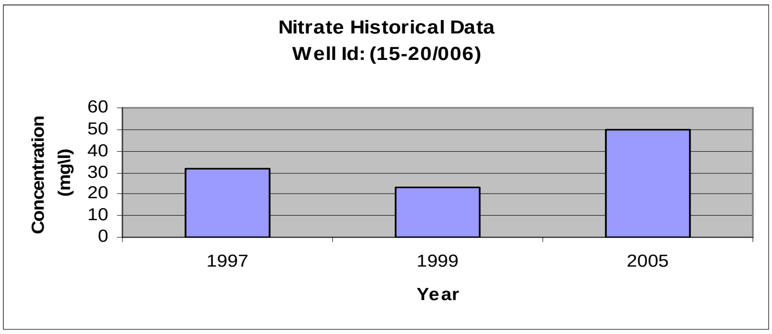
Appendix A – Historical Trends for Nitrate and Chloride for Tulkarm Wells (PWA Master Data Bank, 2005)

1- Nitrate trends for polluted wells in Alkhodera drainage

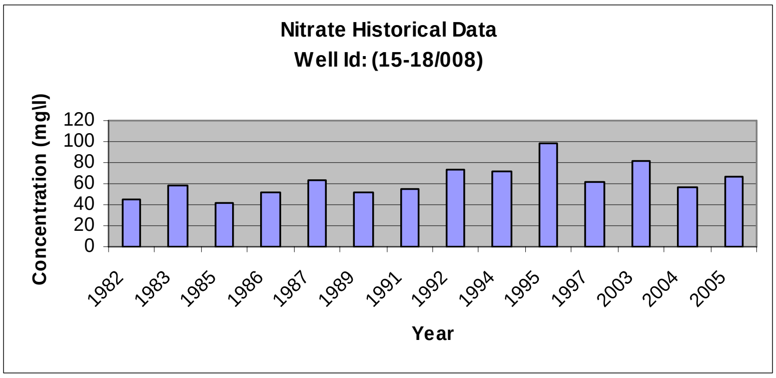


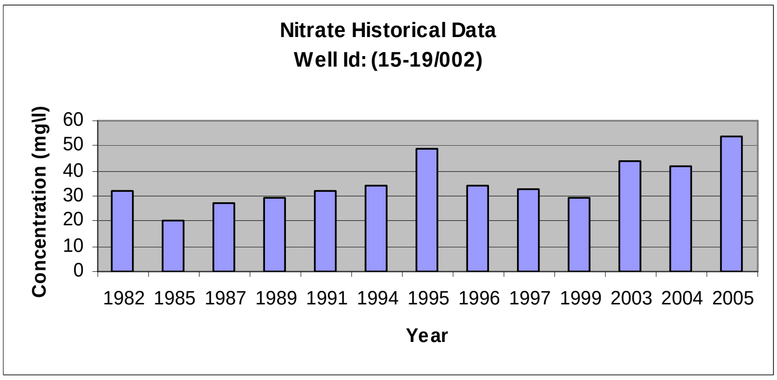


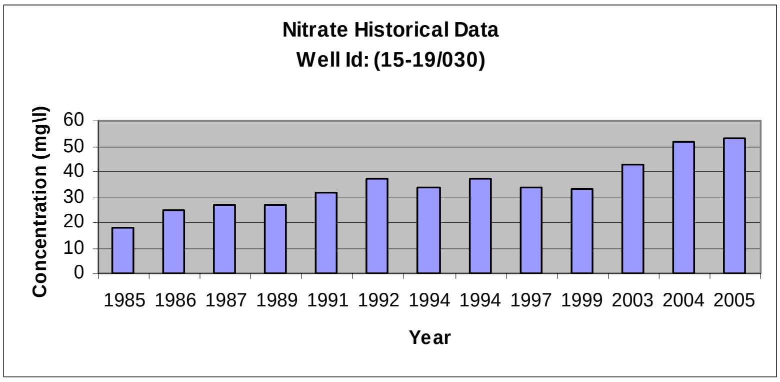


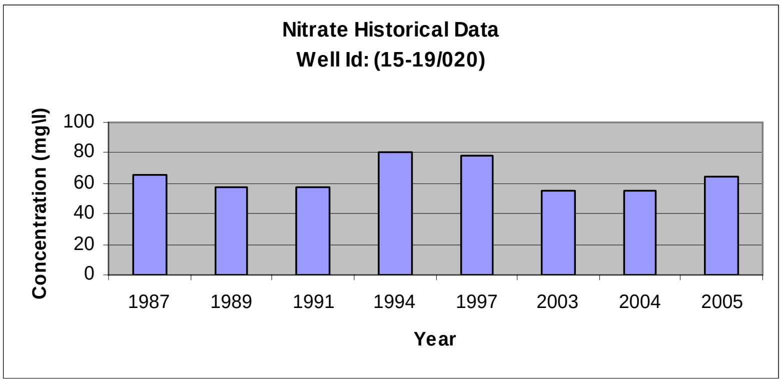


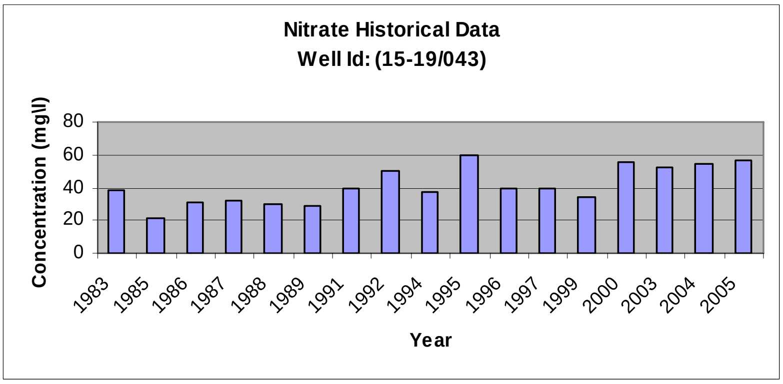
2- Nitrate trend for polluted wells in Iskandaron drainage







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Concentration (mg\l)
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60
40
20
0
1983
1985
1986
1987
1988
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1991
1992
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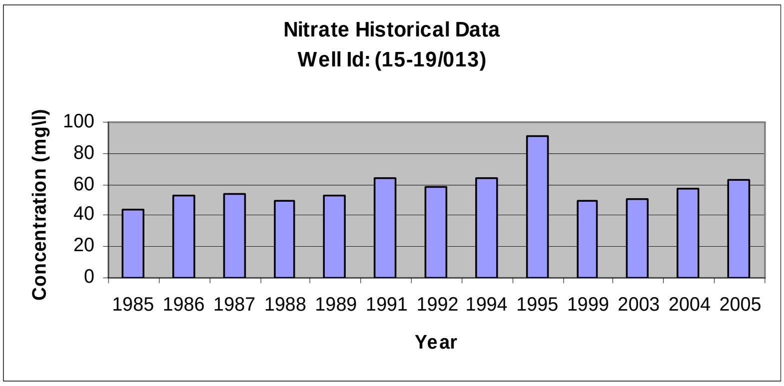
1999
2000
2003
2004
2005
Year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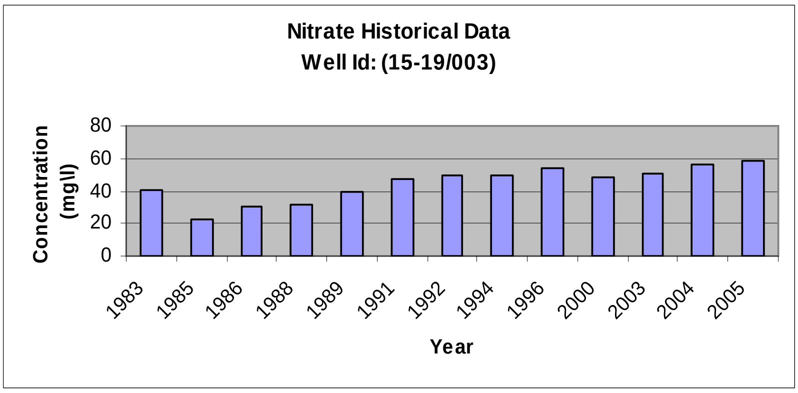
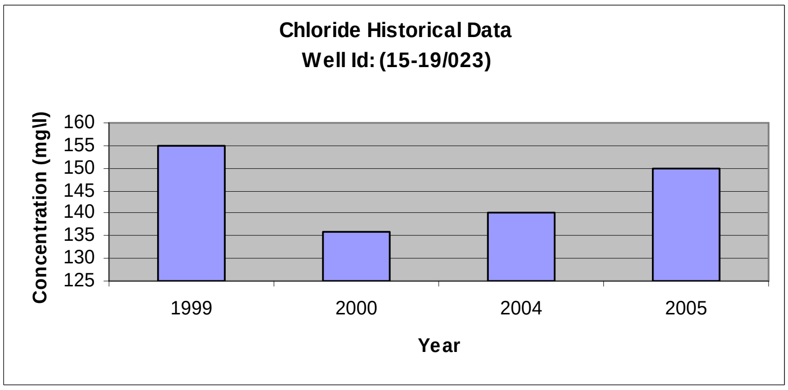
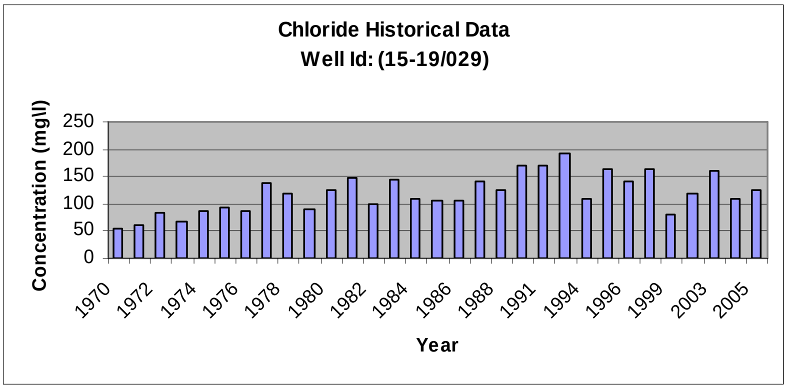
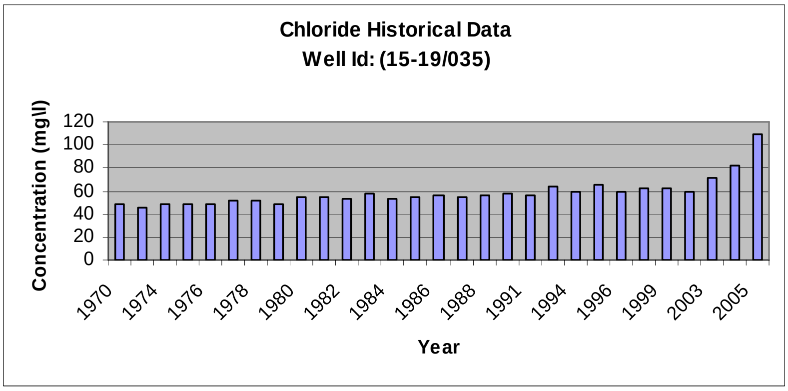
80
60
40
20
0
1985
1986
1987
1988
1989
1991
1992
1994
1995
1999
2003
2004
2005
Year

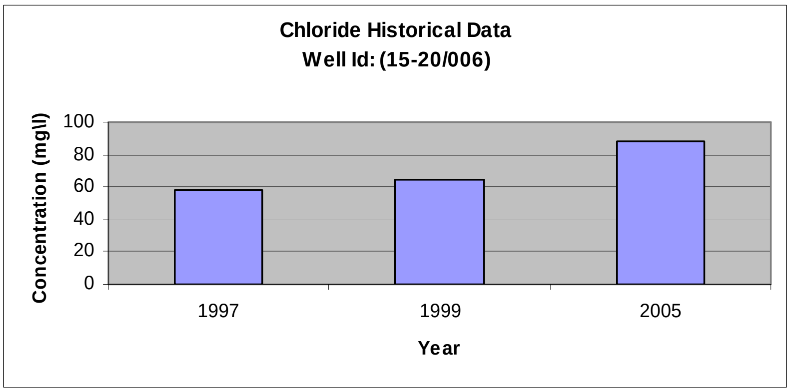

Nitrate Historical Data
Well Id: (15-19/003)
Concentration (mg\l)
80
60
40
20
0
1983
1985
1986
1988
1989
1991
1992
1994
1996
2000
2003
2004
2005
Year

3- Chloride trend for polluted wells in Alkhodera drainage

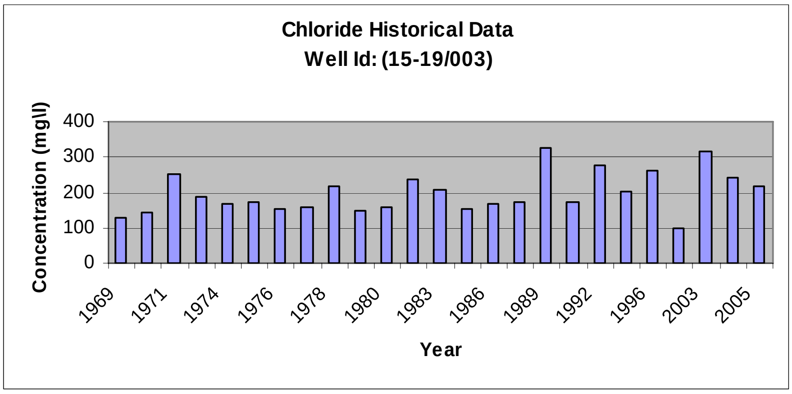


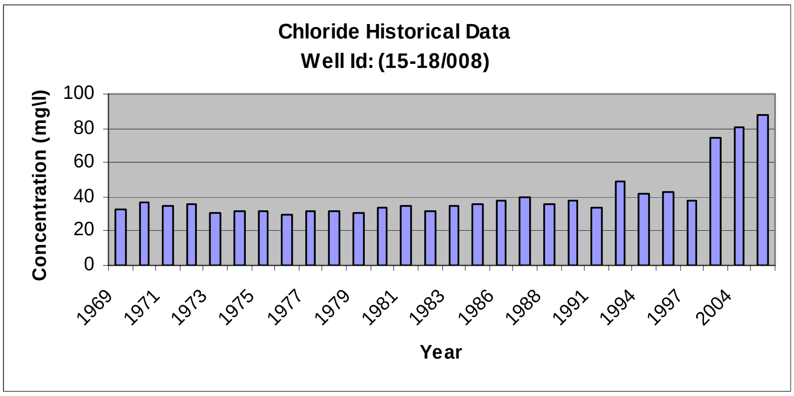


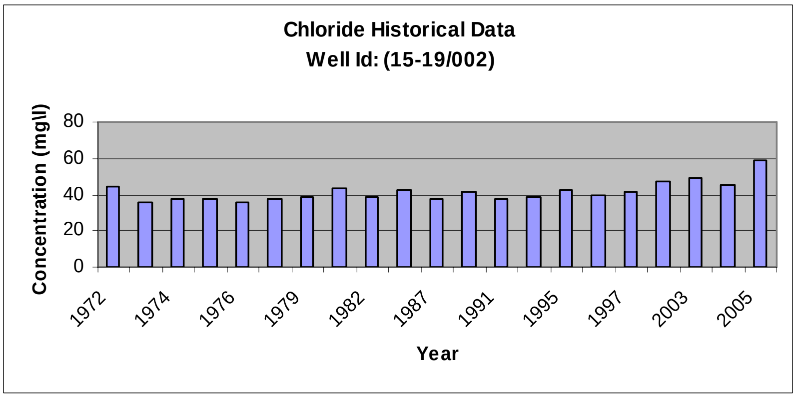


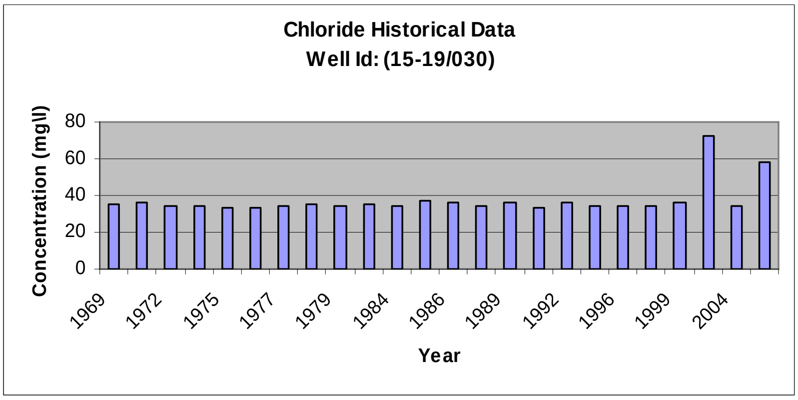


4- Chloride trend for polluted wells in Iskandaron drainage








Chloride Historical Data
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Concentration (mg/l)
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60
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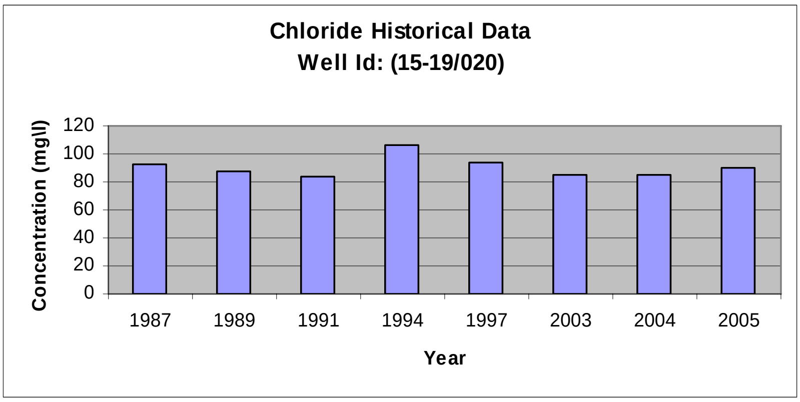
1969
1972
1975
1977
1979
1984
1986
1989
1992
1996
1999
2004
Year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100
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1989
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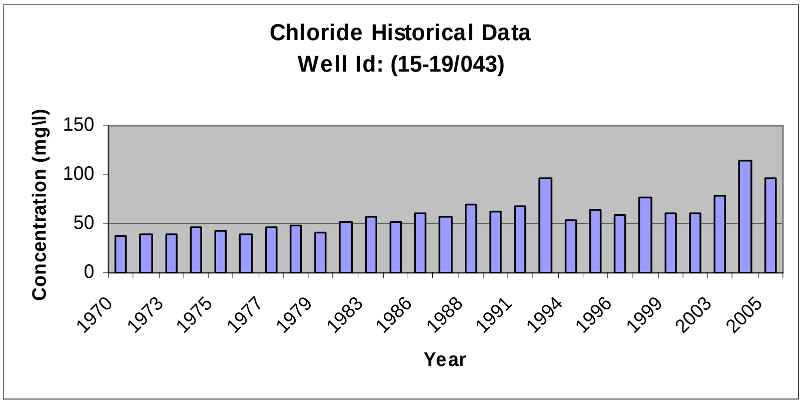
1997
2003
2004
2005
Year


Chloride Historical Data
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Concentration (mg/l)
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100
150
1970
1973
1975
1977
1979
1983
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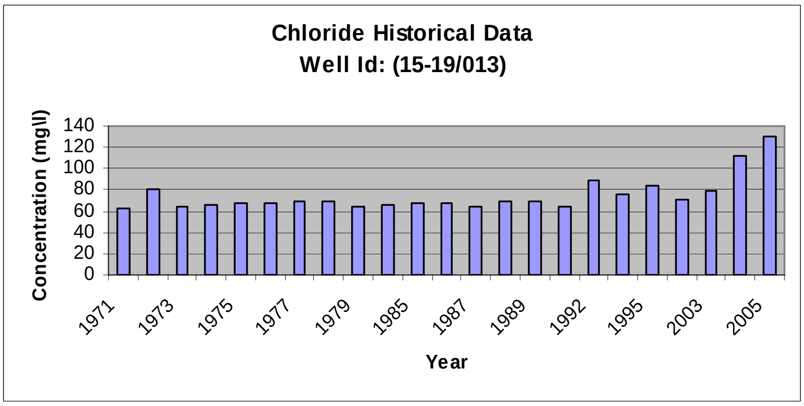
1996
1999
2003
2005
Year


Chloride Historical Data
Well Id: (15-19/013)
Concentration (mg/l)
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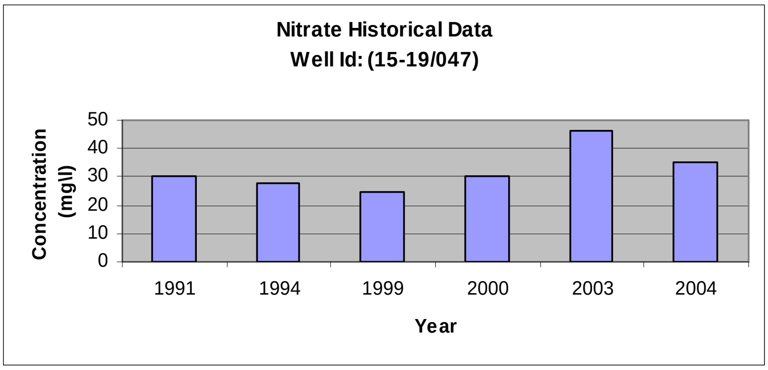
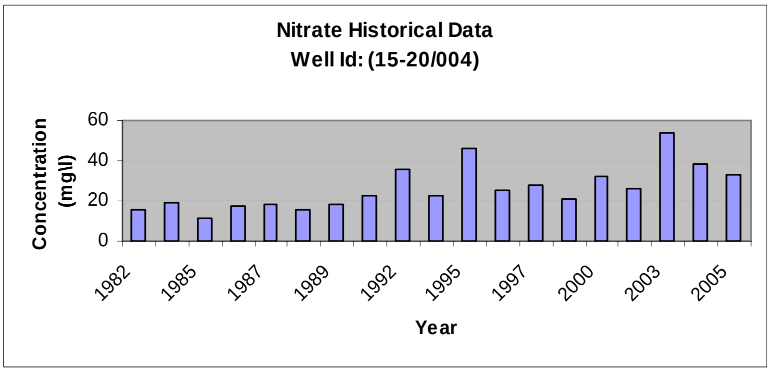
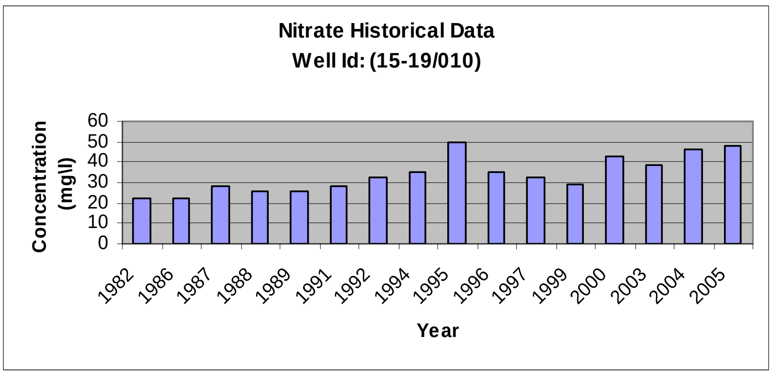
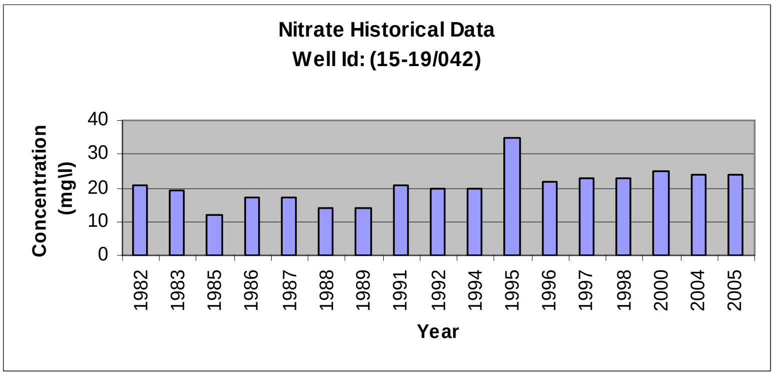
40
60
80
100
120
140
1971
1973
1975
1977
1979
1985
1987
1989
1992
1995
2003
2005
Year

5- Nitrate trend for un-polluted wells in Alkhodera drainage

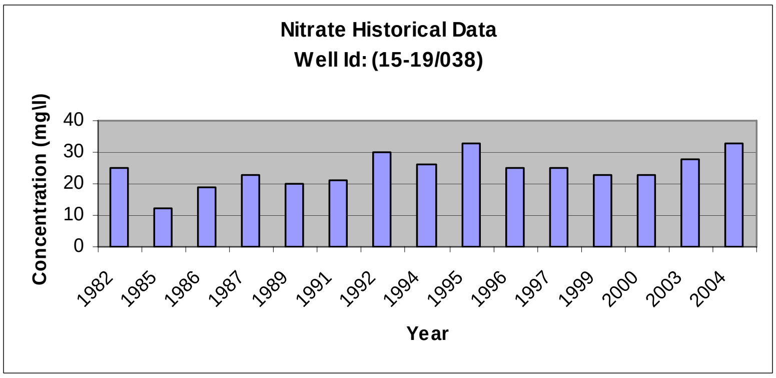


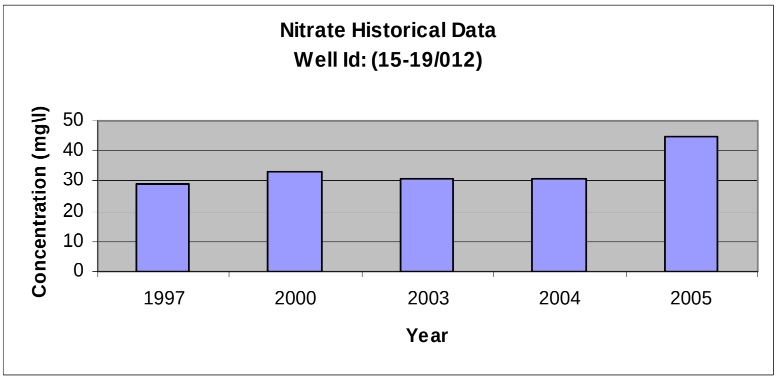


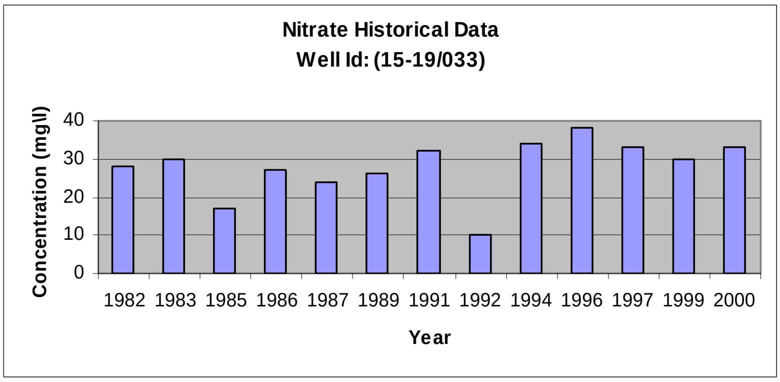


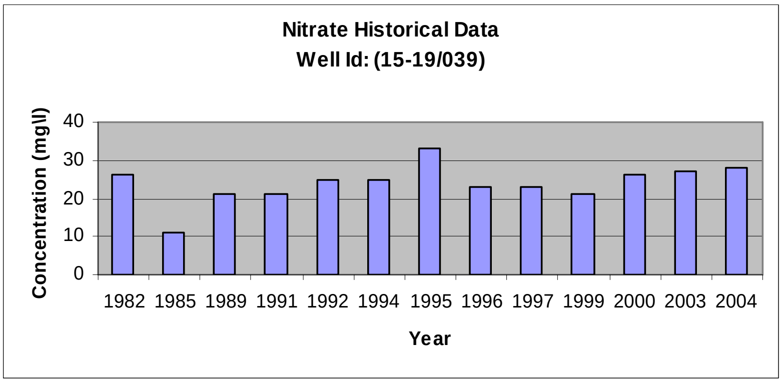


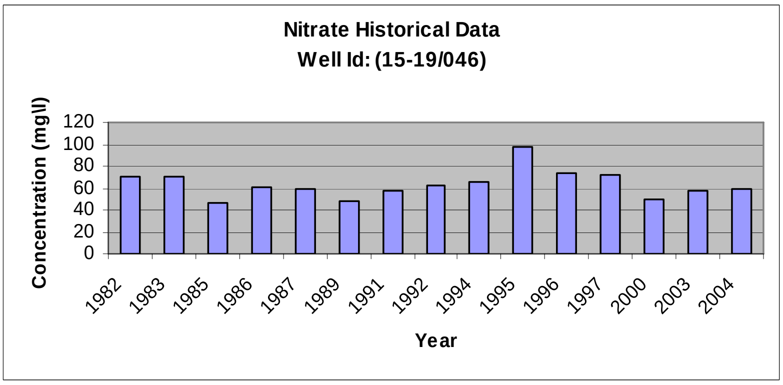
6- Nitrate trend for un-polluted wells in Iskandaron drainage



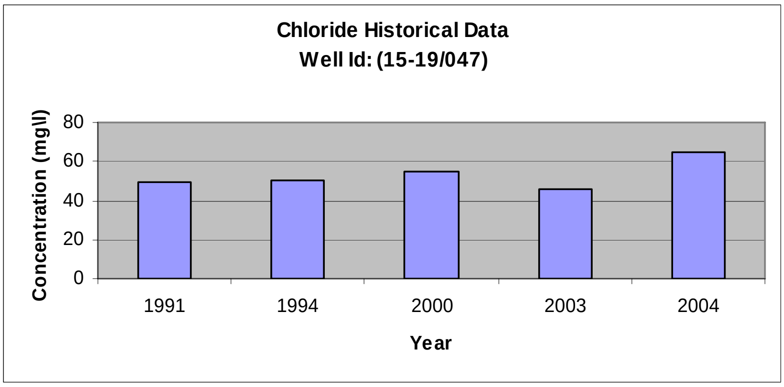


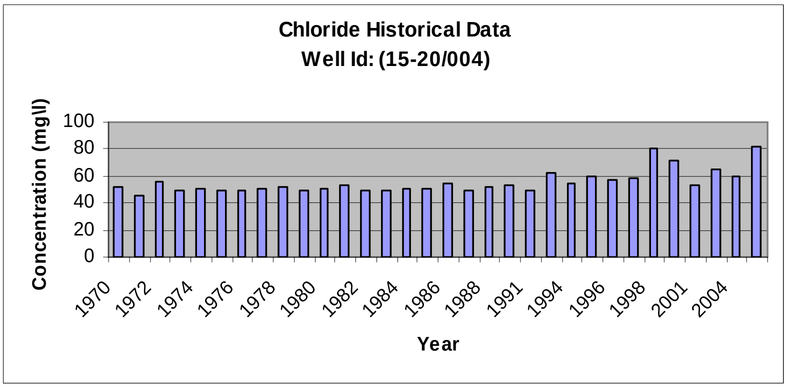


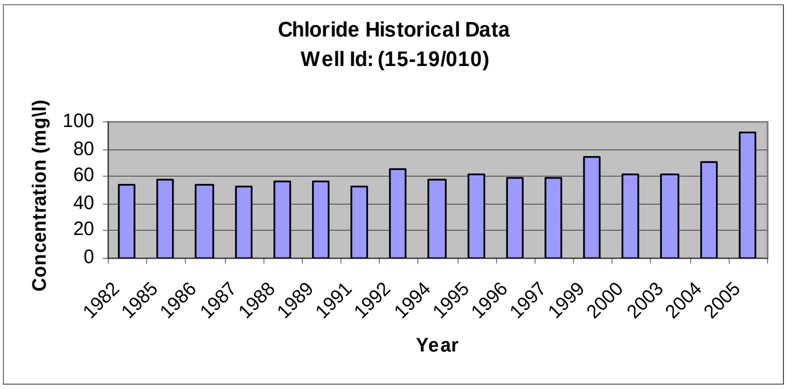


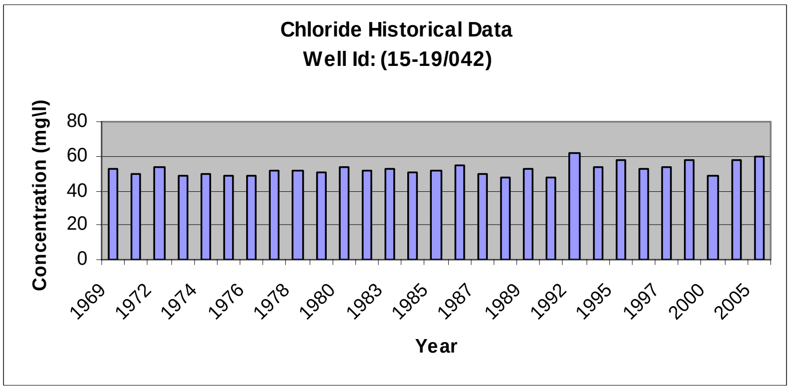


7- Chloride trend for un-polluted wells in Alkhodera drainage

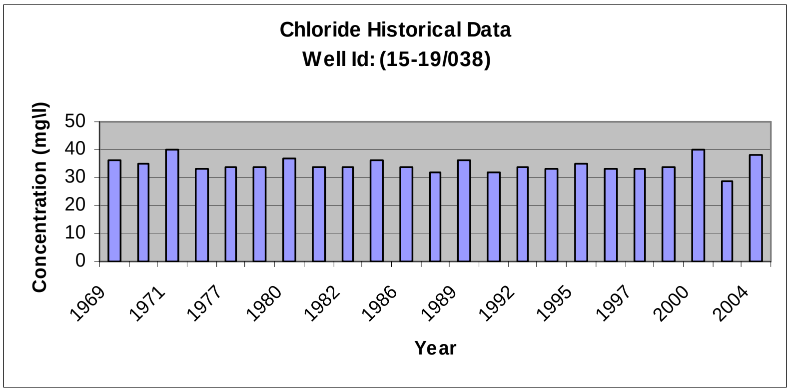


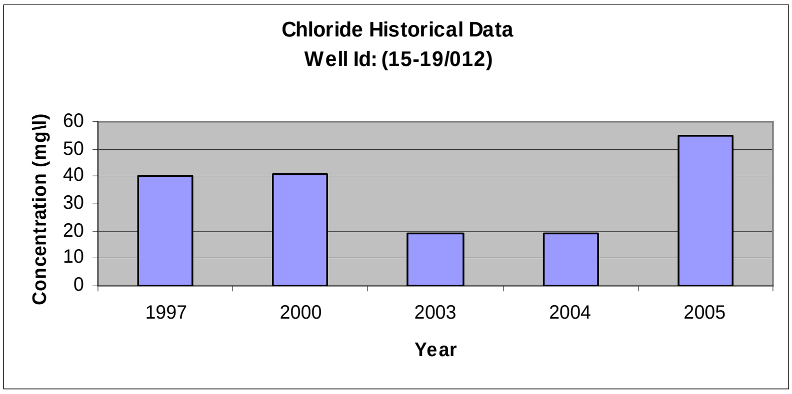


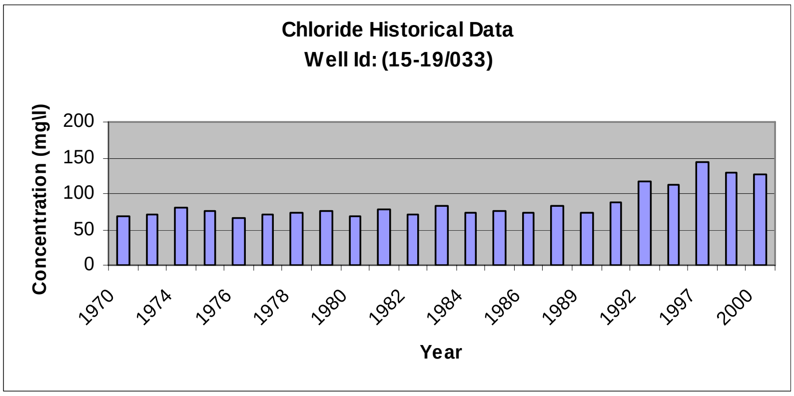


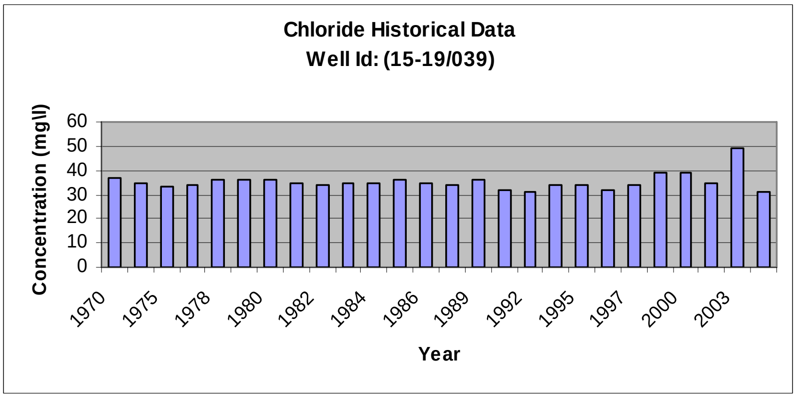


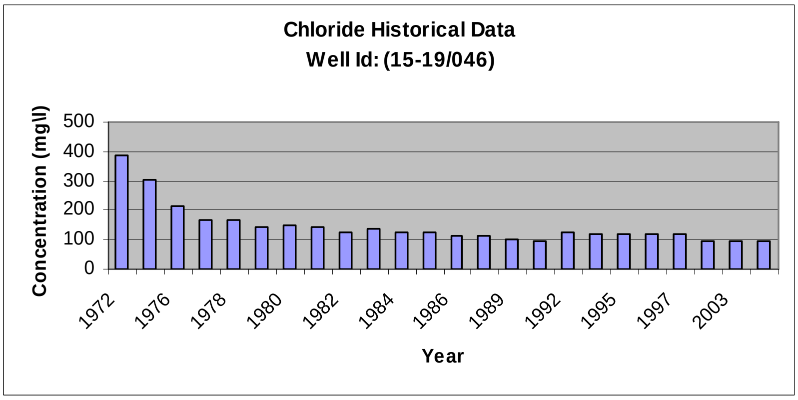
8- Chloride trend for un-polluted wells in Iskandaron drainage




Chloride Historical Data
Well Id: (15-19/012)
Concentration (mg/l)
60
50
40
30
20
10
0
1997
2000
2003
2004
2005
Year


Chloride Historical Data
Well Id: (15-19/033)
Concentration (mg/l)
200
150
100
50
0
1970
1974
1976
1978
1980
1982
1984
1986
1989
1992
1997
2000
Year


Chloride Historical Data
Well Id: (15-19/039)
Concentration (mg/l)
60
50
40
30
20
10
0
1970
1975
1978
1980
1982
1984
1986
1989
1992
1995
1997
2000
2003
Year


Chloride Historical Data
Well Id: (15-19/046)
Concentration (mg/l)
500
400
300
200
100
0
1972
1976
1978
1980
1982
1984
1986
1989
1992
1995
1997
2003
Year

Appendix B - Elevations of top and bottom of upper aquifer and aquitard layers. (SUSMAQ, 2003)

X	Y	GrElev	BotUA	TopLA
154593.79	196749.24	142.00	-352.02	-452.02
155666.88	196749.24	91.99	-264.02	-364.02
153520.70	195786.36	149.00	-420.03	-520.03
154593.79	195786.36	150.01	-331.03	-431.03
155666.88	195786.36	133.99	-229.02	-329.02
156739.96	195786.36	129.99	-155.01	-255.01
157813.05	195786.36	116.98	-133.01	-233.01
153520.70	194823.47	111.01	-381.06	-481.06
154593.79	194823.47	103.01	-274.05	-374.05
155666.88	194823.47	129.99	-194.03	-294.03
156739.96	194823.47	161.99	-147.02	-247.02
157813.05	194823.47	204.99	-77.01	-177.01
158886.14	194823.47	291.99	6.99	-93.01
159959.22	194823.47	337.97	40.98	-59.02
153520.70	193860.59	99.99	-291.00	-391.00
154593.79	193860.59	104.00	-175.99	-275.99
155666.88	193860.59	153.00	-126.99	-226.99
156739.96	193860.59	187.00	-92.99	-192.99
157813.05	193860.59	183.00	-102.00	-202.00
158886.14	193860.59	259.00	-26.00	-126.00
159959.22	193860.59	362.02	82.03	-17.97
161032.31	193860.59	401.01	121.01	21.01
162105.40	193860.59	330.02	50.00	-50.00
163178.49	193860.59	286.04	16.02	-83.98
164251.57	193860.59	316.98	66.95	-33.05
152447.61	192897.70	65.99	-327.02	-427.02
153520.70	192897.70	95.99	-212.01	-312.01
154593.79	192897.70	138.99	-146.01	-246.01
155666.88	192897.70	180.99	-99.01	-199.01
156739.96	192897.70	183.00	-87.00	-187.00
157813.05	192897.70	200.00	-69.99	-169.99
158886.14	192897.70	219.00	-61.00	-161.00
159959.22	192897.70	360.99	111.00	11.00
161032.31	192897.70	409.99	159.98	59.98
162105.40	192897.70	462.00	134.98	34.98
163178.49	192897.70	406.04	72.00	-28.00
152447.61	191934.82	46.99	-302.03	-402.03
153520.70	191934.82	64.99	-215.01	-315.01
154593.79	191934.82	83.99	-196.01	-296.01
155666.88	191934.82	105.99	-144.01	-244.01
156739.96	191934.82	169.00	-81.00	-181.00
157813.05	191934.82	207.00	-43.00	-143.00
158886.14	191934.82	202.00	-48.00	-148.00

159959.22	191934.82	181.99	-73.02	-173.02
161032.31	191934.82	235.99	-74.01	-174.01
162105.40	191934.82	293.02	8.00	-92.00
163178.49	191934.82	451.07	32.00	-68.00
152447.61	190971.93	51.99	-254.03	-354.03
153520.70	190971.93	90.99	-189.01	-289.01
154593.79	190971.93	108.00	-162.00	-262.00
155666.88	190971.93	143.00	-127.00	-227.00
156739.96	190971.93	160.00	-110.00	-210.00
157813.05	190971.93	206.00	-64.00	-164.00
158886.14	190971.93	200.00	-80.00	-180.00
159959.22	190971.93	152.00	-133.00	-233.00
161032.31	190971.93	157.01	-127.99	-227.99
162105.40	190971.93	238.02	-41.99	-141.99
151374.53	190009.05	47.00	-333.04	-433.04
152447.61	190009.05	39.99	-240.03	-340.03
153520.70	190009.05	93.99	-176.01	-276.01
154593.79	190009.05	99.00	-171.00	-271.00
155666.88	190009.05	125.00	-145.00	-245.00
156739.96	190009.05	153.00	-117.00	-217.00
157813.05	190009.05	176.00	-94.00	-194.00
158886.14	190009.05	224.00	-46.00	-146.00
159959.22	190009.05	255.00	-15.00	-115.00
161032.31	190009.05	199.99	-70.01	-170.01
162105.40	190009.05	207.01	-73.00	-173.00
163178.49	190009.05	242.04	-37.98	-137.98
151374.53	189046.16	45.99	-234.03	-334.03
152447.61	189046.16	39.99	-230.02	-330.02
153520.70	189046.16	69.99	-180.01	-280.01
154593.79	189046.16	104.99	-145.01	-245.01
155666.88	189046.16	144.00	-106.00	-206.00
156739.96	189046.16	185.00	-65.00	-165.00
157813.05	189046.16	201.00	-49.00	-149.00
158886.14	189046.16	216.00	-34.00	-134.00
159959.22	189046.16	294.00	24.00	-76.00
161032.31	189046.16	266.99	-3.01	-103.01
162105.40	189046.16	287.99	17.99	-82.01
163178.49	189046.16	213.01	-67.00	-167.00
164251.57	189046.16	293.97	-26.01	-126.01
151374.53	188083.27	58.98	-221.02	-321.02
152447.61	188083.27	137.98	-132.02	-232.02
153520.70	188083.27	100.99	-149.01	-249.01
154593.79	188083.27	99.00	-131.00	-231.00
155666.88	188083.27	106.00	-144.01	-244.01
156739.96	188083.27	168.00	-82.00	-182.00
157813.05	188083.27	230.99	-19.00	-119.00
158886.14	188083.27	311.99	62.00	-38.00
159959.22	188083.27	320.00	50.00	-50.00

161032.31	188083.27	322.99	52.99	-47.01
162105.40	188083.27	256.98	-13.02	-113.02
163178.49	188083.27	224.99	-55.01	-155.01
164251.57	188083.27	317.98	37.99	-62.01
151374.53	187120.39	84.98	-258.02	-358.02
152447.61	187120.39	99.99	-170.02	-270.02
153520.70	187120.39	138.00	-112.01	-212.01
154593.79	187120.39	97.99	-132.01	-232.01
155666.88	187120.39	141.99	-88.01	-188.01
156739.96	187120.39	181.00	-69.00	-169.00
157813.05	187120.39	272.01	2.01	-97.99
158886.14	187120.39	306.01	36.01	-63.99
159959.22	187120.39	317.01	47.00	-53.00
161032.31	187120.39	338.00	58.00	-42.00
162105.40	187120.39	351.98	71.98	-28.02
163178.49	187120.39	356.96	86.97	-13.03
164251.57	187120.39	250.02	-29.98	-129.98
165324.66	187120.39	252.01	-47.99	-147.99
151374.53	186157.50	80.99	-260.01	-360.01
152447.61	186157.50	100.00	-185.01	-285.01
153520.70	186157.50	118.00	-132.01	-232.01
154593.79	186157.50	138.00	-112.00	-212.00
155666.88	186157.50	129.00	-101.00	-201.00
156739.96	186157.50	152.00	-98.00	-198.00
157813.05	186157.50	212.99	-37.01	-137.01
158886.14	186157.50	241.99	-8.01	-108.01
159959.22	186157.50	320.00	70.00	-30.00
161032.31	186157.50	332.00	52.00	-48.00
162105.40	186157.50	391.01	101.00	1.00
163178.49	186157.50	330.99	45.98	-54.02
164251.57	186157.50	275.04	5.04	-94.96
165324.66	186157.50	236.01	-43.97	-143.97
166397.75	186157.50	265.98	-66.97	-166.97
150301.44	185194.62	71.01	-208.95	-308.95
151374.53	185194.62	97.99	-182.00	-282.00
152447.61	185194.62	125.00	-125.00	-225.00
153520.70	185194.62	127.00	-123.00	-223.00
154593.79	185194.62	129.00	-101.00	-201.00
155666.88	185194.62	164.01	-85.99	-185.99
156739.96	185194.62	190.01	-59.99	-159.99
157813.05	185194.62	210.01	-39.99	-139.99
158886.14	185194.62	232.00	-18.00	-118.00
159959.22	185194.62	267.99	17.99	-82.01
161032.31	185194.62	312.00	32.01	-67.99
162105.40	185194.62	370.00	84.00	-16.00
163178.49	185194.62	388.99	71.00	-29.00
164251.57	185194.62	340.03	60.02	-39.98
165324.66	185194.62	293.03	23.03	-76.97

166397.75	185194.62	271.01	-8.96	-108.96
150301.44	184231.73	67.02	-182.97	-282.97
151374.53	184231.73	102.00	-148.00	-248.00
152447.61	184231.73	98.00	-132.00	-232.00
153520.70	184231.73	130.01	-99.99	-199.99
154593.79	184231.73	155.01	-74.99	-174.99
155666.88	184231.73	198.00	-52.00	-152.00
156739.96	184231.73	226.01	-24.00	-124.00
157813.05	184231.73	286.01	16.01	-83.99
158886.14	184231.73	209.01	-40.99	-140.99
159959.22	184231.73	223.01	-26.99	-126.99
161032.31	184231.73	298.00	48.01	-51.99
162105.40	184231.73	316.99	67.00	-33.00
163178.49	184231.73	313.99	63.99	-36.01
164251.57	184231.73	344.99	65.00	-35.00
165324.66	184231.73	367.01	97.01	-2.99
150301.44	183268.85	119.01	-110.98	-210.98
151374.53	183268.85	146.99	-83.01	-183.01
152447.61	183268.85	199.99	-30.01	-130.01
153520.70	183268.85	239.00	9.00	-91.00
154593.79	183268.85	198.00	-32.00	-132.00
155666.88	183268.85	201.00	-49.00	-149.00
156739.96	183268.85	238.00	-32.00	-132.00
157813.05	183268.85	278.00	8.00	-92.00
158886.14	183268.85	322.01	72.01	-27.99
159959.22	183268.85	269.00	19.00	-81.00
161032.31	183268.85	246.00	-4.00	-104.00
162105.40	183268.85	281.00	31.00	-69.00
163178.49	183268.85	286.01	36.01	-63.99
164251.57	183268.85	317.98	47.99	-52.01
150301.44	182305.96	91.01	-158.99	-258.99
151374.53	182305.96	99.99	-150.01	-250.01
152447.61	182305.96	129.99	-120.01	-220.01
153520.70	182305.96	154.99	-95.01	-195.01
154593.79	182305.96	209.00	-41.00	-141.00
155666.88	182305.96	199.00	-51.00	-151.00
156739.96	182305.96	201.00	-49.00	-149.00
157813.05	182305.96	207.00	-43.00	-143.00
158886.14	182305.96	317.00	67.00	-33.00
159959.22	182305.96	316.00	66.00	-34.00
161032.31	182305.96	257.00	7.00	-93.00
162105.40	182305.96	278.01	28.01	-71.99
163178.49	182305.96	299.02	49.02	-50.98
164251.57	182305.96	396.95	126.96	26.96
150301.44	181343.08	92.01	-177.99	-277.99
151374.53	181343.08	105.00	-165.00	-265.00
152447.61	181343.08	97.99	-172.01	-272.01
[illegible]	181343.08	[illegible]	[illegible]	[illegible]

155666.88	181343.08	234.00	-36.00	-136.00
156739.96	181343.08	230.00	-40.00	-140.00
157813.05	181343.08	234.00	-16.00	-116.00
158886.14	181343.08	252.01	2.00	-98.00
159959.22	181343.08	302.00	32.00	-68.00
161032.31	181343.08	299.00	29.00	-71.00
162105.40	181343.08	328.00	78.00	-22.00
163178.49	181343.08	338.02	88.02	-11.98
164251.57	181343.08	445.94	175.95	75.95
150301.44	180380.19	120.00	-130.01	-230.01
151374.53	180380.19	106.00	-144.01	-244.01
152447.61	180380.19	125.99	-124.02	-224.02
153520.70	180380.19	130.99	-119.02	-219.02
154593.79	180380.19	165.99	-84.02	-184.02
155666.88	180380.19	240.99	-29.01	-129.01
156739.96	180380.19	281.99	11.99	-88.01
157813.05	180380.19	284.00	33.99	-66.01
158886.14	180380.19	280.00	29.99	-70.01
159959.22	180380.19	338.00	87.99	-12.01
161032.31	180380.19	374.99	124.99	24.99
162105.40	180380.19	370.99	120.98	20.98
163178.49	180380.19	322.00	72.00	-28.00
164251.57	180380.19	391.97	106.98	6.98
155666.88	179417.31	229.99	49.98	-50.02
156739.96	179417.31	286.00	105.98	5.98
157813.05	179417.31	277.00	96.99	-3.01
158886.14	179417.31	318.00	137.99	37.99
159959.22	179417.31	381.00	200.99	100.99
161032.31	179417.31	412.00	231.99	131.99
162105.40	179417.31	402.99	161.97	61.97
163178.49	179417.31	370.99	101.99	1.99
164251.57	179417.31	351.99	119.96	19.96
159959.22	178454.42	368.02	188.02	88.02
161032.31	178454.42	360.02	180.01	80.01
162105.40	178454.42	361.01	145.98	45.98
163178.49	178454.42	381.00	54.97	-45.03
164251.57	178454.42	377.98	58.96	-41.04
162105.40	177491.54	381.02	157.02	57.02
163178.49	177491.54	396.01	186.05	86.05
164251.57	177491.54	401.99	222.02	122.02
165324.66	177491.54	478.95	298.96	198.96
163178.49	176528.65	416.00	236.02	136.02
164251.57	176528.65	418.99	238.99	138.99
165324.66	176528.65	439.98	279.98	179.98
164251.57	175565.77	418.98	258.98	158.98
165324.66	175565.77	449.00	289.00	189.00