

**POLLUTION AND WATER QUALITY ASSESSMENT OF WADI AL QILT**

**By**

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The findings, interpretations and conclusions expressed in this study do not necessarily express the views of Birzeit University, the views of the individual members of the MSc-committee or the views of their respective employers.

## DEDICATION

To my mother's immaculate soul

To my father for his continuous encouragement

To my brothers and sisters who supported me during my study

To my wife for her efforts, support and patience

To my lovely baby "Kinan"

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## **ABSTRACT**

Pollution and limited access to available water resources are some of the major challenges facing the Palestinians in the West Bank and Gaza Strip. Arid to semi-arid conditions, overexploitation, mismanagement of water resources and being shared with regional countries caused complex but intrinsically inter-related problems of supply, demand, ownership and water quality.

The Jericho Water Treatment Plant (JWTP) is providing drinking water for almost 5,000 inhabitants living in Aqbat-Jabr refugee camp. Recent studies revealed microbial and chemical pollution of the main canal feeding JWTP especially during winter season. As a natural resource and basic element of Palestinian environmental resources, decisions affecting upgrading the current water treatment plant and the quality of the feeding inlet should be based on proven scientific understanding. The study was conducted to provide information about Al Qilt drainage basin including types and possible sources of pollutants.

The system is composed of two major tributaries; Fara and Sweanit that form the main stream. Wadi Al Qilt is formed after the combination of the tributaries with the discharge from Ein Al Fawwar and Ein Al Qilt springs. In order to assess the water quality of Wadi Al Qilt drainage basin, sampling stations were assigned along the path of the wadis starting from Al-Bireh Wastewater Treatment Plant (AWWTP) to JWTP inlet, and samples from the five springs were analyzed to determine their

quality as well. Chemical, physical, biological and hydrobiological studies were conducted between November (2004) and July (2005) in Wadi Al Qilt drainage basin.

Results revealed major trends for most of the measured parameters; decreasing the concentration of various parameters as going from AWWTP to the open transportation canal where the factor behind that is the dilution process resulted from springs' discharge that ends up in the wadis forming Wadi Al Qilt.

Results showed higher concentrations of lead and cadmium than allowable for drinking water in three spring samples, whereas, five samples out of ten were contaminated with fecal coliform, which indicate the presence of pollution sources in the recharge area. While results showed three samples from wadis were contaminated with aluminum, cadmium and lead, and all samples were microbially contaminated.

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## LIST OF ABBREVIATIONS

°C	Degree Centigrade
µg/L	Microgram per Liter
µS	Microsiemens
µS/cm	Microsiemens per Centimeter
Abs	Absorbance
APHA	American Public Health Association
ARIJ	Applied Research Institute/Jerusalem
AWWTP	Al Bireh Wastewater Treatment Plant
BOD <sub>5</sub>	Biochemical Oxygen Demand (after five days)
cm	Centimeter
COD	Chemical Oxygen Demand
CSO	Combined Sewer Overflow
DOC/ NPOC	Dissolved Organic Carbon/Nonpurgeable Organic Carbon
EC	Electric Conductivity
FC	Fecal Coliform
GIS	Geographical Information System
IC	Inorganic Carbon
ICP-OES	Inductive Coupled Plasma-Optical Emission Spectrometry
JWTP	Jericho Water Treatment Plant
km/yr	Kilometer per Year
km <sup>2</sup>	Kilometers Squared
L/sec	Liter per Second
m	Meter
m.a.s.l.	Meters Above Sea Level
m.b.s.l	Meters Below Sea Level
m <sup>3</sup>	Cubic Meters
m <sup>3</sup> /day	Cubic Meters per Day
mg/L	Milligram per Liter
mm	Millimeter
mm/a	Millimeter per Annual
mm/yr	Millimeter per Year
MOPIC	Ministry Of Planning and International Cooperation
mS	Millisiemens
NGO	Non-Governmental Organizations
nm	Nanometer
NOM	Natural Organic Matter
NTU	Nephelometric Turbidity Unit
PCBS	Palestinian Central Bureau of Statistics
PSI	Palestinian Standard Institution

PWA	Palestinian Water Authority
RH	Relative Humidity
SS	Suspended Solids
SUVA	Specific Ultraviolet Absorbance
TC	Total Coliform
TDS	Total Dissolved Solids
TKN	Total Kjeldahl Nitrogen
TS	Total Solids
TSS	Total Suspended Solids
USEPA	United States Environmental Protection Agency
UV	Ultraviolet
$\lambda$	Wavelength

## CHAPTER 1: INTRODUCTION

### ***1.1 Background***

Water is an extremely important issue, not only in the Middle East, but also in every community in the world. Without water there is no life. The scarcity of the water resources in the West Bank and Gaza Strip, due to arid to semi-arid climate, overexploitation, mismanagement and their pollution as well as the fact that these resources are shared with Israel, gave it a great importance. In addition to the arid to semi-arid climate, high population growth and the lack of sewer systems, which results in the infiltration of wastewater into springs and groundwater resources causes water resources pollution.

Groundwater is considered to be the main fresh water resource in the West Bank. There are three main basins in the West Bank, the north-eastern, the western and the eastern basins (Figure 1.1). The crest of the anticlinal structure of the Mountain Aquifer acts as the watershed for groundwater flowing westwards to the Mediterranean or eastward to the Jordan Valley and Dead Sea (Abed Rabbo et al, 1999). Due to the rapid increase of population which can be referred to natural growth and the increasing number of Israeli settlements, the demand for potable water in West Bank for domestic uses has increased in the last two decades. Alawneh

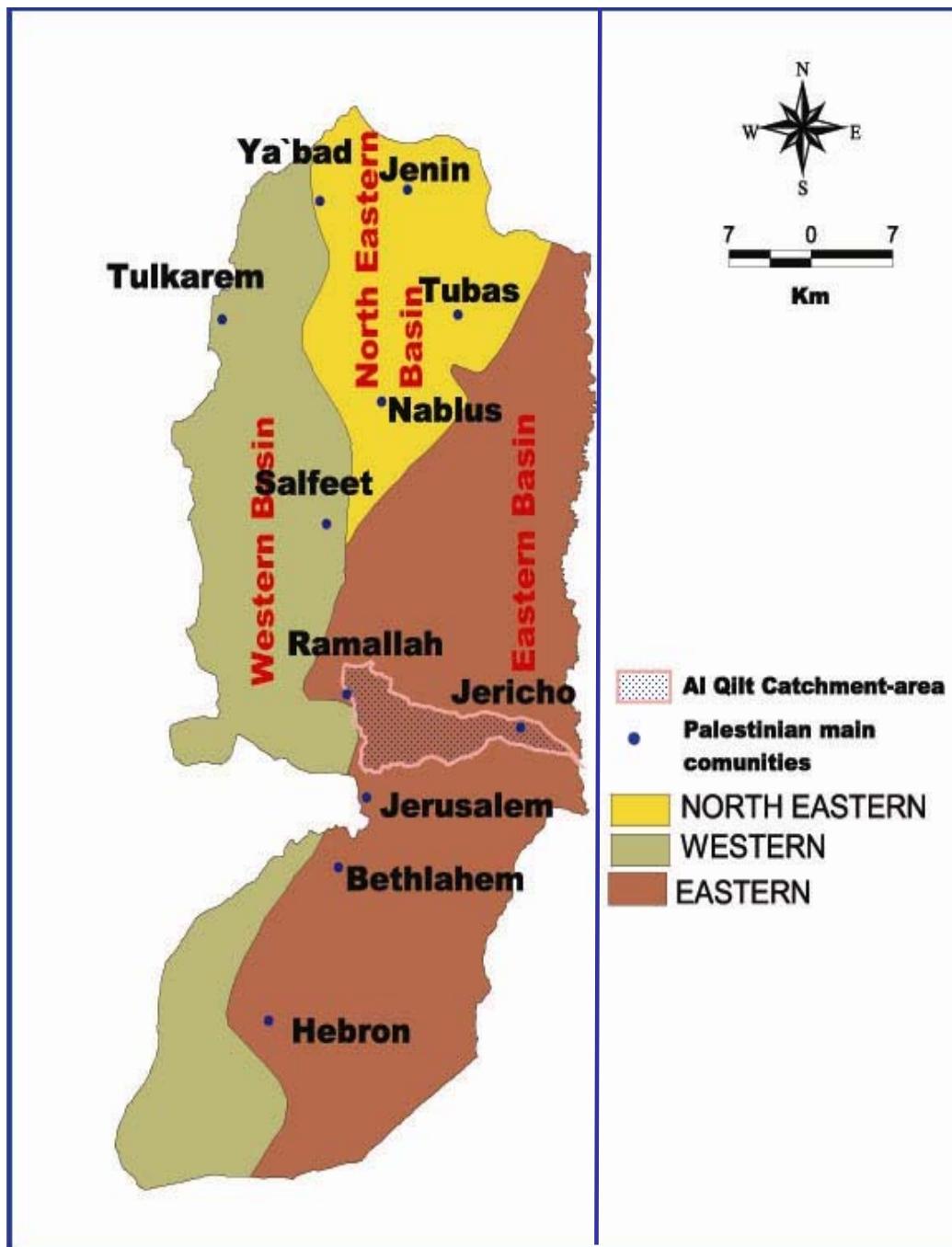


Figure 1.1: Major groundwater basins of the West Bank and location of Wadi Al Qilt

and Al-Sa`ed (1999) reviewed water quality of groundwater and some West Bank springs and reported an annual increment in pollutants, where the chemical water quality (nitrate) will be similar of that in Gaza water wells (Mukhallalati and Safi, 1995).

Jericho water resources are part of the Eastern Aquifer Basin. Groundwater sources in Jericho district are mainly divided between wells and springs. Regarding surface water, several wadi systems in the area have incised steeply into the mountains west of Jericho. These systems include Jerusalem Desert spring system, Wadi Al Qilt spring system, Auja-Fasayil spring system, Wadi El-Fari'a spring system, lower Jordan springs and springs of Northern Jordan catchment (Rofe and Raffety, 1965).

The main system in the area is Wadi Al Qilt system that has a catchment area stretching out from the Jordan River in the east towards Jerusalem and Ramallah in the west. This system is fed from three main springs Ein Fara, Ein Al Fawwar and Ein Al Qilt (Rofe and Raffety, 1965). The system of Wadi Al Qilt springs is the main water source for the **Jericho Water Treatment Plant (JWTP)**. Water is transported from springs to the treatment facility through a 13 km long open transportation canal. The existing JWTP applying slow sand filters system and a chlorination unit is located in Aqbat-Jabr Refugee Camp and serving about 5,000 inhabitants. Algal growth was noticed to cover the sand filter beds at JWTP and an increase in the turbidity of treated effluent during storm weather flow. Nawahda and Al-Sa`ed

(2000) simulated the treatment process using small scale slow sand filters and suggested the establishment of a sedimentation unit for the removal of increased turbidity during the winter season.

The water supply system to the camp consists of springs, open transportation canal, treatment facility, and distribution system. Additional source for drinking water to fulfill the needs of the Camp is obtained from Mekorot supply system which is much more expensive. But this treatment plant is operating only part of the year due to the problems associated with microbiological and other contamination of groundwater. These water quality problems appear regularly during the rainy season. Al-Sa`ed (2005) reported on obstacles for pollution cut from urban Palestinian towns, where erection of urban sewage works are the first priority of the Palestinian Water Authority Policy, as the pollution load has been reduced up to 75 and 95% in organic pollutants (TKN and  $BOD_5$  respectively) by Al Bireh wastewater treatment plant (AWWTP), launched in February 2000. The drainage basin of Wadi Al Qilt was chosen for the present study, as there is a lack of data concerning the impact of AWWTP effluent on the self-purification capacity of the season receiving water body (Wadi Al Qilt). Secondly, evidence of pollution from many springs in this basin as well as the sewage flow along the wadi is a potential health hazard for the local inhabitants and users downstream.

## **1.2 Goal and objectives**

The main aim of this study is to investigate the pollution sources that affect Wadi Al Qilt and the quality of surface water and springs in the drainage basin, to specify the different pollutants, their possible sources and their actual impact on the groundwater resources and to pinpoint on possible measures to improve the situation.

The water quality study aimed to determine the physical and chemical parameters of the surface water, springs and wastewater effluent as well as to evaluate the suitability of the water resources for domestic uses. Further objective is to study the changes in the water quality along the wadi and to evaluate the effect of the wastewater effluent after mixing with springs' water.

This study aims to fulfill the following objectives:

- Identification of the areas and sources of man-made pollution sources in wadi Al Qilt system.
- Determination of water quality of the springs in the drainage basin.
- Determination of water types in the area by interpretation of chemical data using Aquachem package.

- Introduction of adequate protective approaches to improve the quality of these water sources up to the level required for safe drinking water supply purposes before they enter JWTP.

### **1.3 Structure of the thesis**

Chapter 2 provides comprehensive literature review about Wadi Al Qilt drainage basin and investigates previous studies. Materials and methods used to carry out the study are explained in chapter 3. The main results and findings of the study together with the main published literature data are discussed in chapter 4. Finally, chapter five presents the most important conclusions and recommendations.

## CHAPTER 2: LITERATURE REVIEW

### **2.1 General description of Wadi Al Qilt drainage basin**

#### **2.1.1 Location and geography**

Jordan Valley forms the eastern part of the eastern basin, which is considered as one of the main three basins in West Bank. Structurally, the eastern basin is the eastern flank of the Judean anticline, which dips steeply towards the east, where it is dissected by the Jordan Valley step fault escarpment.

Surface and subsurface water of the eastern basin drain towards the Jordan Valley. Surface water comprises the flood flows during winter season, and the base flow of springs, which mainly originate in the western mountainous area. This flow passes during its travel path to the Jordan River and the Dead Sea over the Jordan Valley deposits, where some of these flows percolate to Jordan Valley aquifers (Wishahi, 1999).

Wadi Al Qilt is located in the eastern part of the West Bank. The study area includes part of Ramallah, Al Bireh and Jerusalem (comprises the western part of the study area) and part of Jericho (comprises the eastern part). It represents the major drainage system from the mountain aquifer area between Jerusalem and Ramallah

downwards east to the Jordan River with an area of 174.7 square km. The system includes the major springs, these are

- Ein Fara: a seasonal spring which emerges upstream at an elevation of 325 m.a.s.l. through the floor of the wadi.
- Ein Al Fawwar: a seasonal spring which emerges 4 km downstream of Ein Fara at an elevation of 75 m.a.s.l.
- Ein Al Qilt: emerges 4.5 km downstream of Ein Al Fawwar at an elevation of 10 m.a.s.l. Its flow has little variation from winter to summer.
- Ein Es-Sultan: located to the east of Wadi Al Qilt in the Jericho city.

It is related to the Upper Cenomanian-Turonian aquifer.

Wadi Al Qilt drainage basin is bounded by Nueima drainage basin from north, Soreq and Al Dilb drainage basins from west, Mukallak and Marar drainage basins from south and Jordan River from the west. This catchment, that drains part of the Ramallah and Jerusalem Mountains, is a sub-basin of the Jordan River-Dead Sea basin.

The drainage basin of Wadi Al Qilt is located in the well-known Dead Sea Rift Valley which has elevations in the range of 200 to 250 m.b.s.l. in the east and the west of the area, in the vicinity of Ramallah and Jerusalem the mountains rise up to elevations over 800 m.a.s.l.

## **2.1.2 Population**

Several Palestinian communities and Israeli settlements who may affect the environment and quality of water in the drainage basin are distributed in the drainage basin of Wadi Al Qilt. According to PCBS (2005), the Palestinian population was estimated to be about 96,935 inhabitant; 38,192 in Al Bireh City, 10,103 in Kafr O'qb, 8,796 in Qalandia Camp, 2,238 in Borqa, 3,143 in Jaba', 1,823 in Mikhmas, 24,838 in Al-Ram, 5,916 in Hizma, 9,337 in Anata and 1,345 in Beit Hanina where as the population of Shu'fat and Shu'fat Camp was not estimated because they are considered as part of Jerusalem. On the other hand, not all the population of the Israeli settlements in the catchment area is known. However, the number of Israeli settlers in six settlements was estimated to be about 29,250 settlers distributed in the following settlements, 1,333 in Psagot, 3,922 in Kokhav Ya'kov, 998 in Ma'ale Mikhmas, 740 in Almon, 1,988 in Giv'a Binyamin (Adam) and 20,269 in Neveh Ya'kov, whereas the population of Bisgat Ze'ev, Allon and Pisgat Omer still unknown (PCBS, 2003). Figure 2.1 shows the distribution and names of the various build up areas in the drainage basin.

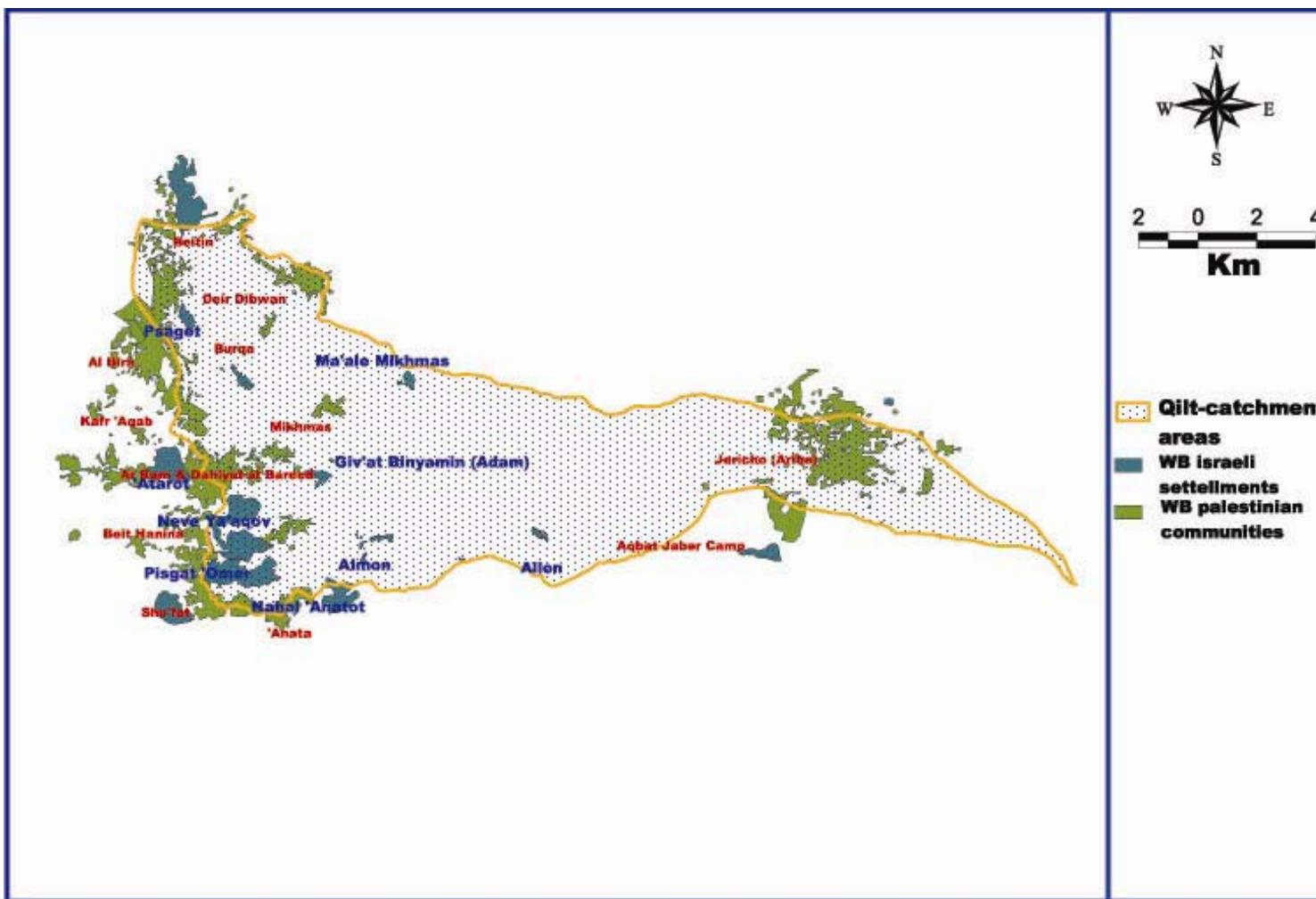


Figure 2.1: Palestinian communities and Israeli settlements in Al Qilt drainage basin

### **2.1.3 Climate**

The West Bank has a typical Mediterranean climate with two distinct seasons: dry hot season from June to October, and cold wet season from November to May. Despite the small area of West Bank, there is a variation in the climate in Al Qilt drainage basin. In the western part of the area, the climate is influenced by the Mediterranean climate, a rainy winter and dry summer. While the climate in the eastern part is classified as arid with hot summers and warm winters.

#### **2.1.3.1 Rainfall**

Along the West Bank there are considerable variations in the quantity of the annual rainfall from year to year and from part to another. Moist air masses from the Mediterranean bring most of the rain that falls on the western part of Al Qilt drainage basin (Ramallah and Jerusalem mountains). The rainfall decreases rapidly from the Judean Mountains (Jerusalem 700 mm/a) down east to the Jordan Valley (Jericho 150 mm/a). The average precipitation in the area of the Dead Sea is around 90 mm/a (Ali, 1999). The average annual rainfall over the main recharge area of about 80 km<sup>2</sup> of the Upper Bethlehem and the Jerusalem formations is 500 mm (Abed Rabbo, et al, 1999).

### **2.1.3.2 Temperature**

The average summer temperature, in the West Bank varies between 20 and 23 °C, reaching a maximum of 43 °C. The average winter temperature is 10 to 11 °C with a minimum of 3 °C. These variations are expected because of the differences in position, elevation, and distance from the coast and the environment around the stations (Ghanem 1999). The temperature increases from north to south and from west to east on contrary to the altitude. January is the coldest month and August is the warmest.

In the western part of Wadi Al Qilt area, the average temperature ranges between 6-12 °C in the coldest month (January), while it ranges between 7-19 °C in the eastern part. On the other hand, it may reach 22-27 °C during August in the western part and 22-38 in the eastern part (ARIJ, 1996).

### **2.1.3.3 Relative humidity**

In the West Bank, temperature, elevation as well as the distance from the coast are the main factors controlling the atmospheric moisture content e.g. expressed as relative humidity (RH %). The driest locations are in the Jordan Valley, while a more temperate climate can be experienced at the highest summits of the mountain ridge. The Relative humidity in the West Bank varies from north to south. The mean annual

relative humidity varies between 50% in the eastern part of Wadi Al Qilt to 70.1% in the western part.

#### **2.1.3.4 Evaporation**

Due to the high temperature and low relative humidity of the air during the summer time, results in high evaporation rate and reaches 298.5 mm. The evaporation rate decreases in winter time due to the increase in humidity and reaches 59 mm.

#### **2.1.4 Hydrogeology of Wadi Al Qilt**

The catchment area of Al Qilt drainage basin is about  $174.7 \text{ km}^2$  with average annual rainfall over the main recharge area of about  $80 \text{ km}^2$  is 500 mm. Nari reduces the effective recharge to about  $42.5 \text{ km}^2$  (Rofe & Raffety, 1963), which represents about  $21.5 \times 10^6 \text{ m}^3$  potentially entering the groundwater system. Of this average annual discharge from Ein Fara, Ein Al Fawwar, Ein Al Qilt and Ein es Sultan is about  $9 \times 10^6 \text{ m}^3$ . The springs of Ein Fara, Ein Al Fawwar and Ein Al Qilt emerge from Turonian. The aquifer is of Cenomanian-Turonian age, the strata dipping eastwards at  $10^\circ - 15^\circ$  (Figure2.2).

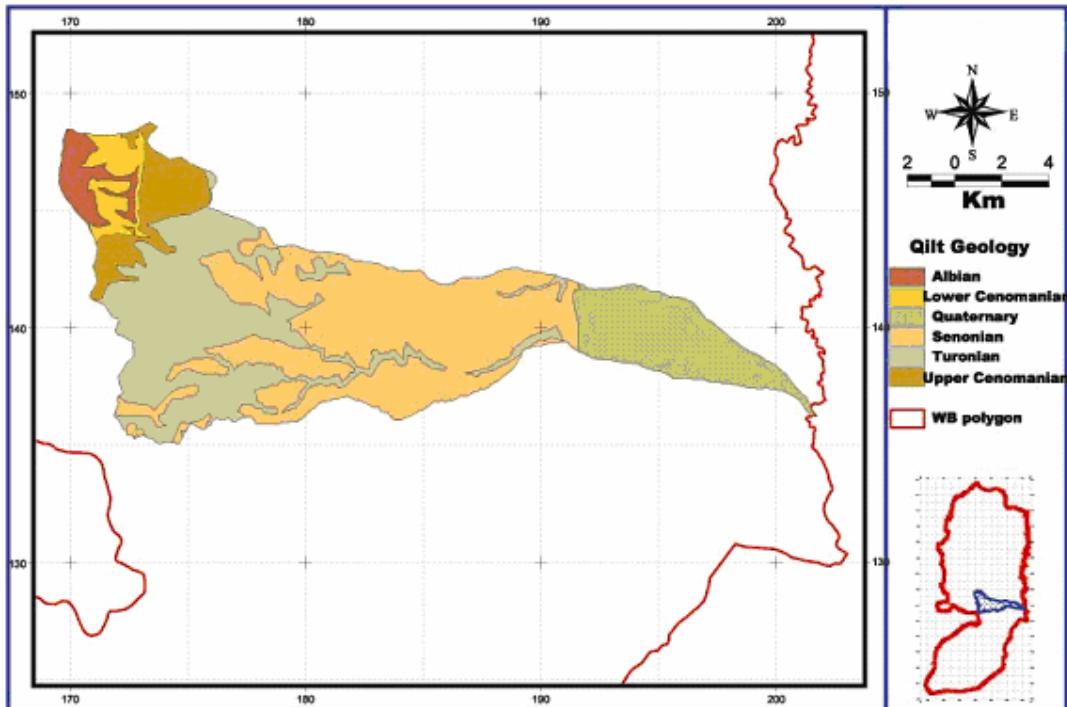


Figure 2.2: Geological map of Wadi Al Qilt (Source: PWA, 2005)

Groundwater flow follows the direction of dip, but the water table is at shallower angle, breaking the surface where the springs emerge. The Cenomanian consists mainly of micritic dolomite which is very hard and virtually nonporous, the void space in the rock occupying only 2.6%. This gives the dolomite an intrinsic permeability of 0.13 millidarcys, i.e., a flow rate of 39.66 mm/yr. However, solution weathering increases the secondary porosity and, consequently actual flow increases as joints and bedding planes are widened. The Turonian is a highly fossiliferous limestone, with fossil fragments making up 30% of the volume of the rock. The matrix is recrystallized calcite. Primary porosity, therefore, is greater than in the Cenomanian, being 8-15% of the rock. The intrinsic permeability is also greater than

in the Cenomanian, being 135 millidarcys. Groundwater flow in the Turonian is up to 1.5 km/yr, indicating the effect of karstic solution weathering in the system (Abed Rabbo, 1999).

There is little variation in the discharge of Ein Al Qilt through out the year. It may therefore be assumed that the water is under pressure and comes from a massive reservoir. The average flow of Ein Fara is 15 L/sec or 1500 m<sup>3</sup>/day. The combined average discharge rate of Ein Al Fawwar and Ein Al Qilt springs are 100 L/sec. Ein Al Fawwar has a large discharge following a heavy rainfall season (Blake and Goldschmidt, 1947). The siphonic spring at Ein Al Fawwar filled the cistern which fed the channel bringing water to Al Qilt and the overflow discharges into the wadi to combine with the flow coming from Wadi Fara and Wadi Sweanit. The pulses from the spring are at 20-minute cycles and used to raise the level of the cistern by as much as 2 m. The karstic nature of the spring is responsible for these pulses. A v-shape cavern is filled before siphonic discharge expels the water in these regular pulses (Abed Rabbo, 1999).

The water table under the Jerusalem Hills is at an elevation of about 450 m.a.s.l. The water table passes from the Cenomanian under the Jerusalem Hills into the Turonian as a result of the Fara monocline (Figure 2.3) (Abed Rabbo, 1999).

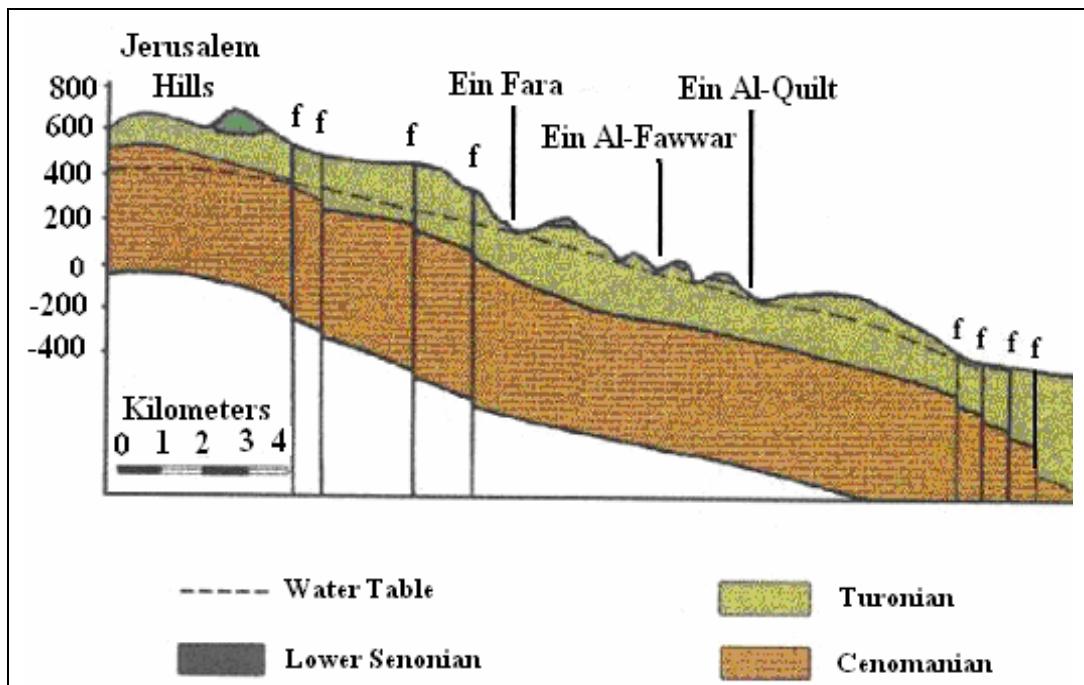


Figure 2.3: Geological sketch section along the line of springs in Al Qilt system  
(source: Abed Rabbo *et al*, 1999)

### 2.1.5 Sources of pollution

Contamination of groundwater may occur by one of the three mechanisms; infiltration recharge from surface water, direct migration and inter-aquifer exchange.

Shallow aquifers may be affected by the first and second mechanisms, while the third mechanism may affect both shallow and deep aquifers. Dissolution of solid waste combined with rainfall produce large quantity of polluted water in the form of leachate. Because of heterogeneous nature of wastes and variations in aquifer properties, dump sites represent a challenging opportunity to try and understand the transport and fate of waste-derived contaminants (Abu-Rukah & Al-Kofahi, 2001).

From environmental point of view, according to field visits of Al Qilt drainage basin, both Israeli settlements (colonies) and Palestinian communities found in the basin may affect both the environment and water resources. Mahmoud and Al-Sa'ed (1997) reported that almost 40% of the total Jewish settlements in the West Bank are considered as highly risk potential pollution sources. According to PCBS (2005), most of the settlements in Al Qilt drainage basin are civic and cooperative. Detailed information about these settlements, types, areas and other are tabulated Appendix 1.

In general, the possible sources of pollution from both, Israeli settlements and Palestinian communities in Al Qilt catchment area can be classified as follows:

- Untreated municipal wastewater, leaching from poorly maintained and functioning latrines and cesspools, and washing of fecal matter and other wastes from the surface of the ground into water bodies.
- Seepage from unsanitary dump sites where the majority of the region's solid waste is dumped.
- Untreated industrial waste discharging into municipal sewer system or directly into valleys.
- Seepage and runoff of agrochemicals such as fertilizers and nonbiodegradable pesticides.
- Stone crushing.

### **2.1.5.1 Untreated wastewater**

Wastewater is characterized in terms of its physical, chemical, and biological composition. Raw wastewater originates from domestic and industrial sources. The characteristics of wastewater are impacted by water consumption rates, population density, industrial practices, and habits of the population. The discharge of raw wastewater causes a major potential health hazard as it carries disease in the form of pathogens and toxic chemicals. Disposed raw wastewater mixes with seasonal surface water, and part of it percolates into the ground and finally may affect groundwater quality.

According to Metcalf and Eddy (1991), the important contaminants of concern in wastewater are:

- **Suspended solids**

Suspended solids (SS) can lead to the development of sludge deposits and anaerobic conditions when untreated wastewater is discharged in the aquatic environment.

- **Biodegradable organics**

These organics are composed principally of proteins, carbohydrates and fats. Biodegradable organics are measured most commonly in terms of  $BOD_5$  (biochemical oxygen demand) and COD (chemical oxygen demand). If

untreated wastewater is discharged to the environment, the biological stabilization of the biodegradable organics can lead to the depletion of natural oxygen resources and development of septic conditions.

• **Pathogens**

Communicable diseases can be transmitted by the pathogenic organism in wastewater.

• **Nutrients**

Both nitrogen and phosphorous, along with carbon, are essential nutrients for growth. When discharged to the aquatic environment, these nutrients can lead to the growth of undesirable aquatic life. When discharged with excessive amounts on land, they can also lead to the pollution of groundwater.

• **Priority pollutants**

Organic and inorganic compounds selected on the basis of their known or suspected carcinogenicity, mutagenicity, teratogenicity, or high acute toxicity. Many of these compounds are found in wastewater.

• **Refractory organic**

These organics tend to resist conventional methods of wastewater treatment. Typical examples include surfactants, phenols, and agricultural pesticides.

- **Heavy metals**

Heavy metals usually added to wastewater from commercial and industrial activities may have to be removed if the wastewater is to be reused.

- **Dissolved inorganic**

Inorganic constituents such as calcium, sodium, and sulfate are added to the original domestic water supply as a result of water use and may have to be removed if the wastewater is to be reused.

#### **2.1.5.2 Seepage from unsanitary dump sites**

Waste generation is an inescapable by product of human activities. Waste disposal, either solid or liquid, represents a considerable threat to the environment and the most important problem is the dispersal of disposed hazardous substances to groundwater. Groundwater contamination was observed around landfills and dumpsites and several contaminants including heavy metals and organic micropollutants (Assmuth & Strandberg, 1992).

Most adverse environmental impacts from solid waste are rooted in inadequate or incomplete collection and recovery of recyclable or reusable wastes, as well as co-disposal of hazardous wastes. Also these impacts are due to inappropriate siting, design, operation or maintenance of dump sites. Toxic materials and pathogenic organisms may end in ground or surface water as a result of the movement of

leachate from dumps and landfills (leachate is the liquid that discharges from dumps and landfills, which is composed of rotted organic waste, liquid wastes, infiltrated rain water and extracts of soluble materials).

Solid waste is likely to contain human pathogens, from soiled disposal baby napkins (diapers), disposable paper handkerchiefs, contaminated food and waste from pets, and its handling and disposal can present the same potential for disease transmission as the collection and disposal of excreta and sewage. In addition, inadequate storage and collection and poor disposal practices in solid waste management serve as breeding sites for rats, flies, mosquito and other vermin which can act as passive vectors in transmitting disease (Mahmoud and Al-Sa'ed, 1997).

#### **2.1.5.3 Untreated industrial waste**

In general, industrial activities are considered as potential pollution sources, due to generation of effluents or leachate which have adverse environmental effects. Such effluents differ in their quality, but they can affect the level of  $BOD_5$ , suspended solids, pH or heavy metals content and other parameters of the receiving water body.

#### **2.1.5.4 Seepage and runoff of agrochemicals**

Several studies have provided evidence that pesticides can be transferred rapidly at high concentrations beyond the root zone (Papadopoulou-Mourkidou *et al*, 2004). Since the maximum concentration permitted in drinking water, for a single pesticide,

is relatively low (0.0004-0.1 mg/L) leaching of pesticides from agricultural soils may threaten the quality of drinking groundwater resources (PSI, 2004).

The main parameters affecting losses of pesticides through leaching are related to: (i) soil properties, (ii) physicochemical characteristics of pesticides, (iii) climatic conditions, and (iv) agricultural practices (Papadopoulou-Mourkidou *et al*, 2004).

### **2.1.5.5 Stone crushing**

Stone crushing (at Mikhmas Bridge) results in severe environmental and health adverse impacts. The evolved dust cause heavily air pollution leading to chemical and physical pollution of water recharging the aquifers.

## **2.2 Previous studies**

The environment, geology, hydrogeology, and hydrochemistry of Wadi Al Qilt drainage basin was described previously by other researchers and NGO's but their focus was mainly on larger regional scale. There is a lack of information about physical, chemical and biological characteristics of Wadi Al Qilt.

- Blake and Goldschmidt (1947) investigated the geology and water resources of Palestine, and discussed the small variation in the flow of Ein Al Qilt and Ein Al Fawwar due to the variation of rainfall.

- Rofe and Raffety (1963) studied the hydrochemistry of springs in the West Bank during 1961 and 1962 including springs in Wadi Al Qilt drainage basin and reported some values about major cations, anions, pH, TDS and conductivity for the five springs in the drainage basin.
- Nuseibeh & Nasser Eddin (1995) collected hydrochemical and flow data through the period 1970-1994 for about 113 springs in the West Bank, including Ein Al Qilt and Ein Al Fawwar springs in the drainage basin.
- Applied Research Institute/Jerusalem (ARIJ) (1996) presented in the environmental profile for the West Bank the status of the environment and some information about geology, hydrology and water quality analysis including Ramallah and Jericho districts which surround Al Qilt drainage basin.
- Mahmoud and Al-Sa'ed (1997) studied the environmental impacts of the Jewish colonies in the West Bank. The study presented that even most Jewish colonies are supplied with sewage networks but they lack central wastewater treatment plants and solid waste dumping sites.
- Abed Rabbo *et al.* (1999) presented the results of water quality and chemistry of springs throughout the West Bank during the period from September 1995 to March 1998. The study aimed to determine the genesis of

various water types through interpretation of the chemical data including some springs in Wadi Al Qilt drainage basin.

- Ali *et al.* (1999) presented some hydrogeological results achieved in Wadi Al Qilt between Jerusalem and Jericho. The study aimed to develop additional usable water resources to help in solving future hydrogeological problems and as a result this study stated that from west to east the salinity increases, while the hydraulic head decreases.
- Wishahi and Khalid (1999) gave an idea about the chemistry and quality of the Jordan Valley aquifers through collecting and analyzing (for all main ions) 58 groundwater wells for penetrating the Jordan Valley aquifers. The study presented that the main chemical parameters showed high levels of concentration, where the Jericho wells showed the higher concentrations of the dissolved solids.
- PWA (2000) presented a summary of Palestinian hydrologic data for West Bank and Gaza aimed to provide excellent information for water-resources management, development, protection, and allocation. It provides flow-volume and water-quality time-series data about almost all springs in the West Bank including the springs in Al Qilt drainage basin.
- Marei *et al* (2005) studied the salinity sources of groundwater in Plio-Plistocene aquifer system in Jericho area, and stated that the salinity increases

eastwards and Na/Cl ratio decrease and reach the minimum in Ein Huglah 0.43. The study showed that Wadi Al Qilt is the main recharge sources for this aquifer system and recharge takes place in the western part of the drainage basin.

### **2.3 Importance of Wadi Al Qilt**

Water is the most precious natural resource in the West Bank and Gaza Strip. Adequate supplies of high quality water are essential for economic growth, quality of life, environmental sustainability. Protection and allocation of water resources is based on sound data regarding the location, quantity, quality, and use of water and how these characteristics are changing over time. The quantity and quality of available water varies over space and time, and is influenced by natural and man-made factors including climate, hydrogeology, management practices and pollution.

Wadi Al Qilt represents the major drainage system from the mountains area between Jerusalem and Ramallah downwards east to the Jordan Valley. Part of the discharge of Wadi Al Qilt (after the combination of discharge of all springs: Ein Fara, Ein Jumeiz, Ein Ru'yan, Ein Al Fawwar and Ein Al Qilt) is used to feed JWTP. The effluent of AWWTP ends up in Wadi Sweanit which combines with Wadi Fara and after around 1 km with Ein Al Fawwar spring discharge to form Wadi Al Qilt. These combinations in Wadi Al Qilt gave it the importance to be studied.

## **CHAPTER 3: MATERIALS AND METHODS**

The literature review aimed mainly to collect the available scientific papers, maps and documents, as well as unpublished academic environmental studies on the geology and water quality and other environmental studies of Wadi Al Qilt drainage basin and its surrounding area. Contamination, potential pollution sources and water quality issues were the most important ones in this study.

### ***3.1 Personal communications and interviews***

Interviews and personal communications with members from the Palestinian Water Authority (PWA), some people who live near Ein Al Qilt spring and with a person from the Environmental Department at Beit-Eil civil Adm-DCO were conducted between December 2004 and May 2005. The aim of the interviews was to update the data that has been collected throughout the literature review, to identify additional problems with the water resources that are not mentioned in the literature, as well as to collect data about the situation of the whole system beginning from Al Bireh and Anata at the west of drainage area to reach Aqbat-Jabr in the east. Data about the wastewater and solid waste disposal methods was also collected. Interviews with the local inhabitants and farmers were also conducted to evaluate the effect of the uncontrolled wastewater disposal on water resources and health as well as to collect the data about the springs in the drainage basin.

### **3.2 Field work**

Field work and field surveys were basic modules in every aspect of this study, especially to confirm the data collected during the interviews, to identify the existing water resources, assigning sampling stations, water sampling, and measurement of water flow rate. Also, observations about water quality (color or odor) through the whole system were recorded.

Going field visits to the study area were not easy mainly in the presence the Jewish check points along the roads leading to Wadi Al Qilt. After several field visits to the study area from November 2004 to March 2005, it was possible to choose the sites of the sampling stations to be representative of the whole system. Due to the difference in water quality of the two wadis, there was a need to study the variation of water quality from the beginning of the flow (near AWWTP effluent) to the end of the open transportation canal feeding JWTP. In addition to the inlet of JWTP sampling station, twelve sampling stations were assigned along the two wadis (Figure 3.1).

Due to the continuous flow of water through wadis from AWWTP to JWTP, sampling stations were assigned through Wadi Al Qilt, starting from AWWTP effluent (as it forms the starting flow in the drainage area), going through Wadi Al Fawwar, then the open transportation canal which feeds JWTP, ending with the influent to the treatment plant.

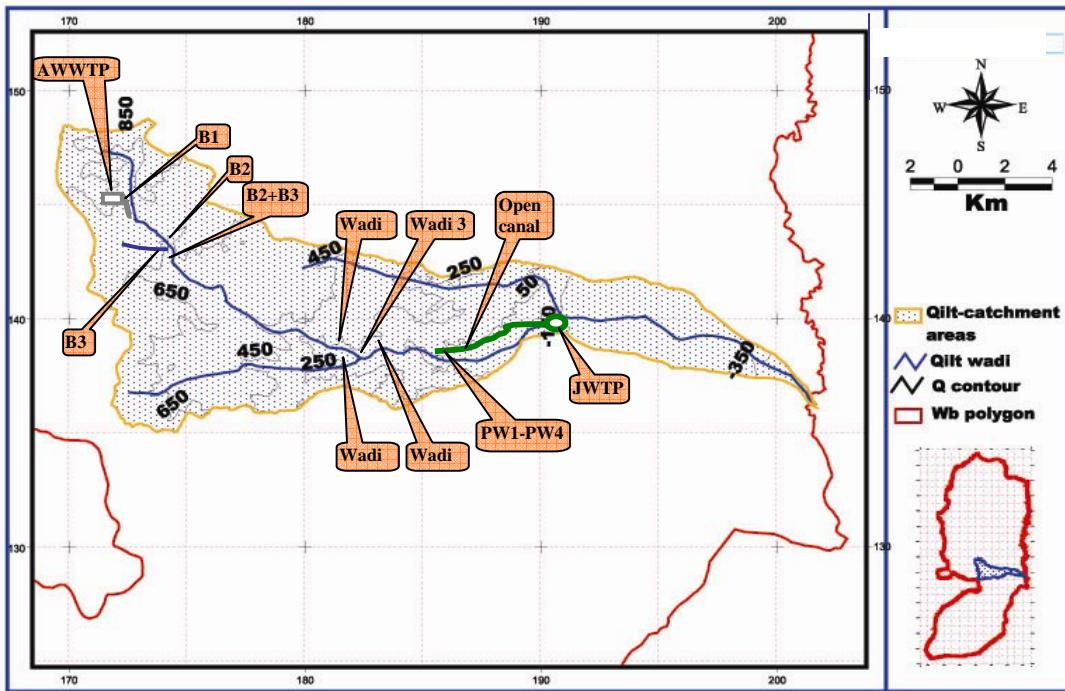


Figure 3.1: Sampling stations along the two wadis

In addition to the sampling stations in the two wadis Ein Al Qilt, Ein Al Fawwar, Ein Fara, Ein Jumeiz and Ein Ru'yan were assigned but the last three were sampled once due to the political situation (Figure 3.2).

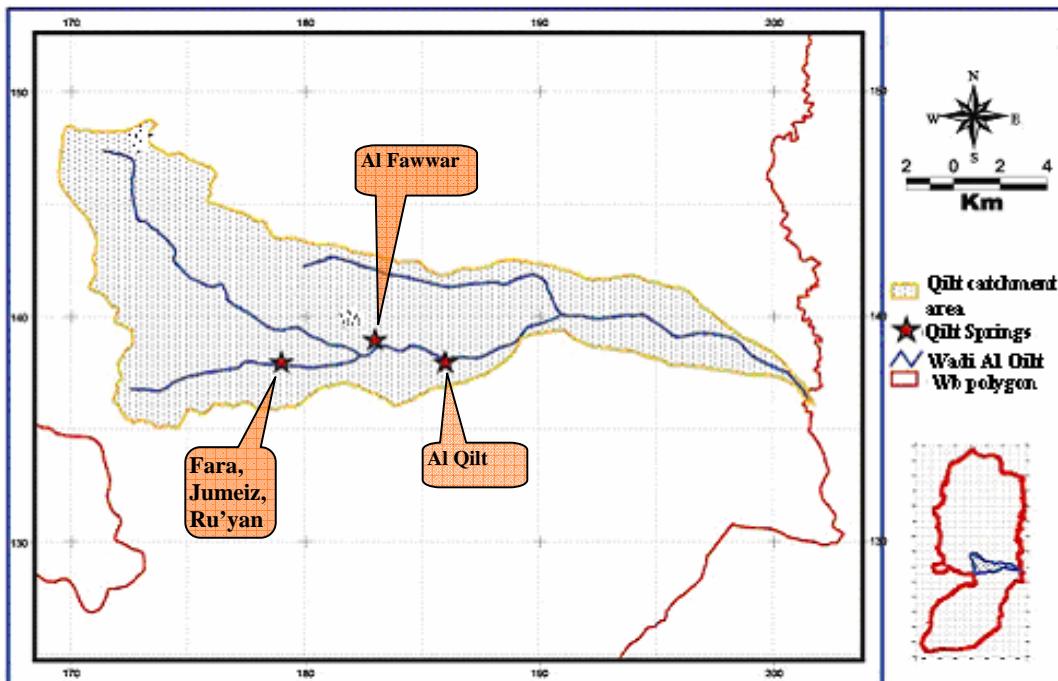


Figure 3.2: Location of springs in Wadi Al Qilt

It was better if the starting time of this study was on September 2004 instead of late December 2004, especially time was very critical in my field visits to assign the sampling stations along the wadis. Better results may be obtained if the sampling stations were assigned along the system on December 2004, and monthly samples were obtained. During the study period, it was possible to take permission from the Israeli department at Beit Eil for only two field visits, and all other visits were on our responsibilities, and sometime we were prevented to enter the study area or to take samples from the sampling stations

Eighteen sampling stations were the target of the sampling campaigns, at different times during the study period. Detailed description of the eighteen sampling stations is presented in Table 3.1. Sampling frequency was variable according to weather status and prevailing political situation in the study area as well as in the West Bank and Gaza Strip.

Fifty six water samples from the wadis and ten samples from springs were collected and analyzed for different parameters at different dates during the study period. Also, when possible the flow was measured at certain sampling stations.

Table 3.1: Sampling stations along Wadi Al Qilt

Sampling station I.D.	Sampling station name	Location
B1	AWWTP effluent	Al Bireh
B2	AWWTP effluent at Mikhmas bridge	Mikhmas Bridge
B3	Stone crushing effluent	Mikhmas Bridge
B2 + B3	Joint point 1	Mikhmas Bridge
Wadi 1	Wadi Sweanit	Al Qilt
Wadi 2	Wadi Fara	Al Qilt
Wadi 3	Joint point 2 (Wadi Sweanit + Wadi Fara)	Al Qilt
Wadi 4	Joint point 3 (Wadi Sweanit + Wadi Fara + Ein Al Fawwar)	Al Qilt
AS/020	Ein Al Qilt	Al Qilt
AS/021	Ein Al Fawwar	Al Qilt
AS/022	Ein Fara	Jerusalem-Alon
AS/022A	Ein Jumeiz	Jerusalem-Alon
AS/022B	Ein Ru'yan	Jerusalem-Alon
PW1	Point before split to cement Qilt canal	Al Qilt
PW2	Cement Qilt canal-500 m ahead	Al Qilt
PW3	Cement Qilt canal-1000 m ahead	Al Qilt
PW4	Cement Qilt canal-1500 m ahead	Al Qilt
TP1	JWTP inlet	Jericho

### **3.3 Water sampling**

The sampling campaigns from all sampling stations shown in Table 3.1, were carried out to cover the study period at different frequencies, starting from November (2004) to July (2005). Due to the political situation in Palestine as a whole and in the study area as special case and the presence of several Israeli check points along the study area, sampling was not easily made from the assigned sampling stations. Sampling from certain stations such as Ein Fara, Ein Jumeiz and Ein Al-Ru'yan springs were not possible and they were sampled only once.

### **3.4 Water analysis**

The purpose of water analysis was to determine the level of pollution of water flowing in Wadi Al Qilt. The way to accomplish this purpose was through measuring the water quality parameters, chemical parameters (major cations, major anions,  $BOD_5$ , COD, DOC, anionic surfactants, ammonium, pH, trace elements), physical parameters (turbidity, TDS, EC), microbiological parameter (fecal or total coliform) and hydrobiological parameter (chlorophyll *a*).

### **3.4.1 Chemical parameters**

#### **3.4.1.1 Measurement of major ions, ammonium, pH, TDS**

Water samples from Wadi Al Qilt were analyzed for major cations calcium ( $\text{Ca}^{+2}$ ), magnesium ( $\text{Mg}^{+2}$ ), sodium ( $\text{Na}^{+}$ ) and potassium ( $\text{K}^{+}$ ). Calcium and magnesium are abundant in rocks and soil, particularly limestones and dolomites. They are relatively soluble. Currently, there are no health concerns associated with these ions, however, concentrations of calcium plus magnesium greater than 100 mg/L (parts per million) are classified as hard. While sodium concentrations are related directly to salinity problems as a very important factor for irrigation water. Higher concentrations of potassium are considered as toxic; mainly the highest recommended value by the Palestinian Standard Institution (PSI) for drinking water is 10 mg/L (PSI, 2004).

Sodium, potassium and calcium were measured at chemistry department; using flame photometer (Sherwood 410), at wavelengths 589.5, 766.5, and 320 nm, respectively. While the three ions and Magnesium were measured for certain samples using Perkin-Elmer Optima 3000 ICP-OES. When the flame photometer was used, samples were diluted because the highest detected concentration using this method is approximately 10.0 mg/ L.

The major anions that were measured for some of the collected samples were bicarbonate ( $\text{HCO}_3^{-}$ ), sulfate ( $\text{SO}_4^{-2}$ ), chloride ( $\text{Cl}^{-}$ ) and nitrate ( $\text{NO}_3^{-}$ ).

Bicarbonate was measured through the titration of the samples versus a standardized acid (HCl) using either automatic titrator to pH 4.8 or manual titration with bromocresol green indicator.

Sulfate was measured by turbidimetric method, in which sulfate ions are precipitated by barium ions and from the absorbance of the suspension, sulfate concentration was determined.

Chloride was measured by Mohr method, in which the water sample is titrated with standard silver nitrate using potassium chromate as indicator.

Nitrate was measured using spectrophotometric screening method (using UV 300/UV-Visible spectrophotometer/ UNICAM,  $\lambda=220$  nm). Concentration was easily determined after plotting calibration curve of several nitrate standards.

Chloride and nitrate parameters are the most important ones, because they are used as indicators of pollution due to the lower concentrations in natural and not contaminated waters and their mobility and stability.

The ammonium concentration was determined for two sets of samples collected during April and May 2005, using ion selective method. Concentrations were easily determined after construction a calibration curve.

The pH of all samples was measured at PWA lab after collecting the samples.

For certain set of samples, total dissolved solids (TDS), total suspended solids (TSS) and total solids (TS) were measured.

#### **3.4.1.2 Trace elements**

All the following heavy metals Ag, Al, Ba, Cd, Co, Cr, Cu, Fe, Li, Hg, Mn, Ni, Pb, Sr, Zn, Be, Se and Mo, were measured using inductive coupled plasma (Perkin-Elmer Optima 3000 ICP-OES) at Birzeit university lab. Samples were acidified and preserved at 4 °C after collection until the analysis.

#### **3.4.1.3 Measurement of organic content**

Laboratory methods commonly used to measure gross amounts of organic matter (greater than 1 mg/L) include biochemical oxygen demand ( $BOD_5$ ), chemical oxygen demand (COD) and dissolved organic carbon (DOC).  $BOD_5$  and COD were determined for three sample groups collected on three different dates for most of sampling points in the system. Two sets of these samples representing the whole system collected in two different months, were analyzed for DOC/NPOC and measuring their ultraviolet absorbance (UV) at a wavelength of 254 nm. In most water samples, the inorganic carbon (IC) fraction is many times greater than the DOC fraction. So eliminating the IC fraction must be done before the DOC analysis and this can be eliminated by acidifying the samples to pH or less to convert IC species to  $CO_2$ . These parameters were measured to determine the level of

contamination due to the presence of several sources of contamination in the area of Wadi Al Qilt.

BOD<sub>5</sub> and COD were conducted at Water Studies Institute lab/Birzeit University, whereas DOC/NPOC were conducted at Environmental lab/Al-Quds University.

Anionic surfactants were measured through the whole system to estimate the level of pollution from household and industrial activities.

### **3.4.2 Physical parameters**

Measurement of the Electric Conductivity (EC) of all samples was measured at PWA lab after collecting the samples.

Turbidity which is a measure of light-transmitting properties of water is another test used to indicate the quality of waste discharges and natural waters with respect to colloidal and residual suspended matter (Metcalf and Eddy, 1991). Turbidity was measured on site directly using field turbidity meter.

### **3.4.3 Biological parameters**

Samples at the source from the springs, Wadi Al Qilt and JWTP inlet were taken and analyzed for microbial pollution, total coliform (TC) and fecal coliform (FC), to determine the potential pollution sources as cesspits, wastewater infiltration and the

uncontrolled disposal of waste. Microbial tests were carried out at the Palestinian Water Authority (PWA) lab using membrane filtration method.

#### **3.4.4 Hydrobiological parameter**

Chlorophyll *a* concentration measurement is an indirect method for the estimation of biomass and photosynthesis rate of the primary producer (algae). Chlorophyll *a* was measured for certain samples taken from the end of the open transportation canal feeding JWTP, to estimate the effect of algae growth through the open canal on sand filters. Chlorophyll *a* was determined in the presence of pheophytin *a*, so acidification step was needed to convert chlorophyll *a* to pheophytin *a* by loss of magnesium upon acidification. Chlorophyll *a* was determined by measuring the absorbance before and after acidification.

#### **3.5 Flow measurement**

The flow was measured at certain points of the system and certain time when it was possible due to security situation and presence of check points in the area, especially the flow measurements need some time to be taken. The flow measurements were carried out by the monitoring team of PWA using current meter method.

A standard methods for the examination of water and wastewater (19 ed.) was used as a reference for all methods of analysis of all measured parameters.

Finally, a software package called Aquachem was used as a tool for the interpretation of the obtained chemical data for springs. Also, the maps for the study area were prepared using software called Geographical Information System (GIS). Interpretation of data was done using excel.

A summary of the analysis is shown in Table 3.2. However, all analytical parameters cited were carried out in different laboratories; some of these were made at Birzeit University Labs, some at PWA lab and others at Al-Quds University labs.

Table 3.2: Measured parameters, methods of analysis, and used instruments for all analysis conducted for sampling points along Wadi Al Qilt catchment

Parameters measured	Instruments used for analysis	Methods of analysis	Location f analysis	Reference
Turbidity	Turbidimeter 2100 P-Hach Turbidimeter 6053-Jenway	APHA 2130	Lab Sampling stations (onsite)	Direct measurement as manufacturer procedure
pH, Conductivity	pH-meter 3320, Jenway Conductivity meter, 4320, Jenway	2520-B	PWA lab	Direct measurement as manufacturer procedure APHA 1995, 19 <sup>th</sup> ed.
Total Coliforms and Fecal Coliforms		9222-B 9221-E	PWA lab	APHA 1995, 19 <sup>th</sup> ed.
Majors cations (Ca <sup>+2</sup> ; Mg <sup>+2</sup> , Na <sup>+</sup> , K <sup>+</sup> )	Flame photometer (Sherwood 410) and Perkin-Elmer Optima 3000 ICP-OES,	3500 3120-B	BZU labs	APHA 1995, 19 <sup>th</sup> ed.
Major anions, HCO <sub>3</sub> <sup>-</sup> SO <sub>4</sub> <sup>-2</sup> Cl <sup>-</sup> NO <sub>3</sub> <sup>-</sup>	Autotitrator Aut-501 TOA, Titration with HCl, UV 300/ UV-Visible spectrophotometer/ UNICAM ( $\lambda=420$ nm) Titration with AgNO <sub>3</sub> using K <sub>2</sub> CrO <sub>4</sub> indicator UV 300/ UV-Visible spectrophotometer/ UNICAM ( $\lambda=220$ nm)	3320 B 4500- SO <sub>4</sub> <sup>-2</sup> 4500- Cl <sup>-</sup> 4500- NO <sub>3</sub> <sup>-</sup>	PWA labs	APHA 1995, 19 <sup>th</sup> ed

Table 3.2 (continued)

Organic material COD BOD <sub>5</sub>	Hach COD reactor DO meter – Oxi 197	5210-B 5220-D	BZU lab	APHA 1995, 19 <sup>th</sup> ed
TS, TDS, TSS	Evaporation (103-105 °C) Filtration and evaporation (180 °C) Filtration and drying (180 °C)	2540-B, 2540-C, 2540-D	PWA lab	APHA 1995, 19 <sup>th</sup> ed
NH <sub>4</sub> <sup>+</sup>	Ion meter-3340/ Jenway	4500-NH <sub>3</sub>	PWA lab	APHA 1995, 19 <sup>th</sup> ed
Surfactant	UV 300/ UV-Visible spectrophotometer/ UNICAM ( $\lambda=652$ nm)	5540-C	PWA (done for certain set of samples)	APHA 1995, 19 <sup>th</sup> ed
DOC /(NPOC)	Multi N/C 2000	5310	Al-Quds University lab	APHA 1995, 19 <sup>th</sup> ed
UV absorbance	HP/ UV-Vis spectrometer ( $\lambda=254$ nm)	5910-B	BZU lab	APHA 1995, 19 <sup>th</sup> ed
Heavy metals *	Perkin-Elmer Optima 3000 ICP-OES	3120B	BZU lab	APHA 1995, 19 <sup>th</sup> ed
Chlorophyll	Hp UV-Visible spectrophotometer	10200H	BZU lab	APHA 1995, 19 <sup>th</sup> ed
Flow	Current meter	-	Monitoring team- PWA	-

\*Heavy Metals: Ag, Al, Ba, Cd, Co, Cr, Cu, Fe, Li, Hg, Mn, Ni, Pb, Sr, Zn, Be, Se, Mo

### **3.6 Validation and quality control**

Certain measures were conducted for quality control of the measured values as follows:

- Standard calibration curves for most analyzed parameters were constructed using the appropriate concentrations that cover the range of samples concentration.
- Blank samples were used with the suitable solvent to reduce matrix effects on the analyzed parameters.
- At least one matrix spike and/or one matrix spike duplication sample was introduced in each batch analyzed for heavy metals and DOC and other parameters when the number of samples was more than ten.
- Some major parameters (such as nitrate and chloride) were analyzed at chemistry labs as double check for that done at PWA.
- Sodium, potassium and calcium concentrations for samples analyzed using ICP-OES were compared with that analyzed using flame photometer.
- Some samples were analyzed for certain trace elements using graphite furnace atomic absorption and the obtained data were compared with that obtained from ICP-OES.

The detection limits, max allowable concentration and regulator for different parameters measured at different labs are listed in Table 3.3.

Table 3.3: Detection limits of analyzed parameters

Parameter	Limit of detection	Max allowable concentration for drinking water	Regulator
Turbidity	1 NTU	5	WHO
COD	10 mg/l	NA	NA
BOD	10 mg/l	NA	NA
$\text{HCO}_3^-$	1 mg/l	NA	NA
$\text{Ca}^{2+}$	1 mg/l	100 mg/l	PSI
$\text{Mg}^{2+}$	1 mg/l	100 mg/l	PSI
$\text{Na}^+$	1 mg/l	200 mg/l	PSI
$\text{K}^+$	1 mg/l	10 mg/l	PSI
$\text{Cl}^-$	4 mg/l	250 mg/l	PSI
$\text{SO}_4^{2-}$	4 mg/l	200 mg/l	PSI
$\text{NO}_3^-$	0.1 mg/l	50 mg/l	PSI
$\text{NH}_4^+$	0.1 mg/l	1.5 mg/l	WHO
Surfactant	1 mg/l	NA	NA
Ag	7 $\mu\text{g/L}$	0.01 mg/l	PSI
Al	40 $\mu\text{g/L}$	0.2 mg/l	WHO
Ba	2 $\mu\text{g/L}$	0.3 mg/l	WHO
Cd	4 $\mu\text{g/L}$	0.005 mg/l	PSI
Cr	7 $\mu\text{g/L}$	0.05 mg/l	PSI
Cu	6 $\mu\text{g/L}$	1 mg/l	PSI
Fe	7 $\mu\text{g/L}$	1 mg/l	PSI
Li	4 $\mu\text{g/L}$	NA	NA
Mn	30 $\mu\text{g/L}$	0.1 mg/l	WHO
Ni	15 $\mu\text{g/L}$	0.05 mg/l	PSI
Pb	40 $\mu\text{g/L}$	0.01 mg/l	PSI
Sr	0.5 $\mu\text{g/L}$	NA	NA
Zn	2 $\mu\text{g/L}$	5 mg/l	WHO
Be	0.3 $\mu\text{g/L}$	4 mg/l	EPA
Se	75 $\mu\text{g/L}$	0.01 mg/l	PSI
Mo	8 $\mu\text{g/L}$	NA	NA
Co	7 $\mu\text{g/L}$	NA	NA

NA: not available

## **CHAPTER 4: RESULTS AND DISCUSSION**

In point source pollution, pollutants are discharged from a concentrated and recognizable source while in non-point source pollution, water flows on the surface dissolving and washing away pollutants and soil sediments along its path and finally discharging into receiving waters. In urban environments, the most important point source is the discharge from the wastewater collection system; and where a treatment plant exists, this would be treated effluent from the plant (Taebi and Droste, 2004).

During the period of this study (November 2004 - July 2005), seventy samples were collected form the whole accessible sampling stations in Wadi Al Qilt that would represent the system, and analyzed for different parameters. A major trend was found through the system (going from the first sampling station at the effluent of AWWTP to last sampling station in Al Qilt canal; PW4) in decreasing the values of turbidity, EC, TDS, TSS, TS, BOD<sub>5</sub>, COD, DOC. This was due to the dilution process which happens firstly, from the combination of Wadi Fara with the AWWTP effluent at Wadi Sweanit point, followed by Ein Al Fawwar spring discharge into Wadi Al Qilt and finally by the flow of Ein Al Qilt spring. The same trend was found for the concentration of sodium and chloride which means they were affected by the dilution process from the discharge of springs.

#### **4.1 Major wadis**

There are two tributaries in Al Qilt drainage basin in which the result of their discharge combined with the flow from the five springs form the main stream named as Wadi Al Qilt. The first tributary is called Wadi Sweanit which originates from the eastern part of Al Bireh before it combines with the second tributary named as Wadi Fara (collects the flow from Ein Fara, Ein Jumeiz and Ein Ru'yan springs). Mostly, AWWTP effluent is considered the main source of Wadi Sweanit discharge.

##### **4.1.1 Variation of EC, TDS, TSS, turbidity and pH along Wadi Al Qilt**

Going from AWWTP to JWTP, a general trend was observed for all parameters measured through the wadis, where the highest values were recorded for AWWTP effluent. Lowered values recorded downstream resulted from the dilution process through the wadis due to the discharge from Ein Fara, Ein Jumaiz, Ein Al-Ru'yan, Ein Al Fawwar and Ein Al Qilt springs into the wadis. Based on the inorganic constituents, water from springs is considered as good and freshwater, while the water from AWWTP effluent is considered as brackish water due to the elevated values of dissolved cations and anions which result in elevated values of EC (reaches a maximum of 1,940  $\mu\text{S}/\text{cm}$ ) and TDS (more than 1,000 mg/L in some cases) (Appendix 2). In addition to the poor quality of treated effluent from AWWTP, disposed treated sewage back into the wadi carrying the treated effluent might be the

reason behind elevated values of several parameters in the section between AWWTP and Wadi Sweanit (Figure 4.1).



Figure 4.1: Remmixing of sewage with treated effluent of AWWTP

Also, unexpected failure in certain parts of the sewer system feeding AWWTP during wet weather flow results in combined sewer overflow (CSO). Water flow in the network of pipes increases dramatically, leading to sewer overflow or the combined flow reaching AWWTP exceeds its maximum capacity. Whatever the case, part of the untreated wastewater is combined with surface runoff and ends up in the tributary carrying the treated effluent of AWWTP.

Figure 4.2 shows the average values of EC, TDS, and TSS values along the wadis starting from AWWTP effluent (B1) until the open transportation canal (PW4). Similar trends are found for these parameters. The highest measured values for EC,

TDS and TSS were for first sampling stations in the first section from AWWTP effluent and to Mikhmas Bridge. Conductivity gives information about the concentration of dissolved salts. In addition to high concentration of salts in domestic wastewater which can not be removed in the treatment plant, the leaching of chemical fertilizers spread on agricultural lands by rainwater also causes high values of both parameters (Bellos and Sawidis, 2005).

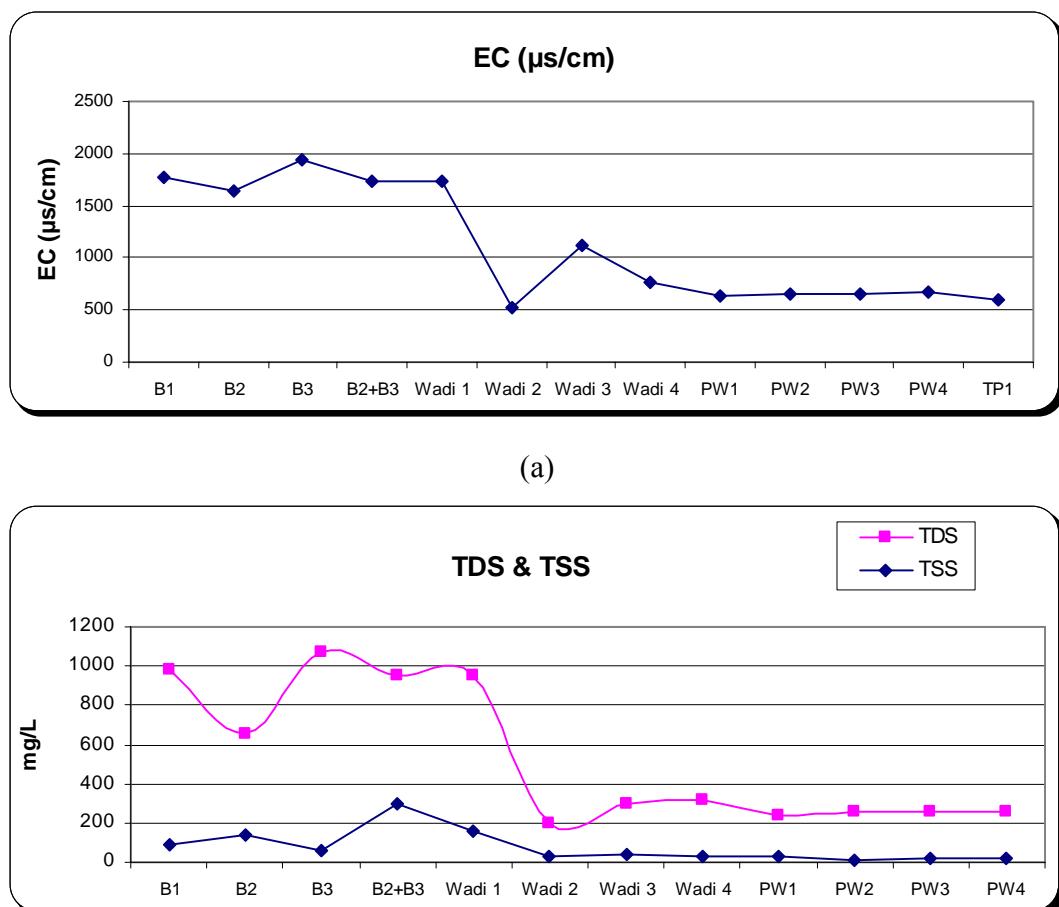


Figure 4.2: (a) Average values of EC, (b) TDS and TSS measured for sampling stations in Wadi Al Qilt

The similar trend was found for turbidity. The highest values were found for the sampling stations near AWWTP effluent and at Mikhmas Bridge then it decreases along the wadi until it reaches its minimum value in the open transportation canal (Figure 4.3). The reason behind the increase in turbidity value at the point of B2+B3 may be referred to intermix of the flows from the two points which may disturb the sediments after mixing.

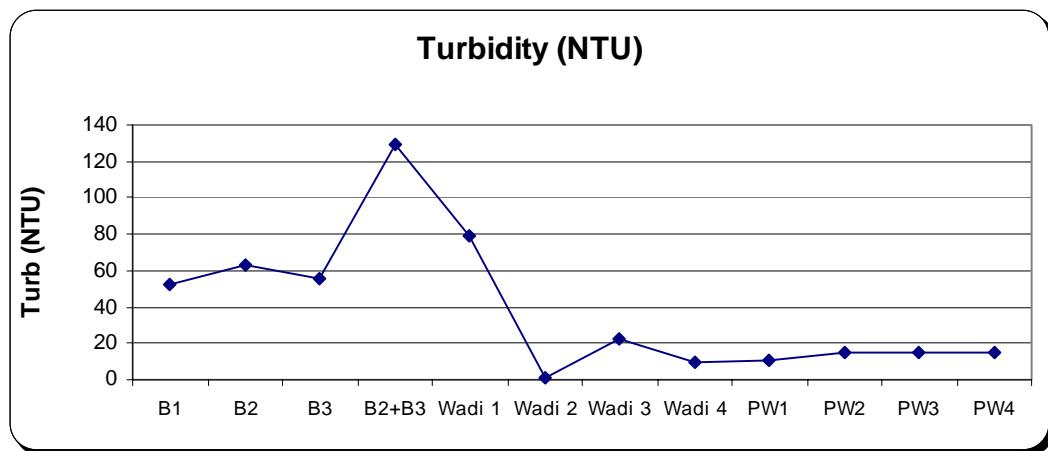


Figure 4.3: Variation of average turbidity through sampling stations in Wadi Al Qilt

The pH measured for sampling stations through Wadi Al Qilt showed significant variation and ranges between 6.57 (for Wadi 1 at 13/03/2005) and 8.4 (for B3 at 16/04/2005) during the period of the study. The highest value of pH was measured for the small wastewater stream at the stone crushing station and that is expected to be mixed with some wastewater from Qalandia Camp. The increase in pH value referred to the presence of basic components found in domestic wastewater (soaps and detergents). This can be explained by the presence of high concentration of

sodium in this sample which was 247 mg/L. On the other hand, the lowest value of pH found in Wadi 1 may be the result of loss of some sodium and other basic ions by adsorption mechanism on the sediments and clay particles at the bottom of the wadi. Also, the dissolution of carbon dioxide and other acidic gases in the flowing water may increase with time due to the open system with the atmosphere. Figure 4.4 shows the average pH values of all sampling stations through Wadi Al Qilt. Detailed measurements of EC, TDS, turbidity and pH values for all sampling stations through Wadi Al Qilt are found in appendix 2.

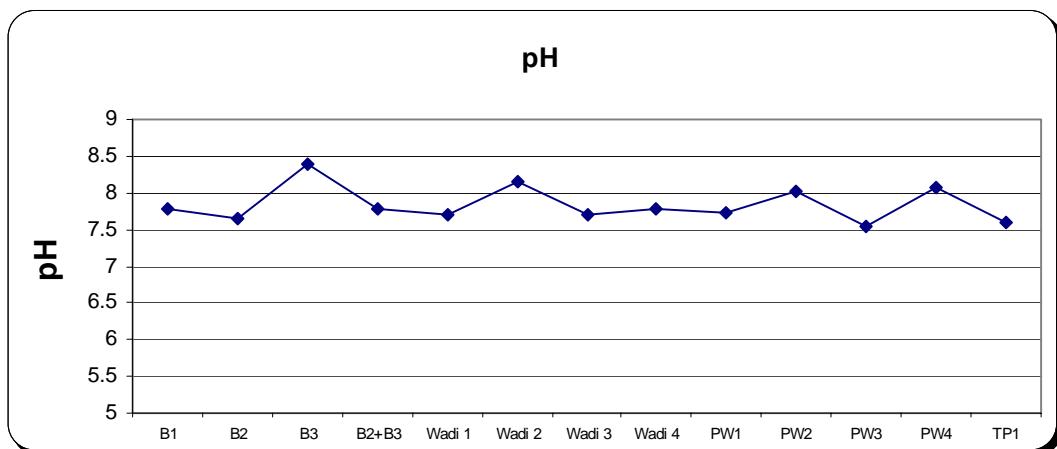


Figure 4.4: Variation of average pH through sampling stations in Wadi Al Quilt

## **4.2.2 Chemical composition**

### **4.1.2.1 Anions**

In addition to the microbiological parameter (discussed later), the following parameters were considered as indicators of pollution in the evaluation of any water resource

- Chloride
- Nitrate

These parameters are generally used for the determination of the level of pollution, type of pollutants and its status. Nitrate is generally an indication of contamination from major nitrogen sources such as a sewage disposal system, animal manure, or nitrogen fertilizers; whereas chloride may originate from dump sites and wastewater containing salt deposits.

A similar trend, as for previous parameters due to the dilution process occurred at different points across Wadi Al Qilt; depression in the concentration was observed (Figure4.5).

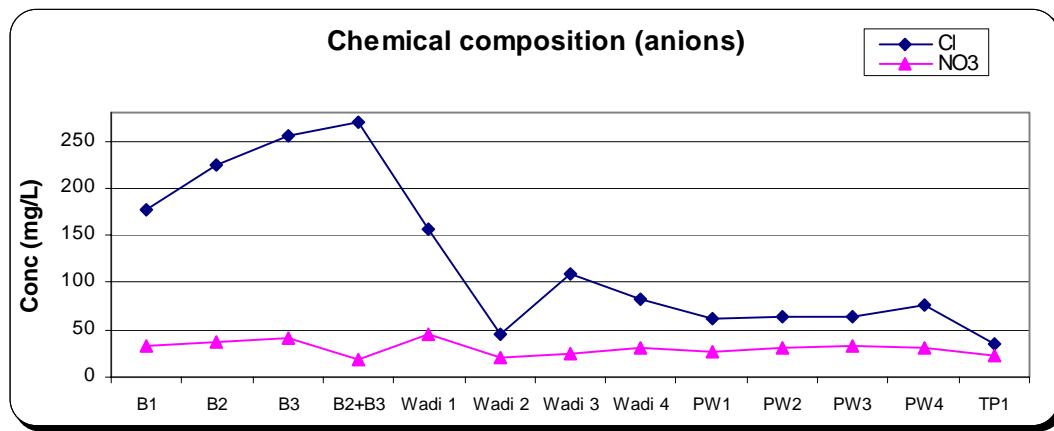


Figure 4.5: Average concentration of chloride and nitrate through sampling stations in Wadi Al Qilt

As it is clear from the figure above, there was a slight elevation in the concentration between AWWTP effluent point (B1) and the point at Mikhmas Bridge (B2+B3). This elevation may be referred to the evaporation process that takes place along the wadi and due to infiltration of part of the flowing water into the bottom sediments. Beside the evaporation and infiltration processes, nitrification during water flow may cause the slight increase in nitrate concentration from B1 to Wadi Sweanit point (Wadi 1).

#### 4.1.2.2 Cations

The four major cations were analyzed during this study, but during the analysis period, calcium and magnesium did not show a significant variation (<100 mg/L), and according to PSI, they are within the allowable concentration for drinking water. Whereas, sodium and potassium ions showed a significant variation in their

concentration, the highest concentration of sodium and potassium were 277 (at Wadi 1) and 33 mg/L (at B<sub>3</sub>) respectively, both measured on 16/04/2005. The minimum concentration of sodium and potassium were 24 and 1.6 mg/L respectively, measured at TP1 on 30/12/2004. Figure 4.6 shows the variation of average concentrations of sodium and potassium through sampling stations of Wadi Al Qilt. Detailed measurements of various major ions are found in Appendix 3.

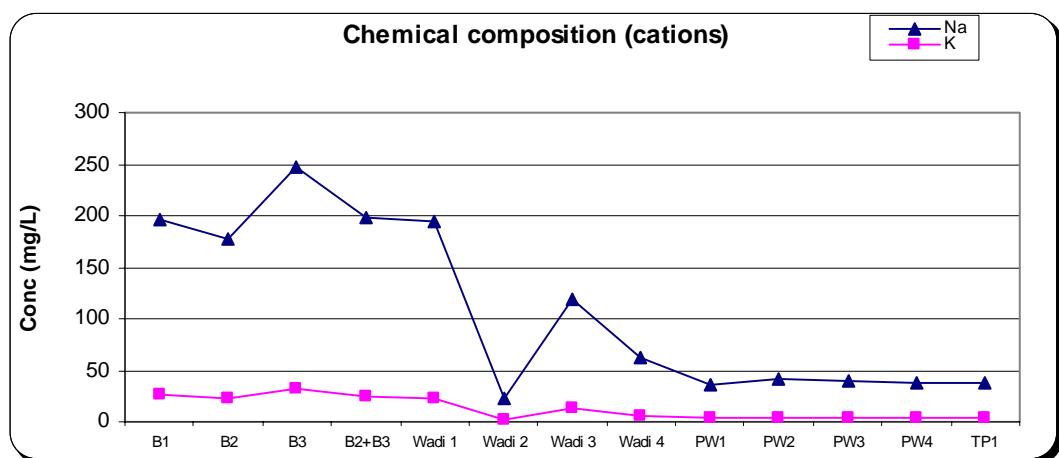


Figure 4.6: Average concentration of sodium and potassium through sampling stations in Wadi Al Qilt.

#### 4.1.2.3 Ammonium

Low-level ammonia nitrogen may be present in water naturally as a result of the biological decay of plant and animal matter. Higher concentrations may be found in raw sewage and industrial effluents. Ammonia is a major component of fertilizers. High concentrations in surface waters can indicate contamination from waste

treatment facilities, industrial effluents or fertilizer run off. In addition to fecal contamination indication, ammonia causes taste, odor problems and results in nitrate formation (WHO, 2004).

Two sets of samples were analyzed for ammonium, but there was a big difference in the measured values between the two runs conducted during April and May (2005) (Table 4.1). Also, there was an increase to an unexpected level in the values calculated for samples collected on April for the combined flow at Mikhmas Bridge (B2+B3) and the point before Al Fawwar Bridge (Wadi 3).

Table 4.1: Ammonium concentration through Wadi Al Qilt

Site I.D.	Site name	NH <sub>4</sub> concentration (mg/L)	
		16/04/2005	15/05/2005
B1	AWWTP effluent	17.5	1.5
B2	Mikhmas Bridge	13.6	2.3
B3	Mikhmas Bridge- Stone Cutting	22.0	Dry
B2+B3	Joint point 1	116.0	*
Wadi 1	Wadi Sweanit	42.0	3.5
Wadi 2	Wadi Fara	0.5	0.1
Wadi 3	Joint Point 2 (Wadi Fara + Wadi Sweanit)	63.0	3.8
AS/021	Ein Al Fawwar	0.5	0.6
Wadi 4	Joint Point 3 (Wadi Fara + Wadi Sweanit + Ein Al Fawwar)	20.2	0.1
AS/020	Ein Al Qilt	0.5	0.2
PW1	Point before split to canal	10.6	0.3
PW2	Canal-500 m ahead	10.5	0.1
PW3	Canal-1000 m ahead "house"	10.6	0.2
PW4	Canal-1500 m ahead "after house"	10.7	0.1

\*: Due to B3 dryness, there was no need to analyze the sampling station at B2+B3 because it is just ten to fifteen meters from B2.

Even the sample was analyzed twice, the value did not change. There is no explanation for such increase in the ammonium concentration when two flows with different ammonium concentration are combined except the hysterical behavior of ion selective electrodes. The expected behavior when two flows are combined is a dilution process takes place, especially the sampling stations are separated with few meters from each other and sampling process did not take more than ten to fifteen minutes.

#### **4.1.2.4 Variation of organic materials along Wadi Al Qilt**

The organic carbon in water and wastewater is composed of a variety of organic compounds in various oxidation states. Some of these carbon compounds can be oxidized further by biological or chemical processes, and the biochemical oxygen demand ( $BOD_5$ ) and chemical oxygen demand (COD) may be used to characterize these fractions. The presence of organic carbon that does not respond to either the  $BOD_5$  or COD test makes them unsuitable for the measurement of total organic carbon. Total organic carbon is a more convenient and direct expression of total organic content than  $BOD_5$  or COD, but does not provide the same kind of information.

Three parameters were measured to determine the level of organic materials in the flowing water in the wadis. COD,  $BOD_5$  and DOC were measured at the assigned sampling stations representing the whole system, starting from AWWTP effluent,

reaching the open transportation canal feeding the JWTP. The same trend was found as for TDS and turbidity; decreasing the concentration of organic material with moving downstream from AWWTP to the open transportation canal due to the dilution process (Figure 4.7). Detailed measurements of these parameters are found in appendix 4.

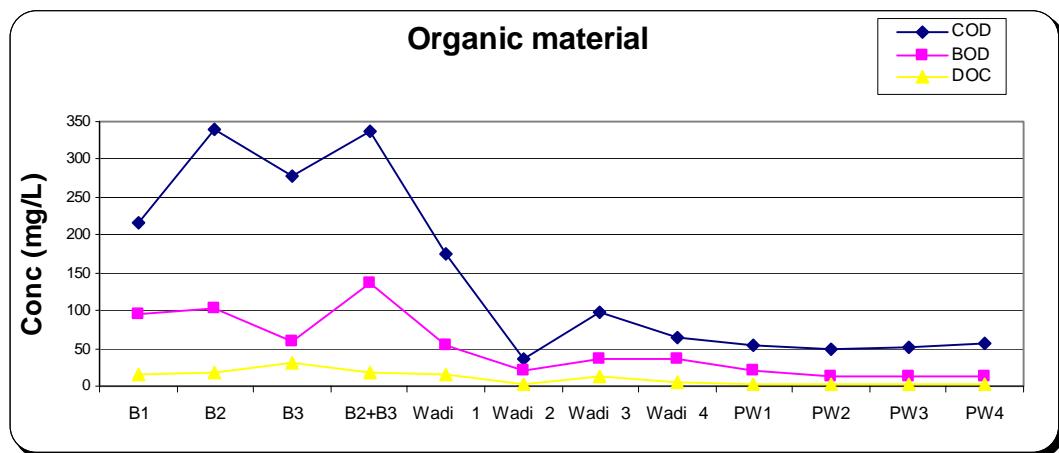


Figure 4.7: Average COD, BOD5 and DOC variation through sampling stations in Wadi Al Qilt.

High values of COD indicate water pollution, which is linked to sewage effluents discharged from urban areas, industry or agricultural practice. The input of anthropogenic contaminants (from point discharges mixing with urban and agricultural runoff) causes distinct, but variable, COD concentration peaks, responsible for increasing the concentrations in nutrients and organic carbon in the fresh surface waters of the flowing water (Bellos and Sawidis, 2005).

**Characterization of organic matter using SUVA index**

Natural organic matter (NOM) is used to describe the complex mixture of organic material present in all drinking water sources such as humic acids, hydrophilic acids, proteins, lipids, amino acids and hydrocarbons. Because NOM characteristics are widely varied chemically and physically, no single analytical technique is available to characterize NOM. As a result, surrogate parameters such as organic carbon content must be used to describe generalized NOM characteristics (USEPA, 1999).

Some organic compounds commonly found in water and wastewater, such as lignin, tannin, humic substances and various aromatic compounds, strongly absorb ultraviolet (UV) radiation. UV absorption is a useful surrogate measure of selected organic constituents in fresh waters, salt waters and wastewater. Strong correlations may exist between UV absorption and organic carbon content, color, and precursors of trihalomethanes (APHA, 1995).

Specific Ultraviolet Absorption (SUVA), the ratio of UV absorption (equals UV absorbance divided by cell path length, measured in  $m^{-1}$ ) to dissolved organic carbon concentration (measured in mg/L), has been used to characterize natural organic matter. SUVA is a calculated value based on two different methods, ultraviolet absorption at 254 nm, and dissolved organic carbon (a filtered DOC sample) (Pons *et al*, 2004). The SUVA calculation is as follows:

$$\text{SUVA (L/mg - m)} = \frac{\text{UV(254nm) (cm}^{-1})}{\text{DOC(mg/L)}} * 100$$

Waters with low SUVA values (less than or equal 2.0 L/mg-m) contain primarily non-humic organic matter and are not amenable to enhanced coagulation. On the other hand, waters with high SUVA values (more than 2) generally are amenable to enhanced coagulation (USEPA, 1999).

Two sets of samples were collected during April and May, 2005 and analyzed for DOC and their absorbance were measured at 254 nm.

The highest values of DOC and UV absorbance were measured for AWWTP effluent, Mikhmas Bridge and Wadi Sweanit. The maximum concentration was 29.86 mg/L, reported on 16/04/2005 at Mikhmas Bridge for the small stream flowing from the stone crushing station with absorbance value of 45.62 (Table 4.2). Higher SUVA values indicate that there was an increase in the relative proportion of aromatic carbon in the DOC fraction (Chow et al, 2005).

The absorbance and DOC values depends on the relative mix of domestic and industrial wastes and the social-economical profile of the community; type of food consumed and availability of drinking water are among the factors that affect the composition of domestic wastewater. Problems can arise in case of fast wastewater composition changes due to storm events for example (Pons *et al*, 2004).

From the calculations of SUVA, two points in the open transportation canal gave a value greater than 2, but DOC in these points were less than 2 mg/L which is very low and water does not need coagulation.

Table 4.2: Calculated SUVA values for sampling stations through Wadi Al Qilt

Samples collected on 16/04/2005				Samples collected on 15/05/2005			
Site I.D	UV Abs ( $m^{-1}$ ) (254 nm)	DOC/NPOC (mg/L)	UV/DOC (L/mg.m)	Site I.D	UV Abs ( $m^{-1}$ ) (254 nm)	DOC/NPOC (mg/L)	UV/DOC (L/mg.m)
B1	24.97	16.71	1.49	B1	27.86	16.69	1.67
B2	26.92	17.67	1.52	B2	27.08	15.83	1.71
B3	45.62	29.86	1.53	Wadi 1	26.64	15.63	1.70
B2+B3	27.39	16.88	1.62	Wadi 2	1.11	2	0.56
Wadi 1	32.54	17.53	1.86	Wadi 3	19.85	12.26	1.62
Wadi 2	1.6	3.22	0.50	Wadi 4	4.93	4.92	1.00
Wadi 3	19.9	12.25	1.62	PW1	1.29	2.46	0.52
Wadi 4	7.58	5.89	1.29	PW2	1.43	2.56	0.56
PW1	3.72	2	1.86	PW3	1.54	2.47	0.62
PW2	3.77	2	1.89	PW4	1.86	2.87	0.65
PW3	4.04	1.98	2.04	-	-	-	-
PW4	3.79	1.87	2.03	-	-	-	-

The use of surrogate parameters for monitoring plant performance and measuring water quality is not new to the water industry. Turbidity, for example, is widely used for controlling and monitoring the operation of treatment plants for the removal of particulate matter. Other surrogates currently used are color (as a measure of NOM) and coliform bacteria (as a measure of pathogen presence) (USEPA, 1999).

#### 4.1.3 Microbiological analysis

The common biological variables that may be found in surface water are bacteria, viruses and protozoa, but their numbers depend on conditions in the drainage basin. Waterborne pathogens that cause disease may be classified as follows: bacteria (such as *Salmonella*, *shigella*, *Escherichia coli* and coliform bacteria), viruses (such as *Hepatitis A*), and parasitic protozoa (such as *Giarda Lamblia*). Bacteria and viruses contaminate both surface and groundwater, whereas parasitic protozoa appear predominantly in surface water and tap water. Bacteria and protozoa generally induce gastrointestinal disorders with a wide range of severity. Bacteria also cause life threatening diseases such as typhoid and cholera.

In general, total coliform (TC) and fecal coliform (FC) are used as indicators for pollution in water analysis. Several samples along the wadis were analyzed for fecal coliform because the flowing water originates from AWWTP effluent and when tested for total coliform gave results that can not be counted. A general trend in the analysis was observed by decreasing the number of fecal coliform colonies going from AWWTP to the open transportation canal. The average results of certain set of samples were plotted as shown in Figure 4.8 in which variation in number of fecal coliform colonies through Wadi Al Qilt was observed. Detailed information is found in Appendix 5. The highest fecal coliform colonies were found for the small stream flowing from the stone crushing station. One of the observations recorded when

samples were taken during the two days; the flowing water had a yellow color with bad smell like that of wastewater.

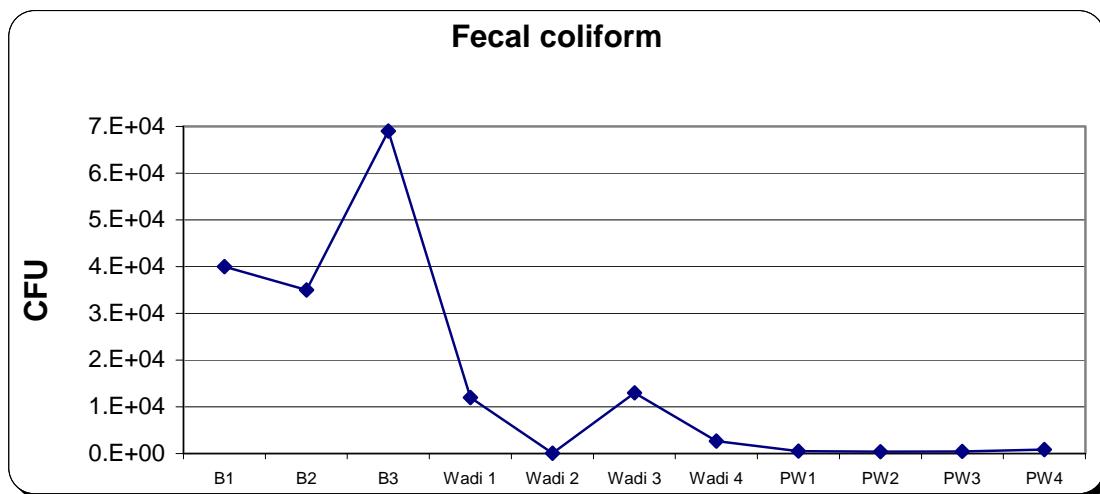


Figure 4.8: Microbiological analysis of sampling stations in Wadi Al Qilt

#### 4.1.4 Variation of pH and conductivity at TP1

Variation of pH and conductivity with time was studied at the end of the open transportation canal; at JWTP influent (TP1). Considering the variation in measured pH values in the period between November 2004 and March 2005, the highest pH value (8.39) was recorded on 05/02/2005. While the lowest pH value (7.06) was recorded at 14/03/2005 (Figure 4.9).

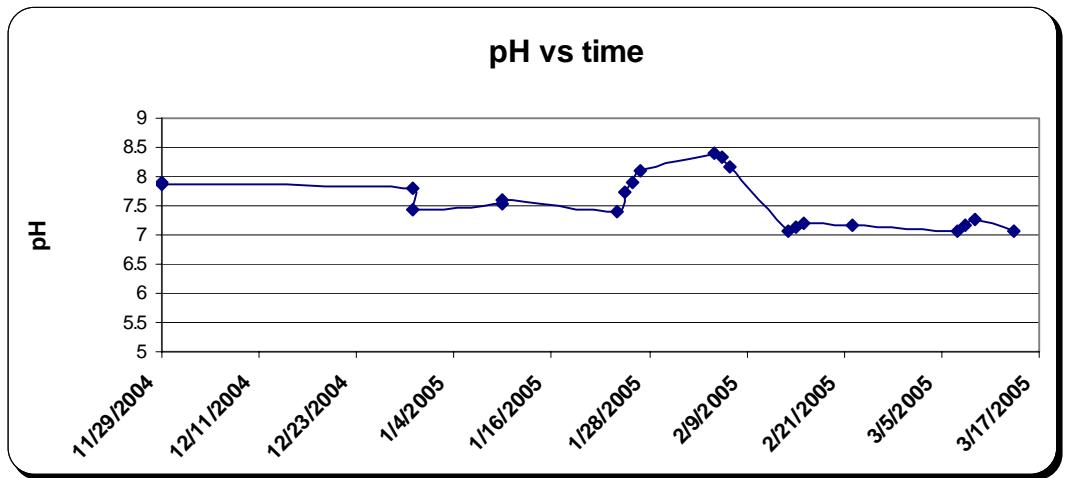


Figure 4.9: Variation of pH at JWTP influent (TP1) between November 2004 and March 2005.

The conductivity of water at the same point varied significantly during the same period and reached a maximum of 702  $\mu\text{S}/\text{cm}$  at 06/02/2005 and a minimum of 500  $\mu\text{S}/\text{cm}$  at 24/01/2005 (Figure 4.10).

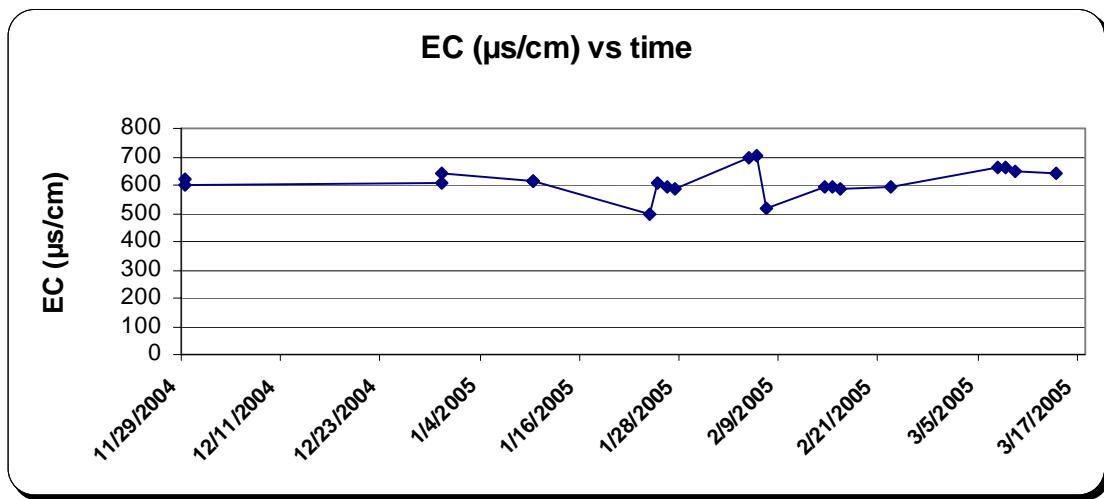


Figure 4.10: Variation of EC at JWTP influent (TP1) between November 2004 and March 2005

The days between 05-13/02/2005 were heavy rainy days and the water in the canal was very turbid with a bad smell. The highest values of pH and conductivity were observed in that period.

According to (Fetter, 1994), rocks at the earth's surface are usually fractured to some degree. The fracturing may be mild, resulting in widely spaced joints. Fractures create secondary porosity in the rock. Water flowing through fractures may enlarge them by solution of material. Limestones and dolomites are formed of calcium carbonate and calcium magnesium carbonate respectively. Water moves initially through pore spaces, as well as along fractures, joints and bedding planes. As more water moves through the bedding planes, they are dissolved and enlarged, causing the rock to become very porous.

The rain water in the western part of the study area is considered very high and reaching 700 mm/a. According to Mahmoud and Al-Sa'ed (1997), due to the high urbanization and large built up areas in the Israeli settlements, huge amounts of drained rainwater have been flooded out of these settlements which may affect the public safety and contribute to ecological damage.

So, as the heavy rain falls on the catchment area that might be contaminated with wastewater or leachate (generated from waste disposal) or any other pollutants, it will wash down these pollutants and moves them into two directions: part of pollutants move with surface runoff which ends up in the wadis (finally in the open

transportation canal) and the second part infiltrates through the geological formations.

This situation might be the acceptable one, if it is known that most if not all the settlements found in the drainage basin of Wadi Al Qilt have neither wastewater treatment plants nor an environmentally sound landfills. Some settlements have wastewater pump station such as Almon and Neveh Ya'kov, but when a mechanical problem may happen in these stations, the flow of wastewater will exceed the capacity of the collection station and begins to drain out. According to personal discussion with a person from Israeli Environmental Department/ Beit Eil, there is a wadi which carries wastewater most of the time between the settlements Almon and Neveh Ya'kov.

Also, the Palestinian communities found in the drainage basin have no wastewater treatment plants except AWWTP or environmentally sound landfills which may affect quality of flowing water in the same manner.

#### **4.1.5 Anionic surfactants**

The main source of surfactants in water and wastewater is the discharge of aqueous wastes from household and industrial laundering and other similar activities. Anionic surfactants form more than fifty percent of total surfactants compared to cationic and

nonionic surfactants. So, the analyses of anionic surfactants give an indication of their level in the flowing water in wadis.

Eight samples were collected on April 2005 from different points through Wadi Al Qilt and analyzed for anionic surfactants. The highest concentration was found at Wadi Sweanit (0.88 mg/L), whereas the lowest concentration was through the transportation canal (0.12 mg/L). Table 4.3 shows some sampling stations analyzed for surfactants and their concentration.

Table 4.3: Sampling stations analyzed for anionic surfactants

Sampling site I.D	Sampling station name	Concentration (mg/L)
B1	AWWTP effluent	0.55
B2	Mikhmas Bridge	0.65
B3	Mikhmas Bridge- Stone Cutting	0.85
Wadi 1	Wadi Sweanit	0.88
Wadi 3	Joint Point 2 (Wadi Fara + Wadi Sweanit)	0.39
Wadi 4	Joint Point 3 (Wadi Fara + Wadi Sweanit + Ein Al Fawwar)	0.88
PW1	Point before split to canal (PW1)	0.15
PW4	Canal-1500 m ahead "after house" PW4)	0.12

#### **4.1.6 Chlorophyll a**

Algae are present in virtually in all surface waters, especially stagnant waters (such as lakes and reservoirs) and in large slow-moving streams that are fairly clear. Raw water drawn from such situations should be monitored regularly and measures should be taken to control or eliminate the algal blooms and to prevent them from reaching the treatment plant.

From the point of view of treatment operations, the most important organisms are algae. These organisms can cause serious problems in the transportation canal or treatment plant basins by accumulation of growths on the walls, which may cause clogging of filters and cause taste and odour problems. It is therefore very important to perform algal identification and counts (Wanger and Pinheiro, 2001).

The concentration of photosynthetic pigments is used extensively to estimate phytoplankton biomass. All green plants contain chlorophyll *a*, which consist approximately 1 to 2% of the dry weight of planktonic algae (APHA, 1995).

Both chemical and physical controls can be used to prevent or remove algae or algae by products from water. Copper sulfate is a common algaecide used to control algae density, whereas coagulation, flocculation and settling processes followed by activated carbon is used subsequently to remove algae and its undesirable tastes and odor (Wanger and Pinheiro, 2001). The copper ion (copper II) is responsible for the

toxicity of all of the formulations. Although the mechanism has not unequivocally been elucidated, it is believed that high levels of copper interfere with photosynthesis. Inhibition of photosynthesis leads to plant death.

Five samples were collected from the end of the open transportation canal during June and July, and analyzed for chlorophyll *a* in the presence of pheophytin. Sampling for the analyses of chlorophyll *a* was during June and July because the temperature of flowing water increases than previous months and the rate of algae growth also increases. The concentrations of chlorophyll *a* in the analyzed samples were as shown in Table 4.4.

Table 4.4: “Chlorophyll *a*” concentration measured at the inlet of JWTP.

Date	Chlorophyll (mg/m <sup>3</sup> )
07/06/2005	9.6
19/06/2005	12.8
02/07/2005	16.8
17/07/2005	12.4
24/07/2005	14.7
Average	13.26

Chlorophyll *a* is often used as an estimate of algal biomass, with blooms being estimated to occur when chlorophyll *a* concentrations exceed 40 mg/L. According to Stanley *et al* (2003), the measured values of chlorophyll *a* in the Lake Mantanee

were in the range from 0 to 118.5 mg/m<sup>3</sup> with an average of 11.62 mg/m<sup>3</sup>. So, the measured values of chlorophyll *a* with an average of 13.26 mg/L at the inlet of the treatment plant for flowing water is considered high compared with that of stationary water in lakes.

#### **4.1.7 Heavy metals**

The speciation and bioavailability of trace elements are regulated by physical and chemical interactions and equilibria. Various factors, including pH, redox potential, temperature, water hardness, carbon dioxide levels, the type and concentration of available ligands and chelating agents, as well as the nature and concentration of the trace element, affect these interactions. The presence of high concentrations of trace elements is problematic in view of the potential toxicity and bioavailability and the chance of bioaccumulation and hazards to human health. Heavy metals do not degrade but are transferred or stored in the aquatic environment where they may become available under the appropriate conditions.

Metal ions can be removed from solution by adsorption, ion exchange, complexation, precipitation and co-precipitation processes. Bottom sediments act as a sink for metals; however, various reactions both microbiological and physicochemical, can transform and redistribute the metals within the sediments and to the water column.

Several samples from different sampling stations and at different times during the study period were analyzed for Ag, Al, Ba, Cd, Co, Cr, Cu, Fe, Li, Mn, Ni, Pb, Sr, Zn, Be, Se and Mo (Appendix 6). Most of the samples analyzed did not show significant concentrations, except for some samples such as the sample collected on 13/03/2005 from the inlet of the open transportation (TP1). The concentration of Al, Ba, Fe and Zn was 450, 161, 197, 617 µg/L respectively. In that point, water was not clear and its color was similar to wastewater with scum on the surface and bad smell (Figure 4.11).



Figure 4.11: Heavy polluted sampling station (TP1)

This color was noticed for that point alone and water at previous sampling stations was nearly clear. If these results are compared with that analyzed at Wadi Sweanit (less values were measured), then this means that there are other sources to

contaminate the water flowing in Wadi Al Qilt after the joint point of Wadi Sweanit with Wadi Fara. Although aluminum is the third most abundant element in the Earth's crust, its concentration in natural waters is low because of the relatively low solubility of aluminum minerals (Miro *et al*, 2004). The major source of lead to contaminate water resources is found in the production of lead acid batteries, solder, alloys, pigments, glazes, and plastic stabilizers, while zinc is used in the production of corrosion-resistant alloys and brass, and for galvanizing steel and iron products. Also, water can be contaminated with lead as a result of runoff which collects high lead concentrations from the disposal sites of vehicles tires. Cadmium metal is used mainly as an anticorrosive, electroplated on to steel. Cadmium sulfide and selenide are commonly used as pigments in plastics. Cadmium compounds these days are used heavily in electric batteries and electronic components. The solubility of cadmium in water is influenced to a large degree by its acidity; suspended or sediment-bound cadmium may dissolve when there is an increase in acidity. In natural waters, cadmium is found mainly in bottom sediments and suspended particles (WHO, 2004).

Strontium and barium are also abundant in earth materials, although their concentrations are one to two orders of magnitude lower than those of calcium and magnesium. Strontium and barium are less soluble than calcium and magnesium, but are found in appreciable quantities in aquifers consisting of sandstone and igneous rocks (Minnesota Pollution Control Agency, 1999). .

Stormwater, and the pollutants it carries, is of major concern for wadis and its tributaries. The huge volume of polluted water that runs off urban pavements creates numerous problems in the wadis such as bank erosion and bed scouring. Polluted stormwater runoff contains bacteria, heavy metals, nutrients, oil and grease, pesticides, and soil particles that negatively impact the quality of water (Taebi and Droste, 2004). Before two days of sampling (on 11/03/2005), it was a heavy rainy day and the rainfall measured in Ramallah was about 13.8 mm (PWA, 2005). On the other hand, due to the karstic nature of the study area, several pollutants may end up in water discharging from springs or surface runoff especially after heavy rain events.

From personal interview with an old man who live there, he told me that in 1955, Al-Husseini dug a small well at Ein Al Mo'agar (1 km upstream from Ein Al Qilt, few meters separate it from Wadi Al Qilt ), and put a colored dye. Then after that, the colored dye was observed in the water discharging from Ein Al Qilt. This means, if there are pollutants that can reach Wadi Al Qilt, it may contaminate the spring. The analyzed sample from Ein Al Qilt at that date also showed significant increase in the concentration of certain heavy metals such as zinc (87 µg/L).

#### **4.1.8 Correlations between analyzed parameters**

Correlations between analyzed parameters were done using SPSS software (Appendix 7). Significant correlations at 0.01 significance level, were observed

between DOC and onsite measured parameters such as turbidity, EC, and TDS. Such correlations can be used downstream at JWTP to indicate the organic content in the water entering the treatment plant. Linear and logarithmic relations were the best forms to correlate the previous parameters (Figure 4.12). Logarithmic relation (**DOC= -3.7372+ (4.1803\* ln(Turbidity))**) was better than the linear form between DOC and turbidity, while the linear form was better to describe the other two relations (**DOC =-6.7571 + (0. 0260\*TDS)** and **DOC = -6.8254+(0.0143\*EC)**).

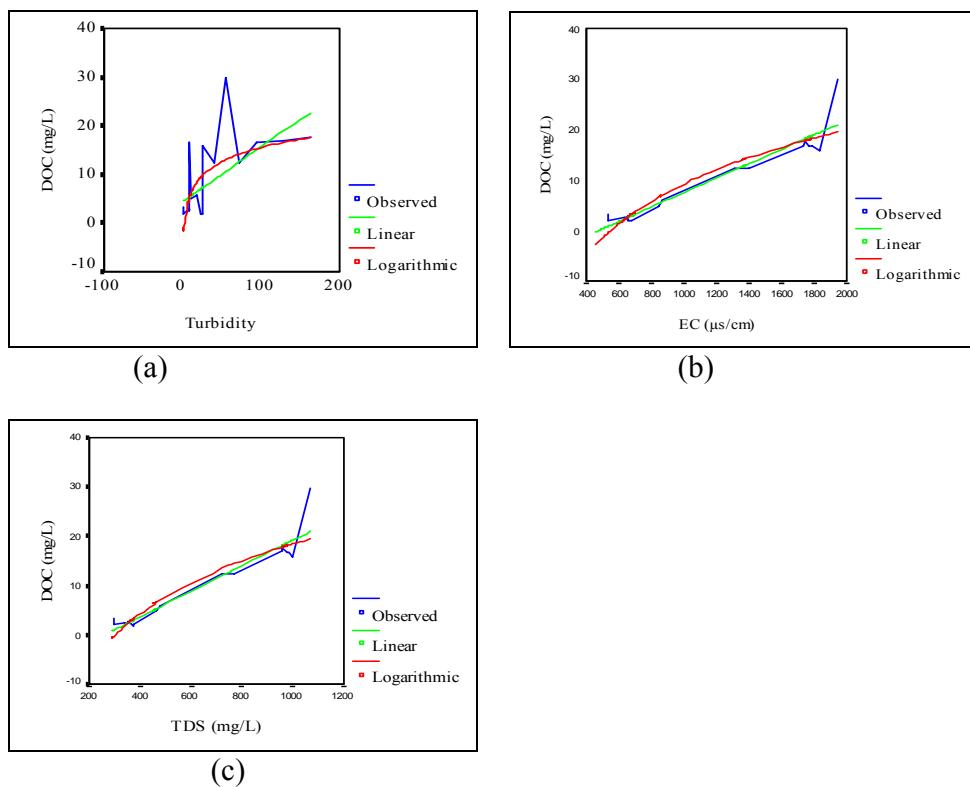


Figure 4.12: Correlations of DOC with (a) turbidity (b) EC (c) TDS

#### **4.1.9 Flow measurements through Wadi Al Qilt**

The flow in the wadis begins at AWWTP and the flow measurements at the AWWTP effluent was in the range 4400-5504 m<sup>3</sup>/d. The minimum flow was recorded for Wadi Sweanit (around 1000 m<sup>3</sup>/d), where the difference between the points might be referred to evaporation and infiltration process, and which explains the elevation in certain conservative parameters (such as chloride) at that point compared with AWWTP effluent. Between Wadi Sweanit and the entrance of the open transportation canal, the flow reaches its maximum (around 47632 m<sup>3</sup>/d) on 13/03/2005, which explains the dilution of all measured parameters. Because the springs in Wadi Al Qilt are seasonal ones and due to surface runoff, the discharge in the wadis decreases after the end of Winter season (Table 4.5).

Table 4.5: Flow measurements at various sampling stations through Wadi Al Qilt

Site ID	Sampling Station name	Sampling Date	Flow (m <sup>3</sup> /d)
B1	Al Bireh WWTP effluent	06/03/2005	5504
B2+B3	Joint point 1	06/03/2005	4683
Wadi 3	Joint Point 2 (Wadi Fara + Wadi Sweanit)	13/3/2005	4380
PW1	Point before split to canal	13/3/2005	47632
B1	Al Bireh WWTP effluent	16/04/2005	4400
Wadi 1	Wadi Sweanit	16/04/2005	1953
Wadi 2	Wadi Fara	16/04/2005	924
Wadi 3	Joint Point 2 (Wadi Fara + Wadi Sweanit)	16/04/2005	2877
Wadi 4	Joint Point 3 (Wadi Fara + Wadi Sweanit + Ein Al Fawwar)	16/04/2005	12545
PW1	Point before split to canal	16/04/2005	24192
B1	Al Bireh WWTP effluent	15/05/2005	4597
B2	Mikhmas Bridge	15/05/2005	3076
Wadi 1	Wadi Sweanit	15/05/2005	1072
Wadi 2	Wadi Fara	15/05/2005	1054
Wadi 3	Joint Point 2 (Wadi Fara + Wadi Sweanit)	15/05/2005	2868
Wadi 4	Joint Point 3 (Wadi Fara + Wadi Sweanit + Ein Al Fawwar)	15/05/2005	14481
PW1	Point before split to canal	15/05/2005	21939

## 4.2 Springs of Wadi Al Qilt

There are five springs found in Wadi Al Qilt drainage basin, three of them are major springs, Ein Fara, Ein Al Fawwar and Ein Al Qilt, and two are minor ones, Ein Jumeiz and Ein Ru'yan. Three of these springs, Ein Fara, Ein Jumeiz and Ein Ru'yan are found at the beginning of Wadi Fara which is separated from Wadi Sweanit which carries the effluent of AWWTP. As shown in chapter three (Figure 3.2), the joint point of these two wadis is located before Ein Al Fawwar with around 1.5 km.

Few meters separate Ein Al Fawwar from Wadi Al Qilt whereas Ein Al Qilt flows directly into the wadi.

#### **4.2.1 Water Quality of springs**

Due to the political situation of the study area, sampling from the assigned stations through Wadi Al Qilt was not easily. Mainly Ein Fara, Ein Jumeiz and Ein Al-Ru'yan springs were sampled once during the study period.

Ten water samples from springs in Wadi Al Qilt were analyzed for several parameters. Results showed little variation in the various parameters especially in EC, chloride and pH, which range between 539 to 632 ms/cm, 23 to 86 mg/L and 6.8 to 7.59 respectively (Table 4.6). The concentration of ions in Ein Al Fawwar spring may be affected by the human activities because the spring originates from a pond and used for swimming by settlers from around settlements.

Table 4.6: Descriptive statistics of chemical and physical parameters of the studied springs in Wadi Al Qilt

Parameter	Min	Max	Average	St. Dev.
Na <sup>+</sup> (mg/L)	22.0	31.0	25.7	2.9
Ca <sup>2+</sup> (mg/L)	37.0	71.0	53.5	12.5
Mg <sup>2+</sup> (mg/L)	19	27	22.2	2.6
K <sup>+</sup> (mg/L)	0.0	2.0	0.97	0.93
Cl <sup>-</sup> (mg/L)	23.0	86.0	45.7	22.3
SO <sub>4</sub> <sup>2-</sup> (mg/L)	10.0	15.0	13.3	2.0
NO <sub>3</sub> <sup>-</sup> (mg/L)	17.0	39.0	25.8	5.6
HCO <sub>3</sub> <sup>-</sup> (mg/L)	192.0	242	218.5	23.2
EC (ms/cm)	539.0	632.0	582.7	31.7
pH, Lab	6.8	7.69	7.2	0.2
TDS (mg/L)	267	380	346.2	41.36

#### 4.2.1.1 Electrical conductivity

The electrical conductivity (EC) is a measure of the total salt content of water based on the flow of electrical current through the sample and inversely proportional to the resistance of the solution and measured in millisiemens (mS) or microsiemens ( $\mu$ S).

The highest measured value was for Ein Al Fawwar spring (632  $\mu$ S) whereas the minimum was for Ein Al Qilt spring (514 $\mu$ S) (Figure 4.13). Based on these values and historical data collected by Palestinian Water Authority (PWA) (EC around 500  $\mu$ S), these springs are considered as good source of water (Ghanem, 1999). Detailed

information about physical and chemical characteristics of the five springs in Wadi Al Qilt is shown in Appendix 8a.

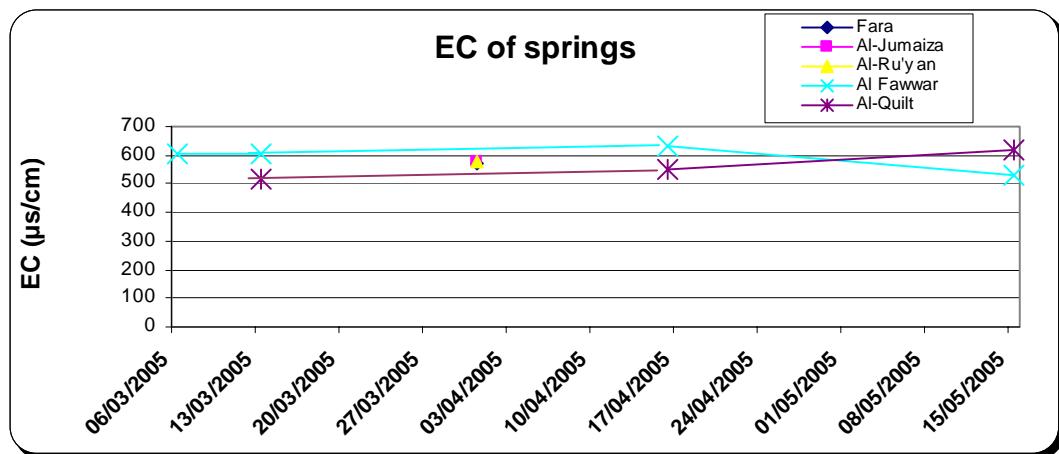


Figure 4.13: EC of Wadi Al Qilt springs

#### 4.2.1.2 Total dissolved solids

Total dissolved solids (TDS) comprise the inorganic salts, principally calcium, magnesium, potassium, sodium, bicarbonate, chloride and sulfate beside some dissolved organic materials. Elevated TDS indicate that the dissolved ions may cause the water to be corrosive or salty or brackish taste. The lowest and highest measured value for TDS were 267 and 380 mg/L both measured for Ein Al Fawwar at two different dates (Figure 4.14).

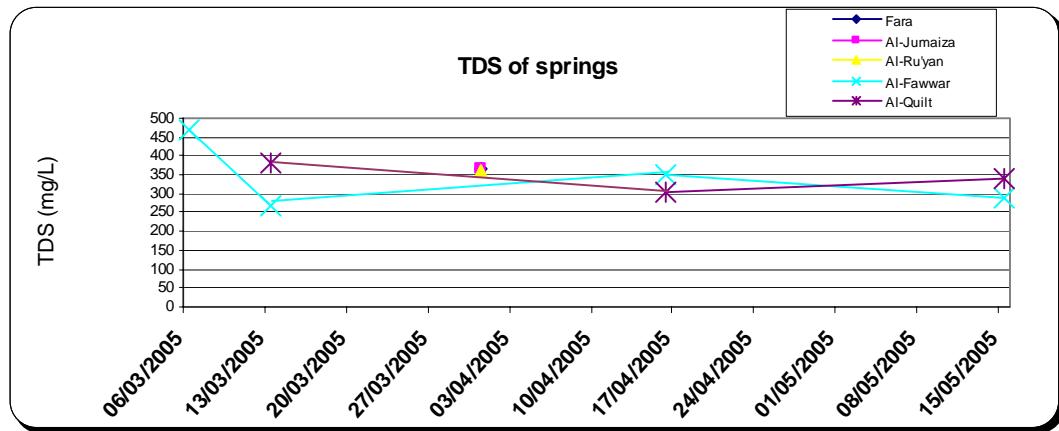


Figure 4.14: TDS of Wadi Al Qilt springs

The highest and lowest measured values of TDS for the springs were 380 and 267 mg/L respectively. A general classification of groundwater according to their content of dissolved ions is shown in Table 4.7. According to this classification, water from these springs is considered fresh water.

Table 4.7: General classification of groundwater according to TDS

Category of water	TDS (mg/L)
Fresh	0 – 1,000
Brackish	1,000 – 10,000
Saline	10,000 – 100,000
Brine	> 100,000

#### 4.2.1.3 pH

The pH of the water indicates the degree of its acidity or alkalinity, reflecting the characteristics of the drainage basin or the underground rock strata through which the raw water has passed. Hydrogen and hydroxide ions enter into many equilibria in addition to the dissociation of water, so it is frequently necessary to specify their concentrations in aqueous solutions and water bodies. Other sources of hydrogen ions include humic and fulvic acids, acid rain and short chain organic acids (Hounslow, 1995). The highest and lowest measured values for pH were 7.69 and 6.8 respectively and both values were measured for Ein Al Fawwar spring (Figure 4.15).

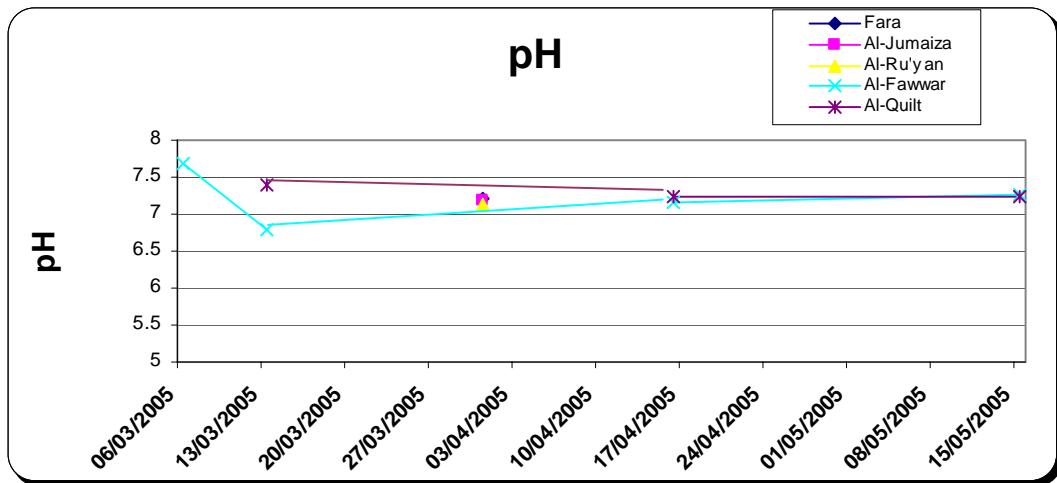


Figure 4.15: pH of Wadi Al Qilt springs

#### **4.2.2 Classification of water types using piper diagram**

Most of the methods that are used for water sample grouping are based on the major inorganic dissolved constituents. No consideration is given to the organic and inorganic minor or trace constituents (Abed Rabbo et al, 1999).

The major ionic species in most natural waters are divided into two major groups; cations  $\text{Ca}^{2+}$ ,  $\text{Mg}^{2+}$ ,  $\text{Na}^+$ ,  $\text{K}^+$ , and anions  $\text{Cl}^-$ ,  $\text{SO}_4^{2-}$ ,  $\text{HCO}_3^-$  and  $\text{CO}_3^{2-}$ . A trilinear can show the percentage composition of three ions. So, to plot four ions from each group, two cations must be grouped ( $\text{Na}^+$ ,  $\text{K}^+$ ) on one axis and two anions must be grouped on the second triangle ( $\text{HCO}_3^-$ ,  $\text{CO}_3^{2-}$ ). According to Langguth (1966), using piper diagram, which is trilinear plot that permits the classification of water samples into seven water types, (Figure 4.16). The seven types are divided into three major groups

-Normal alkaline earth water

a-With prevailing bicarbonate

b-With bicarbonate and sulfate (or chloride)

c-With prevailing sulfate (or chloride)

-Earth alkaline water with increased portion of alkali

- d-With prevailing bicarbonate
- e-With prevailing sulfate and chloride
- Alkaline water
- f-With prevailing bicarbonate
- g-With prevailing sulfate

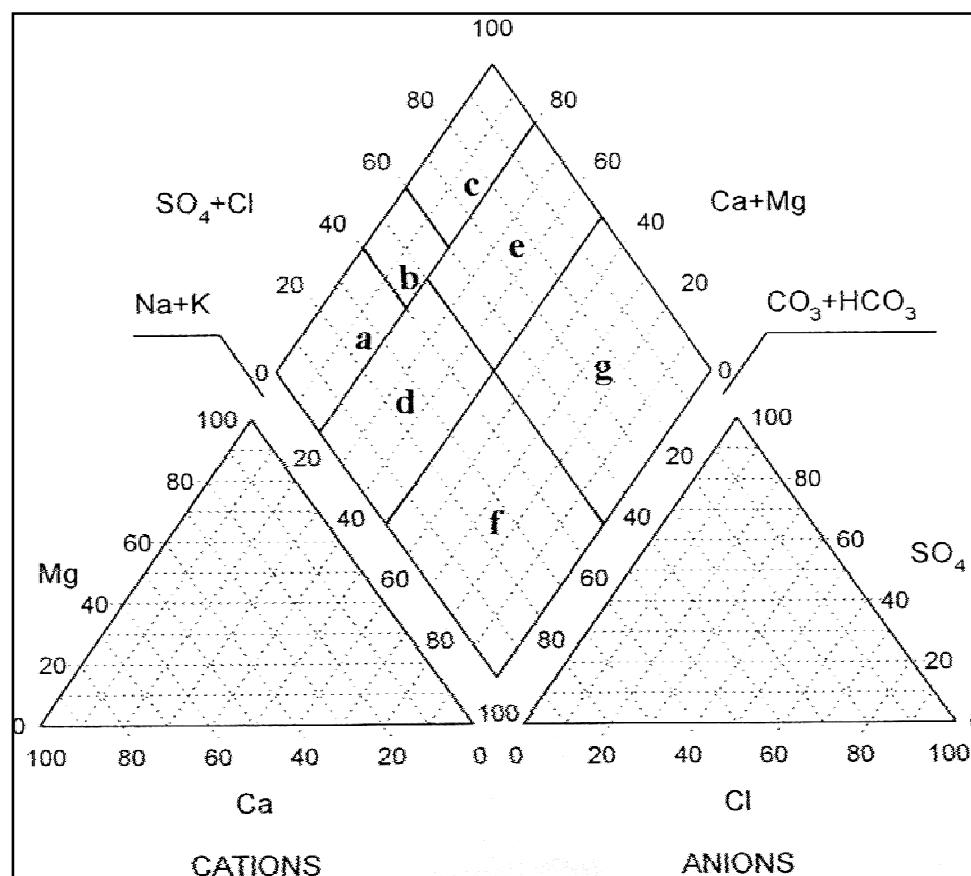


Figure 4.16: Langguth (1966) classification of water types using piper diagram

On a piper diagram, the chemical results of samples from the five springs in Al Qilt drainage basin were plotted on such diagram using special software for windows called Aquachem. The plot shows that these springs are located between the areas of earth alkaline water and earth alkaline water with increased portion of alkali both with prevailing bicarbonate (Figure 4.17).

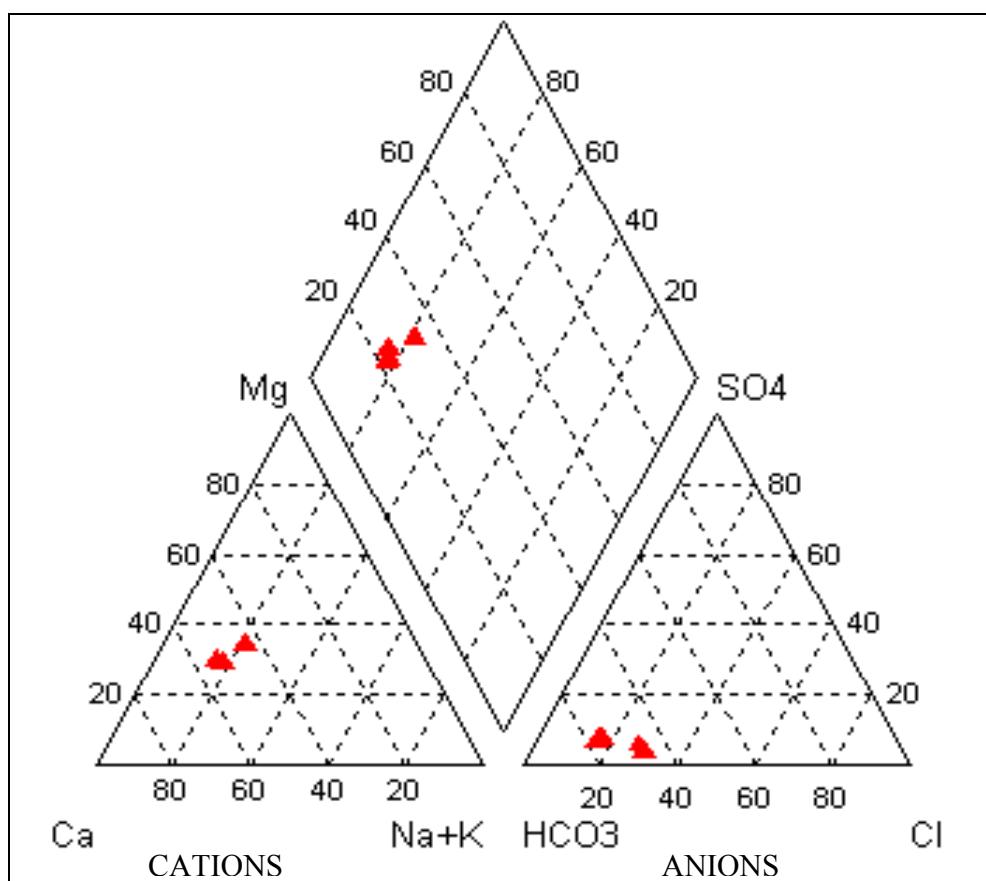


Figure 4.17: Piper plot showing the water type of springs in Wadi Al Qilt

According to MOPIC (1998) the aquifers of West Bank are carbonate aquifers, and the aquifer is of Cenomanian-Turonian age which is composed of dolomite and limestone (Abed Rabbo *et al*, 1999). However, some results show some interference of some ions such as sodium or chloride ions and in one case nitrate were shown which cause the water type to deviate from Ca-Mg-HCO<sub>3</sub> for unpolluted water to other types (Table 4.8).

Table 4.8: Water types of groundwater from springs in Wadi Al Qilt

Spring name	Date	Water type
Ein Jumeiz	31/03/2005	Ca-Mg-HCO <sub>3</sub>
Ein Ru'yan	31/03/2005	Ca-Mg-HCO <sub>3</sub>
Ein Fara	3/03/2005	Ca-Mg-HCO <sub>3</sub>
Ein Al Qilt	13/03/2005	Mg-Ca-Na-HCO <sub>3</sub> -Cl
Ein Al Qilt	16/04/2005	Mg-Ca-Na-Cl
Ein Al Qilt	15/05/2005	Ca-Mg-HCO <sub>3</sub> -Cl
Ein Al Fawwar	06/03/2005	Ca-Mg-HCO <sub>3</sub> -Cl
Ein Al Fawwar	13/03/2005	Ca-Mg-Na-HCO <sub>3</sub>
Ein Al Fawwar	16/04/2005	Ca-Na-Cl-NO <sub>3</sub>
Ein Al Fawwar	15/05/2005	Ca-Mg-HCO <sub>3</sub> -Cl

The mean reason behind such interference is the leaching of some pollutants either from wastewater origin (cesspools, sewage systems and untreated sewage flow in the valleys) or agricultural activities (using of excess pesticides and fertilizers) or salt

deposits (from aquifer itself) or from solid waste (industrial, medical and municipal dump sites may generate leachate with different constituents).

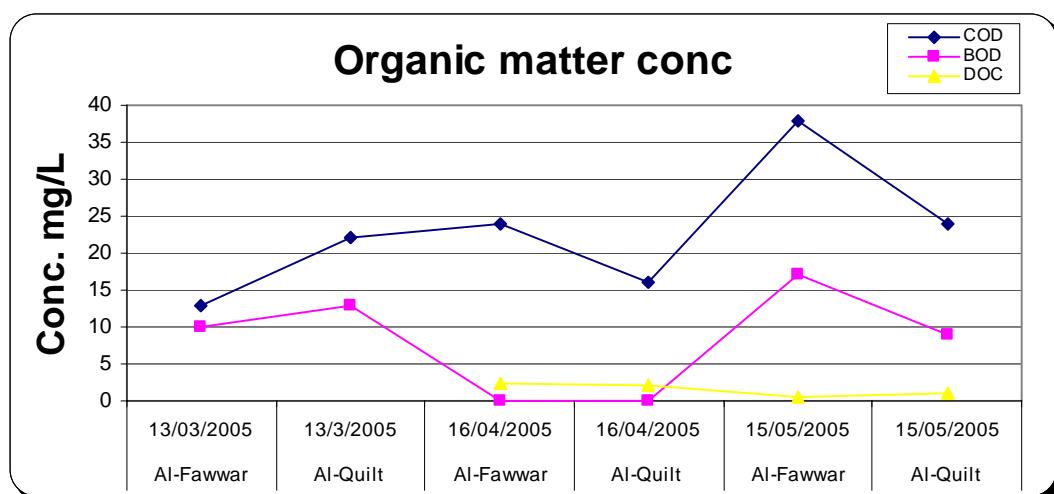
Detailed analyses of physical and chemical characteristics of the springs are shown in appendix 8a. Some parameters were not measured for certain samples, especially when time intervals between sampling campaigns was not very wide.

#### **4.2.3 Organic materials and microbiology of springs**

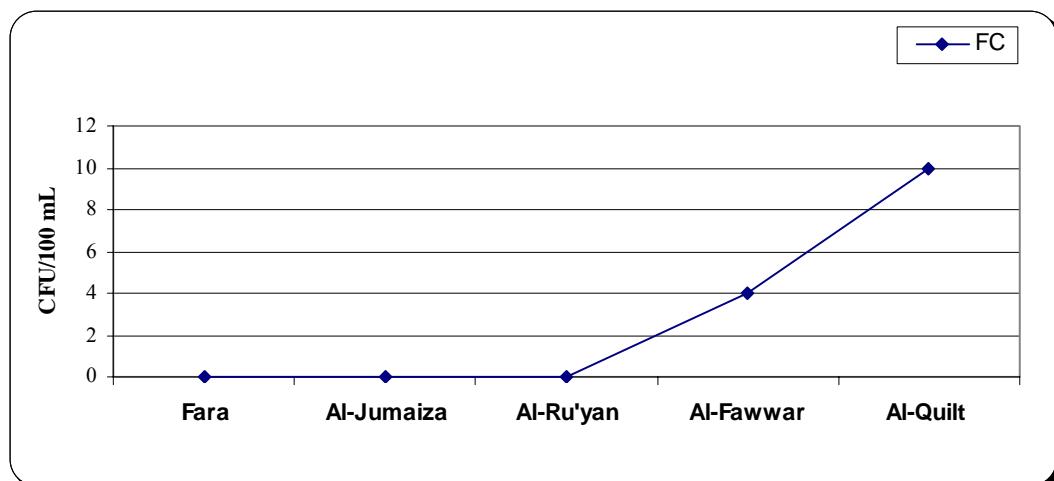
BOD<sub>5</sub> and COD were determined for three samples groups collected on three different dates. However, Ein Fara, Ein Jumeiz and Ein Ru'yan were sampled once and were not analyzed for such parameters. Two groups of these samples collected in two different months, were analyzed for DOC. Samples from the five springs were taken and analyzed for microbiological pollution; TC and FC, to determine the potential pollution sources as cesspits, wastewater infiltration and the uncontrolled disposal of waste.

There was variation in the values measured for different parameters of the three points. Concerning the organic content in the samples, the results show small concentrations which did not reflect any contamination (Figure 4.18a). Whereas, the results show that some of the samples collected from Ein Al Fawwar and Ein Al Qilt are contaminated with coliform bacteria but some are others were free of coliform

(Figure 4.18b). Detailed information about biological parameters and organic matter are found in appendix 8b and 8c respectively.



(a)



(b)

Figure 4.18: Organic content and microbiological characteristics of Wadi Al Qilt springs (a) Organic content, (b) Microbial contamination

#### **4.2.4 Trace elements in springs**

One sample from Ein Al Qilt spring shows high Lead concentration (102 µg/L), furthermore, Zinc concentration in Ein Al Fawwar and Ein Al Qilt was 95 and 90 µg/L (average of two measurements) respectively (Appendix9). According to PSI (2004), the concentration of lead in the sample collected on 15/05/2005 exceeded the maximum allowable concentration in drinking water (0.01mg/L). The concentration of Cadmium in Ein Ru'yan spring was the highest among the five springs, 36 µg/L, which also, exceeds the maximum allowable limits (5 µg/L).

Dolomites and limestones characterize the aquifer which is of Cenomanian-Turonian age. Solution weathering process is considered a very important one in the dissolution of solid matrix. Limestones are affected with the dissolution process to larger extent than do the dolomites. As the pH of infiltrating water increases, the dissolution process becomes faster and leading to wider fissures and bedding planes. As a result of the dissolution process which leads to the formation of karstic systems, these contaminants may move faster through fissures and finally contaminate the springs.

Detailed information about suggested wavelengths, estimated detection limits, alternate wavelengths, calibration concentration and upper limits using ICP-OES are shown in Appendix10.

#### 4.2.5 Flow from springs

During the study period, a significant decrease in the flow of Ein Al Qilt and Ein Al Fawwar springs was observed going from March to May (Table 4.9). The flow of Ein Fara, Ein Jumeiz and Ein Ru'yan springs were measured once due to the political situation. The variation in the flow values did not affect the concentration of major cations and anions; there was no trend in the concentration to decrease or increase. Ein Al Fawwar spring has the highest flow among the five springs in Wadi Al Qilt whereas the lowest flow was of Ein Jumeiz spring.

Table 4.9: Flow measurements at certain dates for Wadi Al Qilt springs

Spring name	Flow m <sup>3</sup> /day			
	Date of measurement			
	13/03/2005	31/03/2005	16/04/2005	15/05/2005
Ein Fara	-	5305	-	-
Ein Jumeiz	-	719.7	-	-
Ein Ru'yan	-	924.5	-	-
Ein Al Fawwar	25488	-	18334	12926
Ein Al Qilt	17764	-	11647	5117

## CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS

The results obtained for physical, chemical and biological parameters showed that the most polluted section through Wadi Al Qilt is the part between AWWTP and wadi Sweanit, indicating pollution of water discharging from springs downstream. Moreover, three springs located in the drainage basin are contaminated with heavy metals, whereas two springs are biologically contaminated. Based on the geological nature of the study area, these springs are directly recharged through fractures and fissures characterizing limestone, so the infiltration of wastewater and other pollutants disposed in the drainage basin will accelerate the deterioration of their quality.

### 5.1 Conclusions

- ✚ According to the field visits made, several sources of pollution may affect water quality downstream such as AWWTP effluent, discharge of wastewater from some Israeli settlements at certain times, stone crushing, human and agricultural activities around Ein Al Qilt.
  
- ✚ Treated effluent of AWWTP and industrial discharges from the crushing station were the main pollution sources for wadi Sweanit.

- ✚ Measurements of flow rates revealed high evaporation and infiltration rates especially in the section between AWWTP and wadi Sweanit.
- ✚ The dilution process might be the main factor behind the low measured concentrations for all parameters in the open transportation canal feeding the JWTP.
- ✚ All analyzed samples for trace elements showed a significant level of zinc but all the values were under the maximum allowable limits, however, one sample from Ein Al Qilt when analyzed for lead exceeded the maximum allowable limits for drinking water.
- ✚ Chemical analysis of water quality parameters of Wadi Al Qilt springs (Ein Fara, Ein Jumeiz, Ein Ru'yan, Ein Al Fawwar and Ein Al Qilt), were in accordance to Palestinian drinking water standards except for one sample from Ein Ru'yan which showed a high concentration of cadmium.
- ✚ All analyzed samples form wadis were microbially contaminated, whereas Ein Al Fawwar and Ein Al Qilt were the contaminated springs

## **5.2 Recommendations**

- ✚ Maintenance of the open canal between Ein Al Fawwar and Ein Al Qilt is highly recommended. Due to good water quality and quantity of Ein Al Fawwar, it is

further suggested to connect this canal with the open transportation canal feeding the JWTP.

- ✚ AWWTP effluent must be treated further more to remove the higher levels of organic and inorganic constituents or if the flowing water from the plant can be diverted before reaching Wadi Sweanit.
- ✚ Closure of the open canal feeding the JWTP and advanced nutrient removal at AWWTP will reduce the algal growth over slow sand filters.
- ✚ Watershed management plan should be developed to reduce water pollution loads of uncontrolled waste disposal sites, cesspools and winter runoff events.
- ✚ Further research studies are needed to develop water quality modeling and simulate pollution loads events.

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## APPENDICES

Appendix 1: Detailed description of Jewish colonies, number of settlers, their area, actions and their possible impacts

<b>Settlement name</b>	<b>Established year</b>	<b>Number of settlers</b>	<b>Area (dunum)</b>	<b>Category</b>	<b>Occupied Palestinian Land</b>	<b>Action</b>	<b>Impact</b>
Psagot	1981	1,333	300 <sup>a</sup>	Cooperative	Al Bireh	Wastewater disposal	Land and water sources contamination
Kokhav Ya'kov	1984	3,922	1,533 <sup>a</sup>	Civic	Kafr O'qb	NA	NA
Giv'a Binyamin (Adam)	1983	1,988	2,862 <sup>a</sup>	Cooperative	Jaba'	NA	NA
Ma'ale Mikhmas	1981	998	1508 <sup>a</sup>	Cooperative	Deir Dibwan	NA	NA
Almon (Anatot)	1983	740	3,424 <sup>a</sup>	Cooperative	Anata	Wastewater disposal	Land and water sources contamination
Allon	1991	NK	347 <sup>b</sup>	NK	Anata	NA	NA
Bisgat Ze'ev	1985	NK	1,573 <sup>b</sup>	Civic	Hizma and Beit Hanina	NA	NA
Pisgat Omer	1985	NK	2,504 <sup>b</sup>	Civic	Hizma	NA	NA
Neveh Ya'aqov	1972	20,269	1,759 <sup>a</sup>	Urban	NA	Wastewater disposal	Land and water sources contamination

<sup>a</sup>: Total area (2001), <sup>b</sup>: Build up area (2002). (Modified after PCBS, 2003).

Appendix 2: Detailed measurements of pH, turbidity, EC and TDS of all sampling stations along Wadi Al Qilt

Site ID	Sampling station name	Sampling Date	pH	Turbidity (NTU)	EC ( $\mu\text{s}/\text{cm}$ )	TDS (mg/L)
TP1	Water Treatment plant - inlet	29/11/2004	7.91		622	
TP1	Water Treatment plant - inlet	29/11/2004	7.87		603	
TP1	Water Treatment plant - inlet	30/12/2004	7.8		607	
TP1	Water Treatment plant - inlet	30/12/2004	7.45		639	
TP1	Water Treatment plant - inlet	10/01/2005	7.53		613	
TP1	Water Treatment plant - inlet	10/01/2005	7.61		611	
TP1	Water Treatment plant - inlet	24/01/2005	7.41		500	
TP1	Water Treatment plant - inlet	25/01/2005	7.75		605	
TP1	Water Treatment plant - inlet	26/01/2005	7.91		590	
TP1	Water Treatment plant - inlet	27/01/2005	8.09		584	
TP1	Water Treatment plant - inlet	05/02/2005	8.39		698	
TP1	Water Treatment plant - inlet	06/02/2005	8.35		702	
TP1	Water Treatment plant - inlet	07/02/2005	8.17		515	
B2	Mikhmas Bridge	06/03/2005	7.45		1381	
Wadi 3	Joint Point 2 (Wadi Fara + Wadi Sweanit)	06/03/2005	7.85		1050	
B3	Mikhmas Bridge- Stone Crushing	13/3/2005				
Wadi 1	Wadi Sweanit	13/3/2005	6.57		1087	
Wadi 2	Wadi Fara	13/3/2005	8.11		508	
Wadi 3	Joint Point 2 (Wadi Fara + Wadi Sweanit)	13/3/2005	6.71		608	
Wadi 5	Al Mu'aqr point	13/3/2005	7.75		600	
PW1	Point before split to canal	13/3/2005	7.53		588	
Wadi Fara 1	Wadi Fara 200 m a head	31/03/2005	7.67		568	
Wadi Fara 2	Wadi Fara 500 m ahead	31/03/2005	7.73		568	
Wadi Fara 3	Wadi Fara 1 Km ahead	31/03/2005	7.91		564	
TP1	Water Treatment plant - inlet	14/02/2005	7.08		590	
TP1	Water Treatment plant - inlet	15/02/2005	7.12		592	
TP1	Water Treatment plant - inlet	16/02/2005	7.2		584	
TP1	Water Treatment plant - inlet	22/02/2005	7.17		595	
TP1	Water Treatment plant - inlet	07/03/2005	7.08		662	
TP1	Water Treatment plant - inlet	08/03/2005	7.16		660	
TP1	Water Treatment plant - inlet	09/03/2005	7.27		646	
TP1	Water Treatment plant - inlet	14/03/2005	7.06		639	
Wadi 3	Joint Point 2 (Wadi Fara + Wadi Sweanit)	05/04/2005	7.59		1202	
TP1	Al Qilt & Al Fawwar	05/04/2005	7.65		458	

## Appendix 2 (continued)

B1	AWWTP effluent	16/04/2005	7.65	95.0	1770	975
B2	Mikhmas Bridge	16/04/2005	7.76	162	1744	960
B3	Mikhmas Bridge-Stone crushing	16/04/2005	8.4	56	1940	1069
B2+B3	Joint point 1	16/04/2005	7.78	129	1738	957
Wadi 1	Wadi Sweanit	16/04/2005	8.2	108	1750	962
Wadi 2	Wadi Fara	16/04/2005	8.27	2	535	296
Wadi 3	Joint Point 2 (Wadi Fara + Wadi Sweanit)	16/04/2005	8.05	73	1314	724
Wadi 4	Joint Point 3 (Wadi Fara + Wadi Sweanit + Ein Al Fawwar)	16/04/2005	7.75	17	865	475
PW1	Point before split to canal	16/04/2005	7.8	25	660	365
PW2	Canal-500 m ahead	16/04/2005	7.93	22	670	369
PW3	Canal-1000 m ahead "house"	16/04/2005	7.93	23	675	373
PW4	Canal-1500 m ahead "after house"	16/04/2005	7.97	22	675	371
B1	AWWTP effluent	15/05/2005	7.92	9.05	1786	985
B2	Mikhmas Bridge	15/05/2005	7.74	26.5	1828	1001
Wadi 1	Wadi Sweanit	15/05/2005	8.32	49.4	1718	944
Wadi 2	Wadi Fara	15/05/2005	8.07	2	537	296
Wadi 3	Joint Point 2 (Wadi Fara + Wadi Sweanit)	15/05/2005	8.3	41.1	1400	769
Wadi 4	Joint Point 3 (Wadi Fara + Wadi Sweanit + Ein Al Fawwar)	15/05/2005	7.87	10.3	845	464
PW1	Point before split to canal	15/05/2005	7.9	7	633	340
PW2	Canal-500 m ahead	15/05/2005	8.1	8.35	647	350
PW3	Canal-1000 m ahead "house"	15/05/2005	7.15	6.83	640	350
PW4	Canal-1500 m ahead "after house"	15/05/2005	8.18	7.6	655	352

Appendix 3: Detailed analysis of major ions for all sampling stations along Wadi Al Qilt

Site ID	Sampling station name	Sampling Date	HCO <sub>3</sub> (mg/l as CaCO <sub>3</sub> )	Ca (mg/l)	Mg (mg/l)	Na (mg/l)	K (mg/l)	Cl (mg/l)	SO <sub>4</sub> (mg/l)	NO <sub>3</sub> (mg/l)
TP1	Water Treatment plant - inlet	29/11/2004	170	65.4		24.2	3.6	40	37	26
TP1	Water Treatment plant - inlet	30/12/2004	165					50	25	23
TP1	Water Treatment plant - inlet	30/12/2004	182	86.8		24	1.6	48	27	22
TP1	Water Treatment plant - inlet	10/01/2005	172	86.8		24.2	4.6	47	30	28
TP1	Water Treatment plant - inlet	10/01/2005	180	79.8		24.2	7	45	23	29
TP1	Water Treatment plant - inlet	24/01/2005	262	264		19.2	6.6	43	25	15
TP1	Water Treatment plant - inlet	25/01/2005	154	69		30.1	2.2	34	19	31
TP1	Water Treatment plant - inlet	26/01/2005	160	73		25.1	0	33	22	29
TP1	Water Treatment plant - inlet	27/01/2005	155	69		27.6	0.5	35	25	28
TP1	Water Treatment plant - inlet	05/02/2005	156	38		105	2.4	38	21	24
TP1	Water Treatment plant - inlet	06/02/2005	127	38	10	107.5	2.4	36	21	24
TP1	Water Treatment plant - inlet	07/02/2005	138	61		30.1	1	29	26	25
B2	Mikhmas Bridge	06/03/2005		20		137	14	200		17
Wadi 3	Joint Point 2 (Wadi Fara + Wadi Sweanit)	06/03/2005		15		98	10	117		23
Wadi 1	Wadi Sweanit	13/3/2005		41		115	13.1	104		53
Wadi 2	Wadi Fara	13/3/2005		32.4		20.7	0	42		20
Wadi 3	Joint Point 2 (Wadi Fara + Wadi Sweanit)	13/3/2005		36.7		77.5	6.3	55		26
Wadi 5	Al Mu3aqar point	13/3/2005		41		32.7	0.6	53		24
PW1	Point before split to canal	13/3/2005		43.1	25	34.16	3.3	58		22
TP1	Water Treatment plant - inlet	14/02/2005						26	13	28
TP1	Water Treatment plant - inlet	15/02/2005						24	13	27
TP1	Water Treatment plant - inlet	16/02/2005						26	13	27
TP1	Water Treatment plant - inlet	22/02/2005						26	14	22
TP1	Water Treatment plant - inlet	07/03/2005						25	12	11
TP1	Water Treatment plant - inlet	08/03/2005						28	25	4
TP1	Water Treatment plant - inlet	09/03/2005						29	22	2
TP1	Water Treatment plant - inlet	14/03/2005						28	26	28
Wadi 3	Joint Point 2 (Wadi Fara + Wadi Sweanit)	05/04/2005						69	26	8
TP2	Al Qilt & Al Fawwar	05/04/2005						24	17	15
B1	AWWTP effluent	16/04/2005		48		211	22	205		14
B2	Mikhmas Bridge	16/04/2005		45		213	25	270		19

## Appendix 3 (continued)

B3	Mikhmas Bridge- Stone Cutting	16/04/2005		58		247	33	255		41
B2+B3	Joint point 1	16/04/2005		44		199	24	270		19
Wadi 1	Wadi Sweanit	16/04/2005		51		277	26	203		23
Wadi 2	Wadi Fara	16/04/2005		27		24	0	54		19
Wadi 3	Joint Point 2 (Wadi Fara + Wadi Sweanit)	16/04/2005		38		154	13	162		19
Wadi 4	Joint Point 3 (Wadi Fara + Wadi Sweanit +Ein Al Fawwar )	16/04/2005		44		63	5	87		27
PW1	Point before split to canal	16/04/2005		41		42	2	72		23
PW2	Canal-500 m ahead	16/04/2005		41		42	2	76		23
PW3	Canal-1000 m ahead "house"	16/04/2005		41		42	2	78		23
PW4	Canal-1500 m ahead "after house"	16/04/2005		41	21	41	2	97		22
B1	AWWTP effluent	15/05/2005		71	32	180	29	150		52
B2	Mikhmas Bridge	15/05/2005		73	33	182	31	178		55
Wadi 1	Wadi Sweanit	15/05/2005		68	33	191	31	164		60
Wadi 2	Wadi Fara	15/05/2005		56	21	21	3	43		25
Wadi 3	Joint Point 2 (Wadi Fara + Wadi Sweanit)	15/05/2005		66	30	143	23	145		51
Wadi 4	Joint Point 3 (Wadi Fara + Wadi Sweanit + Ein Al Fawwar)	15/05/2005		71	22	60	8	79		35
PW1	Point before split to canal	15/05/2005		66	20	33	4	55		37
PW2	Canal-500 m ahead	15/05/2005		71	21	40	4	51		38
PW3	Canal-1000 m ahead "house"	15/05/2005		72	21	36	4	49		40
PW4	Canal-1500 m ahead "after house"	15/05/2005		72	21	36	4	54		39

Appendix 4: Detailed analysis of BOD, COD, DOC of sampling stations along Wadi Al Qilt

Site ID	Sampling station name	Sampling Date	DOC (mg/L)	COD (mg/L)	BOD (mg/L)
Wadi 1	Wadi Sweanit	13/3/2005		98	43
Wadi 2	Wadi Fara	13/3/2005		48	19
Wadi 3	Joint Point 2 (Wadi Fara + Wadi Sweanit)	13/3/2005		38	36
Wadi 5	Al Mu3aqar point	13/3/2005		27	20
PW1	Point before split to canal	13/3/2005		46	31
B1	AWWTP effluent	16/04/2005	16.71±0.393	172	108
B2	Mikhmas Bridge	16/04/2005	17.67±0.141	479	136
B3	Mikhmas Bridge- Stone Cutting	16/04/2005	29.86±0.785	277	58
B2+B3	Joint point 1	16/04/2005	16.88±0.401	338	136
Wadi 1	Wadi Sweanit	16/04/2005	17.53±0.926	276	53
Wadi 2	Wadi Fara	16/04/2005	3.22±0.058	11	9
Wadi 3	Joint Point 2 (Wadi Fara + Wadi Sweanit)	16/04/2005	12.25±0.105	140	30
Wadi 4	Joint Point 3 (Wadi Fara + Wadi Sweanit + Ein Al Fawwar)	16/04/2005	5.89±0.519	58.5	24
PW1	Point before split to canal	16/04/2005	2.00±0.051	54	9
PW2	Canal-500 m ahead	16/04/2005	2.00±0.035	52	11
PW3	Canal-1000 m ahead "house"	16/04/2005	1.98±0.103	56	12
PW4	Canal-1500 m ahead "after house"	16/04/2005	1.87±0.079	55	14
B1	AWWTP effluent	15/05/2005	16.69±0.2	259	80
B2	Mikhmas Bridge	15/05/2005	15.83±0.096	200	72
Wadi 1	Wadi Sweanit	15/05/2005	15.63±0.155	151	67
Wadi 2	Wadi Fara	15/05/2005	2.0±0.0038	52	34
Wadi 3	Joint Point 2 (Wadi Fara + Wadi Sweanit)	15/05/2005	12.26±0.002	116	45
Wadi 4	Joint Point 3 (Wadi Fara + Wadi Sweanit + Ein Al Fawwar)	15/05/2005	4.92±0.032	96	46
PW1	Point before split to canal	15/05/2005	2.46±0.029	54	19
PW2	Canal-500 m ahead	15/05/2005	2.56±0.169	48	17
PW3	Canal-1000 m ahead "house"	15/05/2005	2.47±0.0026	48	16
PW4	Canal-1500 m ahead "after house"	15/05/2005	2.87±0.038	58	12

**Appendix 5: Total Coliform and Fecal Coliform of various sampling stations Through Wadi Al Qilt**

Site ID	Sampling site name	Sampling Date	TC	FC
TP1	Water Treatment plant - inlet	29/11/2004	TMTC	380
TP1	Water Treatment plant - inlet	07/02/2005	135	2
B2	Mikhmas Bridge	06/03/2005		$29*10^3$
B3	Mikhmas Bridge- Stone Crushing	13/3/2005		$11*10^4$
B1	AWWTP effluent	16/04/2005		$400 * 10^2$
B2	Mikhmas Bridge	16/04/2005		$350*10^2$
B3	Mikhmas Bridge- Stone Crushing	16/04/2005		$280*10^2$
Wadi 1	Wadi Sweanit	16/04/2005		$120*10^2$
Wadi 2	Wadi Fara	16/04/2005		25
Wadi 3	Joint Point 2 (Wadi Fara + Wadi Sweanit)	16/04/2005		$210*10^2$
Wadi 4	Joint Point 3 (Wadi Fara + Wadi Sweanit + Ein Al Fawwar)	16/04/2005		$42*10^2$
PW1	Point before split to canal	16/04/2005		$10*10^2$
PW2	Canal-500 m ahead	16/04/2005		$7*10^2$
PW3	Canal-1000 m ahead "house"	16/04/2005		$8*10^2$
PW4	Canal-1500 m ahead "after house"	16/04/2005		$16*10^2$
B1	AWWTP effluent	15/05/2005		TMTC
B2	Mikhmas Bridge	15/05/2005		TMTC
Wadi 1	Wadi Sweanit	15/05/2005		4500
Wadi 2	Wadi Fara	15/05/2005		48
Wadi 3	Joint Point 2 (Wadi Fara + Wadi Sweanit)	15/05/2005		5000
Wadi 4	Joint Point 3 (Wadi Fara + Wadi Sweanit + Ein Al Fawwar)	15/05/2005		1200
PW1	Point before split to canal	15/05/2005		128
PW2	Canal-500 m ahead	15/05/2005		139
PW3	Canal-1000 m ahead "house"	15/05/2005		150
PW4	Canal-1500 m ahead "after house"	15/05/2005		115

Appendix 6: Heavy metals analysis of several samples from various sampling stations through Wadi Al Qilt ( $\mu\text{g/L}$ )

Site I.D.	Sampling point name	Date	Ag	Al	Ba	Cd	Co	Cr	Cu	Fe	Li	Mn	Ni	Pb	Sr	Zn	Be	Se	Mo
B1	AWWTP effluent	16/04/05	0	0	48	3<LOD	5<LOD	0	0	35	7		0	26<LOD		169			
B1	AWWTP effluent	15/05/05	0	0	44	5	8	0	0	52	7		0	22<LOD		145			
B2	Mikhmas Bridge	15/05/05	0	0	30	0	9	0	0	67	7		0	16<LOD		129			
B2+B3	Joint point 1	06/03/05	0	0	39	0	8	5<LOD	0	8	7	3	7<LOD	0	527	39	0	0	0
Wadi 1	Wadi Sweanit	13/03/05	0	0	30	0	6<LOD	0	0	0	8	0	9<LOD	33<LOD	394	27	0	0	7<LOD
Wadi 1	Wadi Sweanit	15/05/05	0	0	13	0	15	0	0	24	7		0	9<LOD		127			
Wadi 2	Wadi Fara	13/03/05	0	0	52	0	0	0	0	0	0	0	3<LOD	0	190	11	0	0	0
Wadi 2	Wadi Fara	15/05/05	0	0	62	0	2<LOD	16	0	3<LOD	0		0	23<LOD		78			
Wadi 3	Joint Point 2 (Wadi Fara + Wadi Sweanit)	06/03/05	0	0	40	0	0	0	0	0	4	3	4<LOD	26<LOD	393	55	0	0	0
Wadi 3	Joint Point 2 (Wadi Fara + Wadi Sweanit)	05/04/05	0	0	32	0	0	9	0	20	4	5	3<LOD	0	359	30	0	0	0
Wadi 3	Joint Point 2 (Wadi Fara + Wadi Sweanit)	15/05/05	0	35<LOD	23	0	10	0	0	18	5		0	21<LOD		114			
Wadi 4	Joint Point 3 (Wadi Fara +Wadi Sweanit + Ein Al Fawwar)	15/05/05	0	0	32	0	17	0	0	2<LOD	0		0	5<LOD		101			
PW1	point before split to canal (stagnant water)	13/03/05	0	450	161	0	4<LOD	2<LOD	20	197	1<LOD		10<LOD	11<LOD		617			
PW1	Point before split to canal	15/05/05	0	0	36	0	14	0	0	0	0		9<LOD	30<LOD		92			
PW2	Canal-500 m ahead	15/05/05	0	0	37	0	16	0	0	13	0		0	31<LOD		113			
PW3	Canal-1000 m ahead "house"	15/05/05	0	0	36	2<LOD	13	0	0	11	0		0	46		95			
PW4	Canal-1500 m ahead "after house"	16/04/2005	0	0	45	1<LOD	6<LOD	0	0	1<LOD	1<LOD		0	9<LOD		107			
PW4	Canal-1500 m ahead "after house"	15/05/2005	0	0	36	4	11	0	0	2<LOD	0		5<LOD	19<LOD		90			
TP1	Inlet to treatment plant	10/01/2005	0	0	40	0	0	0	0	0	0	0	4<LOD	9<LOD	175	6	0	0	0
TP1	Inlet to treatment plant	06/02/2005	0	0	21	1<LOD	4<LOD	10	1<LOD	59	1<LOD		0	21<LOD		64			
LOD ( $\mu\text{g/L}$ )			7	40	2	4	7	7	6	7	4	2	15	40	0.5	2	0.3	75	8

LOD: Limit of detection

Appendix 7: Pearson correlations for analyzed parameters

		PH	Turbidity	EC	TDS	DOC	Ca	Na	K	Cl	NO <sub>3</sub>	NH <sub>4</sub>	BOD	COD
PH	Pearson Correlation	1	-0.140	0.202	0.001	0.151	-0.244	0.198	0.088	0.253	0.326*	-0.063	-0.043	0.014
	Sig. (2-tailed)	0.0	0.555	0.163	0.996	0.525	0.151	0.246	0.609	0.082	0.024	0.792	0.846	0.950
	N	49	20	49	20	20	36	36	36	48	48	20	23	23
Turbidity	Pearson Correlation	-0.140	1	0.673**	0.674**	0.626**	-0.326	0.737**	0.568**	0.866**	-0.417	0.632**	0.830**	0.821**
	Sig. (2-tailed)	0.555	0.0	0.001	0.001	0.003	0.161	0.000	0.009	0.000	0.067	0.003	0.000	0.000
	N	20	20	20	20	20	20	20	20	20	20	20	20	20
EC	Pearson Correlation	0.202	0.673**	1	1.000**	0.953**	-0.176	0.956**	0.961**	0.929**	0.267	0.401	0.831**	0.755**
	Sig. (2-tailed)	0.163	0.001	0.0	0.000	0.000	0.305	0.000	0.000	0.000	0.066	0.079	0.000	0.000
	N	49	20	49	20	20	36	36	36	48	48	20	23	23
TDS	Pearson Correlation	0.001	0.674**	1.000**	1	0.954**	0.112	0.989**	0.978**	0.928**	0.212	0.403	0.836**	0.738**
	Sig. (2-tailed)	0.996	0.001	0.000	0.0	0.000	0.639	0.000	0.000	0.000	0.370	0.078	0.000	0.000
	N	20	20	20	20	20	20	20	20	20	20	20	20	20
DOC	Pearson Correlation	0.151	0.626**	0.953**	0.954**	1	0.082	0.969**	0.945**	0.912**	0.199	0.381	0.742**	0.688**
	Sig. (2-tailed)	0.525	0.003	0.000	0.000	0.0	0.733	0.000	0.000	0.000	0.401	0.098	0.000	0.001
	N	20	20	20	20	20	20	20	20	20	20	20	20	20
Ca	Pearson Correlation	-0.244	-0.326	-0.176	0.112	0.082	1	-0.244	-0.020	-0.227	0.025	-0.388	0.080	0.017
	Sig. (2-tailed)	0.151	0.161	0.305	0.639	0.733	0.0	0.145	0.905	0.177	0.885	0.091	0.710	0.938
	N	36	20	36	20	20	37	37	37	37	37	20	24	24
Na	Pearson Correlation	0.198	0.737**	0.956**	0.989**	0.969**	-0.244	1	0.916**	0.910**	0.191	0.445*	0.840**	0.757**
	Sig. (2-tailed)	0.246	0.000	0.000	0.000	0.000	0.145	0.0	0.000	0.000	0.256	0.049	0.000	0.000
	N	36	20	36	20	20	37	37	37	37	37	20	24	24
K	Pearson Correlation	0.088	0.568**	0.961**	0.978**	0.945**	-0.020	0.916**	1	.879**	0.396*	0.293	0.797**	0.708**
	Sig. (2-tailed)	0.609	0.009	0.000	0.000	0.000	0.905	0.000	0.0	0.000	0.015	0.210	0.000	0.000
	N	36	20	36	20	20	37	37	37	37	37	20	24	24
Cl	Pearson Correlation	0.253	0.866**	0.929**	0.928**	0.912**	-0.227	0.910**	0.879**	1	0.183	0.583**	0.870**	0.870**
	Sig. (2-tailed)	0.082	0.000	0.000	0.000	0.000	0.177	0.000	0.000	0.0	0.208	0.007	0.000	0.000
	N	48	20	48	20	20	37	37	37	49	49	20	24	24

## Appendix 7 (continued)

NO <sub>3</sub>	Pearson Correlation	0.326*	-0.417	0.267	0.212	0.199	0.025	0.191	0.396*	0.183	1	-0.406	-0.034	-0.066
	Sig. (2-tailed)	0.024	0.067	0.066	0.370	0.401	0.885	0.256	0.015	0.208	0.0	0.076	0.873	0.760
	N	48	20	48	20	20	37	37	37	49	49	20	24	24
NH <sub>4</sub>	Pearson Correlation	-0.063	0.632**	0.401	0.403	0.381	-0.388	0.445*	0.293	0.583**	-0.406	1	0.487*	0.735**
	Sig. (2-tailed)	0.792	0.003	0.079	0.078	0.098	0.091	0.049	0.210	0.007	0.076	0.0	0.029	0.000
	N	20	20	20	20	20	20	20	20	20	20	20	20	20
BOD	Pearson Correlation	-0.043	0.830**	0.831**	0.836**	0.742**	0.080	0.840**	0.797**	0.870**	-0.034	0.487*	1	0.880**
	Sig. (2-tailed)	0.846	0.000	0.000	0.000	0.000	0.710	0.000	0.000	0.000	0.873	0.029	0.0	0.000
	N	23	20	23	20	20	24	24	24	24	24	20	24	24
COD	Pearson Correlation	0.014	0.821**	0.755**	0.738**	0.688**	0.017	0.757**	0.708**	0.870**	-0.066	0.735**	0.880**	1
	Sig. (2-tailed)	0.950	0.000	0.000	0.000	0.001	0.938	0.000	0.000	0.000	0.760	0.000	0.000	0.0
	N	23	20	23	20	20	24	24	24	24	24	20	24	24

\* Correlation is significant at the 0.05 level (2-tailed).

\*\* Correlation is significant at the 0.01 level (2-tailed).

## Appendix 8(a): Physical and chemical characteristics of the springs in Wadi Al Qilt

Site ID	Spring name	Sampling Date	pH	EC (μs/cm)	TDS (mg/L)	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	K (mg/L)	HCO <sub>3</sub> (mg/L as CaCO <sub>3</sub> )	Cl (mg/L)	SO <sub>4</sub> (mg/L)	NO <sub>3</sub> (mg/L)
AS/020	Ein Al Qilt	13/03/2005	7.4	514	380	41	24	28	0.3	232	48	15	21
AS/020	Ein Al Qilt	16/04/2005	7.24	550	302	37	-	22	0	-	78	-	17
AS/020	Ein Al Qilt	15/05/2005	7.24	620	341	71	19	26	2	237	61	14	39
AS/021	Ein Al Fawwar	06/03/2005	7.69	602	470	47	27	26	0.1	240	86	10	34
AS/021	Ein Al Fawwar	13/03/2005	6.8	608	267	43	-	27	0	236	55	-	27
AS/021	Ein Al Fawwar	16/04/2005	7.15	632	348	43	-	31	0	-	74	-	31
AS/021	Ein Al Fawwar	15/05/2005	7.27	539	290	64	19	23	2	242	45	13	30
AS/022	Ein Fara	31/03/2005	7.2	573	366	62	21	23	2	195	23	15	25
AS/022A	Ein Jumeiz	31/03/2005	7.18	577	364	66	22	22	1	192	25	15	21
AS/022B	Ein Ru'yan	31/03/2005	7.14	576	362	62	21	23	2	194	23	13	24

## Appendix 8(b): Fecal Coliform analysis of the springs in Wadi Al Qilt (CFU/100mL)

Date	06/03/2005	13/03/2005	31/03/2005	16/04/2005	15/05/2005	Average numbers
Spring name						
Ein Fara	-	-	0	-	-	0
Ein Jumeiz	-	-	0	-	-	0
Ein Ru'yan	-	-	0	-	-	0
Ein Al Fawwar	0	12	-	2	3	4
Ein Al Qilt	-	3	-	28	0	10

Appendix 8(c): COD, BOD<sub>5</sub> and DOC of Ein Al Fawwar and Ein Al Qilt springs

Spring name	Date	COD (mg/L)	BOD <sub>5</sub> (mg/L)	DOC (mg/L)
Ein Al Fawwar	13/03/2005	13	10	-
Ein Al Qilt	13/03/2005	22	13	-
Ein Al Fawwar	16/04/2005	24	0	2.45
Ein Al Qilt	16/04/2005	16	0	2.07
Ein Al Fawwar	15/05/2005	38	17	0.582
Ein Al Qilt	15/05/2005	24	9	0.958

Appendix9: Heavy metals concentration of springs in Wadi Al Qilt ( $\mu\text{g/L}$ )

Sampling point	Date	Ag	Al	Ba	Cd	Co	Cr	Cu	Fe	Li	Mn	Ni	Pb	Sr	Zn	Be	Se	Mo
Ein Fara	31/03/2005	0	0	55	0	0	0	0	0	0	0	3<LOD	0	190	11	0	0	0
Ein Ru'yan	31/03/2005	0	0	57	36	3<LOD	0	0	0	0	0	5<LOD	0	193	9	0	0	0
Ein Jumeiz	31/03/2005	0	0	54	3<LOD	8	0	0	0	0	0	2<LOD	0	200	16	0	0	0
Ein Al Fawwar	06/03/2005	0	0	36	0	0	0	0	0	0	0	10<LOD	151	8	0	0	0	
Ein Al Fawwar	15/05/2005	0	0	36	4	8	0	0	0	0	-	0	31<LOD	-	95	-	-	-
Ein Al Qilt	13/03/2005	0	0	33	2<LOD	9	11	0	8	0	0	0	18<LOD	154	87	0	0	0
Ein Al Qilt	15/05/2005	0	0	37	4	10	11	0	11	0	-	0	102	-	93	-	-	-
<b>LOD (<math>\mu\text{g/L}</math>)</b>		<b>7</b>	<b>40</b>	<b>2</b>	<b>4</b>	<b>7</b>	<b>7</b>	<b>6</b>	<b>7</b>	<b>4</b>	<b>2</b>	<b>15</b>	<b>40</b>	<b>0.5</b>	<b>2</b>	<b>0.3</b>	<b>75</b>	<b>8</b>

LOD: Limit of detection

Appendix 10: Suggested wavelengths, estimated detection limits, alternate wavelengths, calibration concentration, and upper limits using ICP (source: APHA, 1995).

Element	Suggested Wavelength (nm)	Estimated detection limit ( $\mu\text{g/l}$ )	Alternate Wavelength* (nm)	calibration concentration (mg/l)	upper limits concentration (mg/l)
Aluminum	308.22	40	237.32	10.0	100
Barium	455.40	2	493.41	1.0	50
Beryllium	313.04	0.3	234.86	1.0	10
Cadmium	226.50	4	214.44	2.0	50
Calcium	317.93	10	315.89	10.0	100
Chromium	267.72	7	206.15	5.0	50
Cobalt	228.62	7	230.79	2.0	50
Copper	324.75	6	219.96	1.0	50
Iron	259.94	7	238.20	10.0	100
Lead	220.35	40	217.00	10.0	100
Lithium	670.78	4\$	-	5.0	100
Magnesium	279.08	30	279.55	10.0	100
Manganese	257.61	2	294.92	2.0	50
Molybdenum	202.03	8	203.84	10.0	100
Nickel	231.60	15	221.65	2.0	50
Potassium	766.49	100**	769.90	10.0	100
Selenium	169.03	75	203.99	5.0	100
Silver	328.07	7	338.29	2.0	50
Sodium	589.00	30**	589.59	10.0	100
Strontium	407.77	0.5	421.55	1.0	50
Zinc	213.86	2	206.20	5.0	100

\* Other wavelengths may be substituted if they provide the needed sensitivity and are corrected for spectral interferences.

\*\* Sensitive to operating condition.

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(2005) ( 2004)