Pro-Aquifer

Protecting Trans-boundary Groundwater Sources from Pollution: Research, Training and Guidelines for Palestinian and Israeli Municipalities

June 2008

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Protecting Trans-boundary Groundwater Sources from Pollution

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CHAPTER ONE  INTRODUCTION

1.1. Scope of Pro-Aquifer project

The Pro-Aquifer project addresses the protection of groundwater resources from pollution, in the context of shared Israeli-Palestinian groundwater from the unique perspective of local municipalities. This project aims to help municipalities identify polluting activities in their boundaries, as well as develop policy mechanisms and techniques on preventing groundwater pollution. High significance is placed on creating commitment within municipal officials and public figures to protect groundwater, and emphasis is placed on the trans-boundary nature of groundwater resources in the region, and the need to cooperate between Israelis and Palestinians on this crucial issue. Figure 1.1 provides a schematic overview of the main components and outputs of the Pro-Aquifer project.

The project has concentrated on two case studies: the Palestinian municipality of Tulkarm and the Israeli municipality of Umm el Fahem. The choice of these case studies is discussed further in the following section.

This report will provide a detailed description of the activities that pollute groundwater in the jurisdictions of the municipalities, with the aim of building a framework applicable to other municipalities as well. Consequently, guidelines will be developed for the assessment and measures to alleviate groundwater pollution from Israeli and Palestinian municipalities.
1.2. Choice of study areas: Municipality/Location

For the Pro-Aquifer project, two case study municipalities were selected for research: the Palestinian municipality of Tulkarm and the Israeli municipality of Umm el Fahem. Selection of the case study municipalities was primarily based on the criteria proposed by the Steering Committee in January 2007. These criteria included:

- Origin and type of pollution source
- Hydro-geological sensitivity – degree of sensitivity of the aquifer to pollution from a certain locale/pollution source
- Severity of pollution and risk of potential harm to aquifer
- Potential ecological effects
- Availability of data within municipality
- Applicability of the policy model to other municipalities
- Willingness of municipality to cooperate on project
- Population trends.

Selection of the Palestinian municipality case study

In an aim to identify the potential Palestinian city/municipality to be the focus of the Pro-Aquifer Project research and activities, the Palestinian team conducted a brief inventory of several locations and communicated with municipalities and residents in these locations to discuss their needs and willingness to participate in the project. The following table lists these cities:

<table>
<thead>
<tr>
<th>Location</th>
<th>Population (Based on PCBS 1997)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Ramallah</td>
<td>18,017</td>
</tr>
<tr>
<td>2 Beit Sahour</td>
<td>11,285</td>
</tr>
<tr>
<td>3 Beit Jala</td>
<td>12,239</td>
</tr>
<tr>
<td>4 Tulkarm</td>
<td>33,949</td>
</tr>
<tr>
<td>5 Salfit</td>
<td>7,103</td>
</tr>
<tr>
<td>6 Jericho</td>
<td>14,744</td>
</tr>
<tr>
<td>7 Jenin</td>
<td>26,681</td>
</tr>
<tr>
<td>8 Tubas</td>
<td>11,771</td>
</tr>
</tbody>
</table>

The next step was to apply the selection criteria set by the joint technical committee on each city and calculate the resulted scores based on these criteria. Table 1.2 summarizes the scores given to each city and displays the ranking of the cities based on their respective scores.

<table>
<thead>
<tr>
<th>City</th>
<th>Total Score</th>
<th>Rank</th>
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<tr>
<td>Tulkarm</td>
<td>9.1</td>
<td>1</td>
</tr>
<tr>
<td>Ramallah</td>
<td>7.8</td>
<td>2</td>
</tr>
<tr>
<td>Jenin</td>
<td>7.8</td>
<td>3</td>
</tr>
<tr>
<td>Salfit</td>
<td>7.7</td>
<td>4</td>
</tr>
<tr>
<td>Jericho</td>
<td>7.5</td>
<td>5</td>
</tr>
<tr>
<td>Beit Jala</td>
<td>7.4</td>
<td>6</td>
</tr>
</tbody>
</table>
Therefore, as Table 1.2 indicates, Tulkarm ranked in first place as the most appropriate case study for the project. The team communicated with the City Mayor and the Engineering Department staff regarding the project. They both expressed great interest in participating and cooperating.

Selection of the Israeli municipality case study
Following a similar process, the Israeli municipality case study was selected. The candidate Israeli municipalities included: Rosh Ha'ayin, Umm el Fahem, Hagilboa, Menasha, Zimmer, and Baka el Garbia. Several interviews with the Israeli Water Commission, Ministry of Environmental Protection and municipal officials were conducted to ensure that the selected municipalities met the criteria set and to acquire additional information. The selection criteria and resulting information were then assigned a weight for analysis, and a rank to differentiate between each city. The final score for each city was calculated as: Score = Weight * Rank. Table 1.3 displays the results.

<table>
<thead>
<tr>
<th>Weight %</th>
<th>Beit Sahour</th>
<th>Tubas</th>
<th>Hydro-geological sensitivity</th>
<th>Umm el Fahem (city)</th>
<th>Rosh haein (city)</th>
<th>Regional council menashe</th>
<th>Regional council hagilboa</th>
<th>Local council zimmer</th>
<th>Baka el garbia (city)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Rank</td>
<td>Score</td>
<td>Rank</td>
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<td>3</td>
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<td>7</td>
<td>108.5</td>
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<td>5</td>
<td>32.5</td>
<td>5</td>
<td>32.5</td>
<td>6</td>
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</tbody>
</table>
As it can be seen from the SUM line of table 1.3, Israeli municipalities that clearly stand out in terms of being most suitable for this project, based on the specified criteria are: Rosh Ha’ayin and Umm el Fahem. Umm el Fahem was ultimately selected on the basis of its greater level of willingness to cooperate with the project partners.

Thus, as noted above, the Palestinian municipality of Tulkarm and the Israeli municipality of Umm el Fahem were selected to be case study research sites for the Pro-Aquifer project.

1.3. Hydrological Importance

**Tulkarm Municipality**
Tulkarm area is located on the north-western strip of the Mountain Aquifer. This recharge area is particularly vulnerable to pollution from sewage, solid waste, agriculture and industrial pollution and other types of pollutants. The sensitivity is also attributed to the fact that the area of Tulkarm is also a location for groundwater utilization.

Sewage flow in the recharge area of the Mountain Aquifer leads directly to pollution of groundwater. Moreover, groundwater in that area is closer to the surface, requiring a shorter period of time for pollutants to percolate and reach it. Some of the most abundant water extractions from the Mountain Aquifer are located in that area. Alarmingly, it is also the location of some of the most serious pollution spots.

Unfortunately, Tulkarm district is served by a waste water treatment plant that is old, limited in capacity and that cannot cope adequately with today’s population. Plans to build a new sewage treatment plant exist, however, due to the political situation no work has taken place to date. The city’s sewage flows across the Green Line, and is treated in an emergency treatment plant in Israel.

**Umm el Fahem Municipality**
The Umm el Fahem region constitutes part of the recharge plain of the Mountain Aquifer. The area is also particularly vulnerable to any source of pollution since the outcropping formations within the region represent recharge zones for the Mountain Aquifer starting from Bina (Jerusalem) formation up to Soreq and Kisalon (Upper Beit Kahel) formations. Moreover, the majority of outcropping formations are marine sediments composed mainly of highly fractured carbonate rocks such as limestone, dolomite, and chalk.

The Umm el Fahem region is also characterized by the existence of several major faults and joints oriented east-westwards and by karstic features. These structures have significant contribution in increasing the recharge rates and consequently the infiltration rates of pollutions to groundwater. Therefore, the Umm el Fahem region is considered as one of the most sensitive areas with regards to any source of pollution.

1.4. Environmental Challenges

**Tulkarm Region**
Many potential groundwater pollution sources can affect the study area of Tulkarm which can be summarized in the following:
- Wastewater: domestic and industrial
- Solid waste dumping sites
- Agriculture activities
Both Palestinian communities and Israeli settlement activities contribute to the potential groundwater pollution that affect the Western Aquifer Basin which is lying over a very sensitive area and can be easily affected by any type of pollution which in turn adversely affects the area.

One of the most important environmental challenges that face Tulkarm is the existence of untreated wastewater of Wadi Zeimer, which passes through the city. This wadi has several adverse impacts on the whole environment of the area.

**Umm el Fahem Region**

Israel joined the global effort for environmental protection and established a designated Ministry of the Environment in December 1988. The ministry aimed to gather various divisions that were previously distributed in different ministries, such as the Ministry of the Interior, Ministry of Health and Ministry of Agriculture. A specific unit at the Israeli Central Bureau of Statistics (CBS) to collect data related to environmental issues was established to fulfill the need for reliable information to support evidence based on decision processes. (CBS, 2006)

Consecutive years with below average rainfall accompanied by increased water consumption due to population growth and increased living standards have escalated the water shortage problem in the region. In addition to problems related to water quantity, there is also concern about water quality, and intensive consumption has caused a decline in water quality as well (CBS, 2006).

**1.5. Objectives of the project**

The overall objective of the project is the alleviation of groundwater pollution sources from Israeli and Palestinian municipalities.

More specifically, the goals of the project are to:
1- Research sources of groundwater pollution from anthropogenic activity in Palestinian and Israeli municipalities.
2- Establish guidelines for monitoring, management and alleviation of sources of groundwater pollution in Palestinian and Israeli municipalities.
3- Strengthen technical know-how and build a network of Israeli and Palestinian water practitioners at the municipal level.
4- Create commitment within Palestinian and Israeli municipalities to improve environmental performance in their jurisdictions using the guidelines established.
CHAPTER 2 GENERAL DESCRIPTION OF THE STUDY AREAS

2.1 General Description of Tulkarm City

2.1.1 Location

Tulkarm city is situated on the western part of the northern West Bank, in the foothills of the Nablus mountains, about 15 kilometers west of Nablus. It is bounded by the Jenin, Nablus and Qalqilya districts in the north, east and south, respectively, and is bounded by the 1948 cease-fire line in the west. This central location between the plains and the mountains has made it commercially significant and has had a great effect on its growth. The rich farmlands of the surrounding area have also contributed to its development.

![Location map for Tulkarm city](image)

2.1.2 Topography and Drainage

Tulkarm city lies on the western slopes of the West Bank, which are characterized by gentle slopes. The elevation in the city ranges between 50 to 180 meters above sea level (see figure 2.2). There are many wadis located in the district such as Wadi Abu Nar, Wadi Ammar, Wadi Hawwatut, Wadi Zeimar etc.
The two main drainage systems in the Tulkarm area are:
1. Wadi Zeimar, which is the main sewage wadi in the region, and
2. Wadi Tin.

2.1.3 Climate
The climate in Tulkarm is similar to that of the Mediterranean type, which is characterized by long, hot, dry summers and short, cool, rainy winters. Tulkarm is distinguished by the moderating effect the sea breeze has on its climate. Rainfall is limited to the winter and spring months, mostly between November and March while summers are completely dry. Snow and hail, although uncommon, may occur anywhere in the area especially over the highlands. The average temperature in the winter ranges from 8 to 16 °C, while the average temperature in the summer ranges from 17 to 35°C.

The average annual precipitation rate in Tulkarm is about 640 mm (SUSMAQ, 2002), which is un-concentrated and irregular, characteristic of the Mediterranean Basin. The district has about six rainy months extending from October to April with 70% of the annual rainfall occurring between December and February and only 20% usually occurring in October and November and the remaining 10% between March and April. Infiltration rates are approximately in the range 30-40% of the annual precipitation, while runoff is approximately 2-5% of annual precipitation.

2.1.4 Population
Population increase is the fundamental parameter affecting future water needs. This determines not only municipal demand, but also agricultural demand (to feed the population) and industrial demand (to provide an economy to support the economic development of the population).
The current population of the Tulkarm district is estimated at 172,793 people, which includes the two refugee camps, Tulkarm and Nur Shams, representing about 7% of the total West Bank population (PCBS, 2006). The number of people living in the rural areas is estimated at 71,738, representing 41% of the total population of the district. About 21,464 people live in the refugee camps while the rest are residing in the urban areas.

2.1.5 Land Use
The Tulkarm city borders cover 13.8 km², which are approximately 6% of the total district’s area. The city is divided into six built up urban areas: Shweka, Anabta, Thinnaba, Tulkarm, Faron, and Irtah, as shown in figure 2.3.

![Figure 2.3 Urban blocks in Tulkarm city](image)

There are various land use classes within the municipality, including the built up areas and green lands, which include forests and shrub lands. Some of the local crops grown within the municipality borders are cauliflower and bush ocra. Figure 2.4 displays the various designated land use classes.
2.1.6  Soil
The major soil associations found in the Tulkarm district are Grumusols, Terra Rossa, Brown Rendzinas and Pale Rendzinas. These soil types are considered suitable for agricultural purposes. Figure 2.5 shows the major soil associations in the city.

The following is a description of the dominating soil associations:

Grumusols
Grumusols is a soil type association which covers about 1,201 hectares, or about 3.5%, of the district. It is found in an area with smooth to gentle sloping topography of Tulkarm. The soil is originally formed from fine textured alluvial or Aeolian sediments. The usage of this soil type is currently limited to cultivate wheat.

Terra Rossa, Brown Rendzinas and Pale Rendzinas
This type of soil association makes up a total area of 25,252 hectares, about 75% of the district. The parent materials from which this soil originally was initiated are mainly dolomite and hard limestone. This type of soil is a characteristic of the hilltop areas with numerous rock outcrops that could reach to about 30% to 50%. The soil depths of this type vary accordingly, starting from 0.5 meter at the mountainous areas and up to 2 meters at the hilltops. In general, this soil type has a pH range of 7.5-8.1 (slightly basic) with clay-to-clay loam soil texture. Cultivation of field crops, mainly wheat, barley, vineyards, olive and fruit trees, especially on valley shoulders, are the dominant agriculture patterns on these soils.
2.1.7 Geology

The geological formations of the Tulkarm governorate range in age from Upper Cretaceous to Quaternary. The district is mainly covered by sedimentary carbonate rocks such as limestone, dolomite, marl and chalk. The general geology of the Tulkarm area is represented in Figure 2.6. A brief description of the lithological formations encountered in the Tulkarm district is presented below (in order of older to younger):
Upper Cenomanian
The Upper Cenomanian formation (also known as the Bethlehem formation) consists of limestone, dolomite with chalk, and marl. Outcrops are found mainly on the flank of the A’nabta anticline. The dolomite forms a rugged morphology on gentle slopes.

Turonian
The Turonian formation (also known as the Jerusalem formation) consists of a series of massive, thick- to- thin bedded limestone to dolomitic limestone and dolomites with a thickness of approximately 70-130 m. The lower part of the Turonian formation consists mainly of limestone and dolomite with marl and some chalk, making it sometimes difficult to be distinguished from the underlying Bethlehem formation. Towards the top of this formation, chalk beds with occasional chert bands are common, and the formation is transitional to the overlying chalk facies. The Turonian formation has a well-developed karst feature and is commonly used as a building stone. It is exposed in the A’nabta anticline and is considered a very good aquifer.

Senonian
The Senonian formation is mainly made up of Cretaceous Rocks, which are composed of chalk. Outcrops exist in the A’nabat anticline and on the western limb of Nablus-Beit Qad syncline. In the A’nabta area, the chalk is thin and consists of marly base and passes upwards through bedded and crystalline limestone that has few marl partings.

Eocene
The Eocene formation is composed of tertiary rocks, which are exposed in the A’nabta area and in the Nablus-Beit Qad syncline. It is mainly composed of chalk and limestone. The exposure area of this sub-series is widespread and covers about one third of the total area of the Northern West Bank. Five facies of this formation have been identified: chalk with minor chert, chalk with minor interbedded nummulitic limestone, limestone with minor interbedded chalk, bedded massive nummulitic limestone and reef limestone. The presence of the limestone and the conglomerate lenses form a good aquifer while the chalk and marl act as a good aquiclude.

Quaternary
Quaternary rocks are divided into the following formations:
1. Lisan Formation: these recent sediments are mainly composed of alluvium consisting of limestone, chert and clay. The thickness of these sediments varies from one place to another. The rock fragments comprising the deposits are mainly derived from rock formations adjacent to the wadi area.
2. Nari Formation: it occurs mainly in high rainfall areas where carbonate rocks are dissolved by percolating water. It forms a thin coating over the limestone with a thickness of about 10-15 m.
## Figure 2.7  Stratigraphic Section of the West Bank (Source: HWE database)
2.1.8 Hydrogeology

The Tulkarm district is underlined hydro-geologically by the northern part of the western groundwater basin. It is located in the semi-coastal region. The aquifer in the Tulkarm area makes up the northwestern part of the West Bank aquifer to the west of the regional watershed. It subdivides the Mountain Aquifer into east and west basins. Groundwater flow is directed towards the west and northwest.

2.1.9 Aquifers

The major aquifers in the area are the Shallow Aquifer and the Upper Cenomanian-Turonian complexes. The Abu Dis acts as an aquitrad hence, forming a water barrier. Since the Upper Aquifer is the predominant aquifer in the region, it is described in full below.

![Aquifers in Tulkarm city](image)

**Figure 2.8 Aquifers in Tulkarm city**

**The Upper Aquifer System**

The Upper Aquifer is represented by the formations of the age Turonian (Jerusalem formation) and Cenomanian (Bethlehem and Hebron formations).

**Turonian Aquifer**

The Turonian aquifer is part of the Upper Aquifer but can be classified as a distinct local aquifer if the formation beneath it acts as an aquitard as is the case in some areas in the eastern and southern parts of the West Bank. The Turonian aquifer is considered a fairly good aquifer especially where the saturation thickness is in tens of meters. This aquifer is of good thickness and extent in the Tulkarm area (approximately 130 m thick). The
water quality of this aquifer is generally good but in some areas there is evidence of deterioration because of sewage and agro-chemical pollution.

**Cenomanian Aquifer**
The formations of this aquifer are the Bethlehem and Hebron. The aquifer is an important regional source of water supply for domestic use. The Cenomanian Aquifer has high recharge values. It is heavily exploited in the areas near Tulkarm and Qalqilya because the aquifer is at a shallow depth in this area. The depth to water is rarely more than 200 m below ground surface.

### 2.1.10 Wells and springs

There are no springs in the Tulkarm district therefore wells have been constructed to utilize the groundwater resources. These groundwater wells are used to provide water for both domestic and irrigation purposes. Figure 2.9 shows the locations of the groundwater wells in Tulkarm.

![Groundwater wells in Tulkarm city](image)

There are a total of 67 wells in the Tulkarm district, 25 of these wells are located within the municipality borders (figure 2.9). Three of the 25 wells are used for domestic purposes, while 21 are used for agriculture. One well is abandoned (HWE database).

### 2.1.11 Surface water

The Tulkarm area contains several wadis, which drain the region to the west and finally to the Mediterranean Sea. Wadi Zeimar, is the main wadi in the region. However, in the dry season, the water flow in the wadi is purely raw wastewater, made up of domestic and industrial wastewater discharged from the Nablus, Anabta...
and Tulkarm areas.

2.1.12 Infrastructure
   2.1.12.1 Sewage lines and Cesspits

Wastewater generated by households is either transported by sewers to central facilities for treatment and disposal or disposed of on-site by some type of cesspits. Wastewater disposal services (sewage networks) are available to about 75% of the localities within the Tulkarm municipality borders and refugee camps. The remaining 25% are served with cesspits (as shown in figure 2.10), the contents of which are pumped by tanks, transported and dumped into wadis and open areas, accompanied by large amounts of harmful bacteria, viruses and undesired microorganisms.

![Figure 2.10 Areas served by cesspits in Tulkarm city](image)

Approximately 60km of main and lateral sewage network is available in Tulkarm city. The diameter of the existing pipes in the network (main and lateral) ranges from 6-24”. The city is served by a combined system, thus the streets are normally flooded in the rainy season. The wastewater is collected by four interceptors and one force main and conveyed to the existing wastewater treatment ponds, which are located in the western part of the city, adjacent to the Green line.
The major cause of groundwater pollution is probably the seepage of wastewater from cesspits. Most of the cesspits in the Tulkarm district are built without a concrete basement in order to encourage sewage infiltration to the ground and thus minimize the cost of emptying. Sewage infiltration from cesspits into the ground formations may reach the groundwater aquifer, constituting a major source of groundwater pollution. Most of the cesspits are emptied by vacuum tankers and disposed of into the main sewage wadi - Wadi Zeimar.

2.1.12.2 Failure points
There are quite a few failure points in the wastewater collection network in Tulkarm, due to ageing and deterioration of the pipes. The force main, which conveys wastewater to the pumping station at Irtah, is in relatively good condition and does not contain any significant failure points.

2.1.12.3 Illegal connections
Unaccounted for water, the difference between the amount of water supplied and the amount billed, is mainly caused by leakage in the system and illegal connections. The leakage in the system is estimated around 30% - 40%.

In many places around the city people have connected themselves illegally to the sewage system as well. These pirate connections are a hazard to the sewage line and can act as a trigger for failures in the main line because of the added pressure on the system, resulting in leaks that are considered a hazard to the groundwater.

2.1.12.4 Pumping Stations
There is one wastewater pumping station in Tulkarm, located in the south-eastern part of the city. This pumping station was established in 1997 and consists of 3 submersible pumps, connected in parallel. Water is pumped from the north in Irtah to the sedimentation ponds in the western part of the city. The pumping station is maintained regularly, thus no leakage is recorded. Steel coated, concrete pipes connect the pumping station to the sedimentation ponds, so very little leakage occurs there as well.
2.2 General Description of Umm el Fahem

2.2.1 Location

Umm el-Fahem- meaning ‘Mother of the Charcoals' in Arabic- was established in the 13th century and is Israel’s second fully Arab town after Nazareth. It is located on the Israeli side of the green line - the border with the territories occupied in 1967 - and is the main center of the Wadi Ara area.

![Location map for Umm el Fahem study site](image)

Figure 2.12 Location map for Umm el Fahem study site

2.2.2 Topography

The Umm el Fahem region constitutes part of the recharge plain of the Mountain Aquifer. The elevation of the city ranges between 220 to 510 meters above sea level. This area is characterized by the existence of several major faults and joints oriented east-westwards and by karstic features. These structures have significant contribution in increasing the recharge rates and consequently the infiltration rates of pollutions to groundwater.
2.2.3 Climate

The climate in Umm el Fahem is similar to that of Tulkarm, which is characterized by long, hot, dry summers and short, cool, rainy winters. The temperature in the winter averages about 10°C, while the average temperature in the summer is about 32°C.

2.2.4 Population

Umm el Fahem was granted status as a local council in 1960 and became a municipality around 1985. Its area covers approximately 5,625 acres, which is about 23 km². It has 41,000 inhabitants, all of which are Muslim, with a natural population growth rate of 2.7% per year. It ranks very low on the socioeconomic scale -- the municipality has been given a rating of 2 out of 10 by the Israeli Central Bureau of Statistics -- in terms of unemployment, income, etc.

2.2.5 Land Use

The Umm el Fahem region is classified into five main land use categories, as shown in figure 2.13. The central built up urban area covers about 2.5 km², while the inclusion of the suburbs leads to a total built up area of approximately 3.9 km². The remaining surrounding lands are mainly orchards, shrub lands and forests, with some small, dispersed areas of field crops.

![Figure 2.13 Land use classification for Umm el Fahem study area](image)

2.2.6 Soil

The soil in the Umm el Fahem region is volcanic in origin, and therefore is very porous and full of cracks, which makes the Aquifer very susceptible to contamination. The main soil types in the study area, as shown in figure 2.14, are:
• Terra Rossa and Rendzinas- on a moderate to partially steep slope
• Terra Rossa- on steep slope
• Alluvium and Grumusols
• Brown rendzinas and light rendzinas- on moderate to partially steep to very steep slopes
• Brown rendzinas- on moderate to partially steep to steep slope

![Figure 2.14 Major soil associations in Umm el Fahem](image)

**2.2.7 Geology**

The geological formations in the Umm el Fahem study area range in age from Upper Cretaceous to Tertiary. The Umm el Fahem region is mainly covered by chalky Limestone and karstic Dolomite of the Upper Cenomanian period. The outcropping formations are of Cenomanian to Quaternary age (see figure 2.15). Lithological composition of these formations consists mainly of limestone, dolomite, marl and chalk.
2.2.8 Hydrogeology

The groundwater resources used by Israel are abstracted from aquifers extending from the West Bank of the Jordan River to the Mediterranean Sea. Although this area comprises two countries, the groundwater system is shared disregarding the political boundaries. Umm el Fahem has a total water intake of 2,900 cubic meters yearly, divided accordingly:

- Domestic: 71.24%
- Municipal: 10.66%
- Building: 5.13%
- Industrial: 1.4%
- Water loss: 11.57%

![Figure 2.15 Outcropping geological formations in Umm el Fahem](image)

![Figure 2.16 Water use in Umm el Fahem](image)
2.2.9 Aquifer Basins

The Umm el Fahem region lies over two main shared aquifer basins: the Western basin and the Northeastern basin, as shown in the figure below.

![Aquifer Basins Diagram](image)

The western aquifer basin is one of the main aquifer basins shared between the Palestinian and Israelis. Eighty percent of the recharge area of this basin is located within the West Bank, while 80% of the storage area is located within the Israeli borders. One of the two wells in Umm el Fahem taps into this basin, whose water flows towards the west. The two main aquifers which are present in the western basin are the upper and lower aquifers.

The northeastern aquifer basin drains the Eocene aquifer and Neogene aquifers. The groundwater in this basin flows north and northeast towards Bisan natural outlets (springs) in Israel.

2.2.10 Wells and springs

There are about 17 natural springs in the vicinity, some flowing through the city, as well as 2 wells. The two wells, constructed in 1968 and 1977, are both used for domestic (mainly drinking) purposes.
2.2.11 Infrastructure

2.2.11.1 Sewage lines and Cesspits

About 85%-90% of Umm el Fahem`s neighborhoods are connected to the main sewage system. The remaining 15% are connected to septic tanks and are due to be connected to the main system (there is an approved plan) in the near future. Septic tanks constitute a major hazard to ground water as many times they are maintained poorly and leak. There are at least 2 large neighborhoods within Umm el Fahem that are not connected to the main sewage system and rely on septic tanks. There is an additional neighborhood that does not even have a septic system/tank. So the municipality connected the latter houses to an above ground septic system that runs the sewage into the wadi at some distance from the neighborhood. According to the municipality, this is due to change in the near future that a new sewage line (no`10) has been approved by the relevant authorities and will be built that will connect all 3 of these neighborhoods to the main system. But this does not mean that every individual household will be connected, and it will be the responsibility of the municipality to enforce connections. Each household must pay to be connected, so this could be a problem.

Umm el Fahem has a drainage system running parallel to the sewage system. The diameter of some of the system is not sufficient to collect the entire runoff, so the system frequently backs up and overflows. This poses an extreme hazard to ground water, because the water picks up oil and other materials/waste from the street that is hazardous and/or toxic, or otherwise poses a threat. The municipality is working on replacing much of the drainage system, but part of the problem of runoff is that the entrances to the system are clogged with debris, because they are not regularly maintained.

2.2.11.2 Gutters – connected to sewage system

Umm el Fahem is located on hilltops and has very sharp slopes. During the winter, the slopes of the roads cause rainwater to runoff and hit the houses that sit below the road in heavy bursts. In addition to water falling on the roads themselves, additional rainwater comes pouring onto the road(s) from the roofs of houses that sit above the
road(s). As such, the houses below the road are at risk of flooding. The solution to this problem was to connect the gutters of the roofs to the sewage system- with the parallel drainage system. The connecting of the gutters to the sewage system puts too much pressure on the sewage system and causes it to back up and break down. This, in turn, causes the system to overflow and break down and cause sewage to back up onto the land, which is an environmental and health hazard in and of itself (and thereby poses a threat to ground water, as well).

2.2.11.3 Failure points

In both the drainage and sewage systems, 4-5 failure points exist. This is due, in both cases, to collapse of the concrete of which the pipes are made in/around the monitoring points along the lines.

2.2.11.4 Illegal connections

In many places around the city people have connected themselves illegally to the sewage system. These pirate connections are a hazard to the sewage line and can act as a trigger for failures in the main line, because it will put too much pressure on the system, resulting in leaks that are considered a hazard to the ground water.

2.2.11.5 Pumping Stations

Most of Umm el Fahem's sewage system works by gravity. There is one pumping station. Originally, it was designed as a sewage treatment facility for small quantities, but it collapsed. However, the municipality converted it into a pumping station, which means sewage now is pumped from this station to another location (no local treatment occurs). Because this structure was not designed as a pumping station, it does not operate very effectively. Moreover, the pumping station, as such, is poorly maintained and constitutes both a health and ground water threat. Thus, there is constant leaking and flooding of raw sewage from the station.
CHAPTER 3  GROUNDWATER POLLUTION SOURCES WITHIN THE STUDY AREAS

3.1 Pollution Sources within Tulkarm City

3.1.1 Domestic Wastewater

As in most sewer lines, leakages are regularly found. Any major leaks are usually immediately repaired by municipality personnel. Due to lack of data, it is difficult to determine the exact amount of leakage occurring in the sewage network. Interviews with engineers in the Tulkarm Municipality have indicated that approximately 55% of the wastewater running in the sewage network reaches the treatment plant, meaning that there is approximately 45% leakage in the sewer lines. The main sewer line leading from the pumping station, in the locality of Irtah (where the pumping station is located) to the treatment plant has not been reported to have been the source of any leakage.

Leakage of raw wastewater causes a great risk to groundwater contamination. If it reaches the water table, it is likely to contaminate nearby wells, which may be used for drinking and irrigation.

3.1.2 Industrial wastewater

There are several light industries in Tulkarm City. Stone-cutting facilities, building materials factories and garages are the most prevailing industries. In particular, these industries generate large amounts of liquid waste that is illegally disposed of either into open areas and planted lands or into the sewer pipes. The liquid waste consists of high amounts of grit and slurry which cause accumulation and clogging in the sewer pipes. Wastewater disposal practices of certain types of businesses, such as automobile service stations, dry cleaners, machine manufactures and metal fabricators (all found in Tulkarm City) are of particular concern because the waste they generate is likely to contain toxic chemicals.

3.1.3 Light industries

Some of the light industries found in Tulkarm city are: tile factories, cement factories, food industries (such as processed meat and dairy products), garages, gas stations, olive mills, slaughterhouses, stone cutters, metal cutters and some chemical industries. These are shown in figure 3.1. Modern economic activity requires transportation and storage of material used in manufacturing, processing, and construction. Along the way, some of this material can be lost through spillage, leakage, or improper handling. The disposal of wastes associated with these activities contributes to a source of groundwater contamination. Some businesses, usually without access to sewer systems, rely on shallow underground disposal. These cesspits are a form of disposal that can lead to contamination of underground sources of drinking water.

Wastewater disposal practices of certain types of businesses, such as automobile service stations, are of particular concern because the waste they generate is likely to contain toxic chemicals. Underground and above ground storage tanks holding petroleum products, acids, solvents and chemicals can develop leaks from corrosion, defects, improper installation, or mechanical failure of the pipes and fittings.
3.1.3.1 Gas stations
There are 5 main gas stations serving Tulkarm city. Three of these gas stations are located in very close proximity to each other in the center of the city. All the stations use underground storage tanks, yet there is no established monitoring system for leakage.

3.1.3.2 Olive mills
There are 2 olive mills in the Tulkarm Municipality borders. They are both located in Al-Shwaikheh, a suburb of Tulkarm City. Olive mill wastewater (OMW) is generated by the olive oil extraction process, which is a seasonal activity, only being carried out during the olive harvest season (from mid-October to early January). OMW from the two olive mills is disposed into the wadis where it mixes with untreated municipal wastewater and with rainwater. The high organic polluted wastewater affects the soil, groundwater and water courses downstream and causes a major problem for the treatment facility.

3.1.3.3 Slaughterhouses
There are two slaughterhouses in Tulkarm city. These slaughterhouses are required to have a permit issued by the Municipality. The slaughterhouses are regularly monitored by a veterinarian and Tulkarm Municipality staff, and they are required to hold a certificate issued by the Ministry of Health.

The main problem with slaughterhouse wastewater is that the effluent is concentrated with waste- mainly animal blood- which poses a great risk to the sewage system and the
wastewater treatment process. There is also the threat of infiltration of this contaminated water to the groundwater table.

### 3.1.3.4 Garages

There are several garages in Tulkarm. Runoff from these garages causes contamination of soil, as well as surface and groundwater pollution. Oil and gas spilled onto paved areas are easily washed away by water, either from hoses or rainfall and carried into surrounding lands and wadis. There is no on-site treatment of this contaminated water which may contain copper and brass from engine degreasers, as well as antifreeze, grease, oil, and even asbestos from engine and brake residues.

![Figure 3.2 Oil and grease runoff from garages in Tulkarm City](image)

### 3.1.4 Heavy industry

Heavy industries are those which involve the use of large or heavy machines or which produce large or heavy products, such as coalmining, ship-building etc. There are no such heavy industries in Tulkarm.

### 3.1.5 Solid Waste

In the entire Tulkarm district, there are a total of 15 dumping sites (PCBS, 2007). Most of these dumping sites have been made without concern for groundwater and aquifer contamination. Dumping sites are considered to be more localized “point” sources of potential groundwater pollution. As the nature of dumping sites in the West Bank are unlined and non-engineered, leachate generation during the winter season might contribute to groundwater pollution. There is no existing monitoring system for measuring any chemicals or metals that may periodically leach to the underlying aquifers.

There is no sanitary landfill for solid waste within the borders of the Tulkarm municipality. The solid waste generated is being dumped in a dumpsite that is located in an area of land, 3 km south of the city. The site does not comply with environmental standards and has not been approved by Palestinian authorities. Waste is being openly burned at the site throughout the day and medical and hazardous wastes are being buried at the site.
Smoke from the site reaches nearby residential areas in the area of Tulkarm as well as adjacent Israeli localities across the green line. Unavailability of funding remains a significant barrier for establishing sanitary landfills for Palestinians, and for rehabilitating established sites for both Palestinians and Israelis. Lack of funding prevents solutions such as a regional landfill for Nablus, Tulkarm and Qalqiliya or Hebron.

The lack of waste separation implies that hazardous and medical waste disposal is also uncontrolled. Batteries, liquid wastes, and potential hazardous wastes are mixed in with solid (household) wastes. Unluckily, hazardous solid waste is mixed with municipal solid waste during both collection and disposal. Liquid waste materials are disposed into uncontrolled dumping sites as well as sewers and cesspits.

![Figure 3.3 Waste being openly burned in the Anabta Dump site](image)

### 3.1.5.1 Legal dump sites

There are two main dumping sites just outside the Tulkarm municipality borders. The Anabta dumpsite is about 4 dunams or 4000m² in size, located on the east side of the city along the main Nablus road leading to the City. The Faru’un dumping site is approximately 10 dunams and is located south of the City.

These two dumping sites serve the Tulkarm City/municipality and the surrounding villages. These areas were not designated recently to be dumping sites, rather they have been used as dump sites long before anyone can remember. There are no licenses for these plots of land and there are no existing monitoring systems for measuring any chemicals or metal that may periodically leach to the underlying aquifers.

### 3.1.5.2 Illegal dump sites

Illegal dumpsites are quiet common in Tulkarm city. Random and scattered areas of land are used for dumping waste, varying from construction debris, car parts (including oils and grease, etc.) to domestic waste and slaughtered animal remains. As in several other Palestinian cities, the locations of these dumping areas are random, having been started
out of necessity by the communities without any specific concern for groundwater and aquifer contamination.

3.1.5.3 Restored sites

There are no restored sites in Tulkarm.

3.1.5.4 Transfer stations

As mentioned earlier, the existing uncontrolled solid waste dumping sites in Tulkarm represent a clear example of improper management of solid wastes. There are currently no sanitary landfills or transfer stations in Tulkarm, but as of this year, the Tulkarm municipality and House of Water and Environment obtained funding to design, construct and run a new proper transferring and sanitary landfill in Tulkarm city by the rehabilitation of an existing dumping site. This project is still in the initial stages, and is expected to begin sometime this year.

3.1.6 Agricultural

3.1.6.1 Runoff from fertilizers

The Tulkarm district has good fertile soil, suitable climate, and relatively high annual rainfall, rendering it prosperous in rain-fed farming and irrigated agriculture. Despite this fact, there are no areas of land within the borders of the Tulkarm municipality classified as agricultural lands yet there are some privately owned tracts of land grown with local crops of cauliflower, corn and Bush Ocra (a.k.a. “mlukhiyah”). There are only a few of these agricultural fields and they are quiet small in area, thus runoff from fertilizers does not constitute a significant hazard there.

Figure 3.4 Cauliflower and Bush Ocra fields in Tulkarm
3.1.7 Waste – organic matter

There are several privately owned, small-scale livestock sheds in Tulkarm City, containing primarily goats, sheep and chickens. These sheds are relatively small, thus the organic matter produced from them is negligible.

3.1.8 Other human activity that might contribute to groundwater pollution; other groundwater threats

Other potential sources of groundwater contamination are: airborne contaminants, surface water, and cemeteries. Contaminants that are transferred through the air may originate from a large number of sources such as industrialized and mining areas, urban areas, and road systems. Airborne contaminants released by these and other activities include nitrates, sulfates, and trace metals which travel through the air and then dissolve in rainwater reaching the land surface. Washing the contaminants down to the water table may pose a threat to groundwater quality. At cemeteries, the dead are buried in the unsaturated zone. Leachate from graves causes groundwater contamination, although such cases are not well documented.

3.2 Pollution Sources within Umm el Fahem

3.2.1 Domestic Wastewater

A number of wastewater leakages have been identified in the Umm el Fahem system and most of these have been addressed. As systems go, it is quite normal that from time to time a fault can happen that results in wastewater leakage. If for some reason the fault occurs at a certain location on a regular basis that would constitute a hotspot. In the past year, the Ministry of Environment contacted the municipality regarding problems with wastewater/leakages. Consequently, the municipality hired a private contractor to remedy such leakages. This has shortened response time to remedy such problems dramatically, thereby reducing the risk to groundwater contamination.

3.2.2 Industrial wastewater

There are hundreds of businesses in Umm el Fahem. Some 200 of them are required to conform to conditions from the Ministry of Environmental Protection in order to receive their business licenses. For example, industrial wastewater might exist, which might require pre-treatment. If there's no pre-treatment, then this could constitute a risk to ground water.

3.2.3 Light industries

The light industries found in Umm el Fahem are similar to those in Tulkarm. The main industries mentioned are gas stations, olive mills, slaughterhouses, and garages.

3.2.3.1 Gas stations

There are 2 formal gas stations in Umm el Fahem run by major gas companies, Dor and Paz. These are run according to law; they have underground storage tanks that are monitored regularly for leakage. On the other hand, Umm el Fahem has hundreds of above-ground gas tanks that operate as private illegal gas "stations," without any
protection/embankment/platform to prevent leakage. The locations of some of these tanks are often moved from place to place and are sometimes hard to find.

![Figure 3.5 Illegal gas stations in Umm el Fahem](image)

### 3.2.3.2 Olive mills
There is 1 olive mill in Umm el Fahem which is located on the western side of Route 65 – the main road going alongside the municipality. This side of the road is of low and medium sensitivity in terms of groundwater risk and, therefore, was not included in the survey of groundwater hazards. The subject of olive mills is most apparent in the Palestinian authority.

### 3.2.3.3 Slaughterhouses
There is 1 slaughterhouse in Umm el Fahem. The slaughterhouse is required, like other businesses, to have a business license (issued by the municipality). The Ministry of Environment can add restrictions to a business license, as noted above. The slaughterhouse is monitored by a veterinarian; however, the municipality typically does not enforce business licenses. The slaughterhouse has a lot of waste that poses a risk to the sewage system. The main concern is the grade of waste seeping into the sewage system, e.g., blood from carcasses. The main question is whether the slaughterhouse is complying with its business license requirements. And, if the slaughterhouse emits waste to the sewage system, then there is a potential risk for blockages that ultimately could pose a threat to ground water.

### 3.2.3.4 Garages
There are many garages in Umm el Fahem, all of which require permits from the Ministry of Environment. There are various stages in obtaining a business license; many garages are in the process of obtaining a license. The main problem arising from garages is the contamination of soil with oils, especially if there is no pre-treatment. Many garages are located in a high hydrological sensitivity area.

### 3.2.4 Heavy industry
Umm el Fahem does not harbor heavy industry.
3.1.5 Solid Waste

3.1.5.1 Legal dump sites
Umm el Fahem has 2 legal dump sites. One is a transfer station for household waste. The second is a disposal site for construction debris. Both of these sites are owned by the municipality and run by private companies. They are not well maintained compared to such sites in other municipalities. That said, they are, of course, better than illegal sites, especially since these legal sites have sufficient infrastructure so as to avoid groundwater contamination.

The municipality has a sanitation department that employs 5 people – responsible for identifying waste sites, etc. However, in reality, waste management is left to the Ministry of Environment. The Ministry has 1 officer responsible for approximately 20 municipalities, including Umm el Fahem, so enforcement is quite weak. This is why there are so many waste sites/illegal dumping in Umm el Fahem.

3.1.5.2 Illegal dump sites
The city has hundreds of illegal dump sites. These consist of many different types of waste (e.g., can range from slaughtered animal remnants to construction debris). There also is no real pattern to the location of such "sites," though many can be found at the outskirts of the neighborhoods and the city. Nevertheless, these sites are being monitored and they have been duly noted to be included in the mapping stage of this project. Illegal dump sites are a major hazard to ground water (and one of the primary hazards in Umm el Fahem), as many of these sites are very large in terms of the land area they cover.

Figure 3.6 Household waste at transfer station
3.1.5.3 Restored sites
Some of the illegal sites that existed for years were eventually addressed and restored by the municipality. One example is a playground that was constructed on an illegal dumping site. The problem with such sites is that the treatment is mainly cosmetic. The process of treatment was to cover the site with earth; this means that the waste itself was not treated and, significantly, still constitutes a significant threat to ground water. It is unlikely that there are any sites in Umm el Fahem that have been restored in a manner that does not threaten ground water.

3.1.5.4 Transfer stations
As previously mentioned, there is 1 transfer station in Umm el Fahem. Transfer stations are subject to a specific section of the Israeli law that specifies the requisite infrastructure, site maintenance, odor control, etc. In addition, business license law specifies the amount of waste that can enter the transfer station each day and the length of time waste can remain at that location. If judged by these specifications, the transfer station in Umm el Fahem fails to meet these national standards. Often, non-household waste ends up in this site. However, in reality, there is no real threat to ground water, because the station operates in a contained area over a concrete base that does not allow water to seep into the ground water. If the drainage system fails, then this station also could pose a severe threat to ground water, because the waste is so concentrated.
Rather, the non-household waste illegally disposed at this site poses a risk to community health, because it has animal waste, for example, lying on the ground. Birds, bugs and other animals swarming around the carcasses can carry germs and diseases from such waste to humans.

![Animal remnants dumped illegally in transfer stations](image)

**Figure 3.9** Animal remnants dumped illegally in transfer stations

### 3.1.6 Agricultural
#### 3.1.6.1 Runoff from fertilizers

Although historically there is a strong connection between land cultivation and the Arab way of life, Umm el Fahem has grown into a city and has shifted from agriculture to commerce. There are only very few agricultural fields and the ones that exist are also very small; thus, runoff from fertilizers (because not much is used) does not constitute a significant hazard to ground water there.

### 3.1.7 Waste – organic matter

There are some 50 livestock sheds scattered around Umm el Fahem. The total organic matter is negligible with respect to potential threat of groundwater contamination.

![Small herd of sheep](image)

**Figure 3.10** Small herd of sheep
3.1.8 Other human activity that might contribute to groundwater pollution; other groundwater threats

Lack of awareness is the primary reason for pollution/illegal waste disposal in Umm el Fahem that subsequently threatens ground water. As ground water can not be seen with the naked eye, people have the mistaken notion that garbage discarded on land will not constitute a hazard to ground water. However, even garbage illegally dumped on concrete has the potential via runoff, movement of the waste via a vehicle or person, etc., to eventually pose a threat to ground water. Generally, Umm el Fahem suffers from inadequate cleaning instruments and the cleaning of the city streets is left to a private contractor which does not perform up to standard and is politically hard to replace.

Figure 3.11 Inadequate cleaning instruments cause people to throw garbage in the streets
CHAPTER 4  VULNERABILITY, HAZARD AND RISK ASSESSMENT AND MAPPING

4.1 Vulnerability Assessment, Hazard and Risk Mapping for Tulkarm city

4.1.1 Vulnerability Assessment

Karst aquifers are well known for their particular vulnerability to contamination arising from their special characteristics, like thin soils, point recharge in dolines, shafts and swallow holes, as well as concentration of flow in the epikarst zone. Such characteristics result in contaminants easily reaching groundwater, where they are transported rapidly in karstic conduits over large distances. Since aquifers in the Tulkarm district are karst aquifers, the PI method for vulnerability assessment was adopted, considering that the PI method was specifically developed as a conceptual framework for mapping the vulnerability of karstic aquifers.

The PI Method is a GIS-based approach to mapping intrinsic groundwater vulnerability with special consideration of karst aquifers. It was adopted through the COST Action 620 program, which established a system for the mapping of intrinsic vulnerability of karst groundwater and for the characterization of the vulnerability of groundwater to specific contaminants or groups of contaminants.

The PI method is based on an origin-pathway-target model (Figure 4.1). The origin of the assumed hazard is the ground surface; the groundwater table in the uppermost aquifer is the target; the pathway includes the layers between the ground surface and the groundwater surface.
The PI-method takes two main factors into account: the Protective cover (P-factor) and the Infiltration conditions (I-factor).

The P-factor considers: soil field capacity, subsoil type, lithology type and fracturing, aquifer type and recharge conditions. The P-factor is divided into five classes; from P = 1 for a very low degree of protection to P = 5 for very thick and protective overlying layers. The spatial distribution of the P factor is shown on the P map.

The I-factor considers the infiltration conditions and accordingly the flow concentration of the surface water. The I-factor is 1.0 if the infiltration occurs diffusely, e.g. on a flat, highly permeable and free draining surface. In contrast, the protective cover is completely bypassed by a swallow hole, through which surface water may pass directly into the karst aquifer. The I-factor is 0.0 in such a case. The catchment of a sinking stream is assigned a value between 0.0 and 1.0, depending on the proportion of lateral flow components. The I-map shows the spatial distribution of the I factor. Figure 4.2 displays a simplified flow chart for the PI method.

The final protection factor $\pi$ is the product of P and I. It is subdivided into five classes. A protective factor of $\pi \leq 1$ indicates a very low degree of protection and an extreme vulnerability to contamination; $\pi = 5$ indicates a high degree of protection and a very low vulnerability. The spatial distribution of the $\pi$-factor is shown on the vulnerability map.

![Simplified Flow Chart for the PI Method](image)

**Figure 4.2** Simplified Flow Chart for the PI Method

### Determination of Protective Cover (P-Factor)

The P factor indicates the effectiveness of the protective cover. The calculation scheme is shown in Figure 4.3. The score B for the bedrock is obtained by multiplying the factor L for the lithology and the factor F for the degree of fracturing and karstification. The scores for the subsoil and the bedrock are then multiplied by the respective thickness in
m (factor M). The score for the total effectiveness of the protective cover $P_{TS}$ is calculated as shown in Figure 4.3. The range of possible scores for the total protective function $P_{TS}$ is subdivided into five classes, which are the final P factors in the PI method.

It can be misleading to assign a low vulnerability to an area where the aquifer under consideration is overlain by a higher aquifer. In this case, the higher aquifer needs protection. Therefore, the PI method always takes the groundwater table in the uppermost aquifer as the target. As a consequence, a higher aquifer is not considered to be protection for the underlying aquifer.
Figure 4.3  Determination of the P Factor

Determination of Infiltration Conditions (I-Factor)

The I-factor expresses the degree to which the protective cover is bypassed by lateral, surface and subsurface flow. If the infiltration occurs directly on a flat surface without significant concentration of flow, the I factor is 1.0, indicating that the protective cover is not bypassed and is 100 % effective. On the other hand, the protective cover is...
Protecting Trans-boundary Groundwater Sources from Pollution

completely bypassed by a swallow hole through which surface water directly enters the karst aquifer. In such a case, the I factor is 0.0. The catchment area of a sinking stream is assigned a value between 0.0 and 1.0 according to the extent of surface and subsurface flow. The spatial distribution of I-factor is shown on I map. Such flow is considered to be especially dangerous within the catchments’ area of a sinking stream because contaminants can directly enter the karst groundwater. Therefore, I factor (I map) is obtained using the following two components:

- The ‘I’-factor’ expresses the estimated direct infiltration relative to surface and lateral subsurface flow. The controlling factors are soil properties, slope and vegetation. The spatial distribution of I’-factor is shown on I’-map.
- The ‘surface catchments map’ shows the surface catchments’ areas of sinking streams disappearing into a swallow hole and buffer zones of 10 m and 100 m on both sides of the sinking streams.

The amount of surface and subsurface flow is dependent on rainfall intensity and site properties. Characteristics of single events, like precipitation rate, cannot be included in the concept of vulnerability – otherwise we would have to draw a different vulnerability map for each rain event. Therefore, the proportion of surface and subsurface flow is estimated only on the basis of the site properties and assuming average storm rainfall, which might occur several times per year.

The critical values for hydraulic conductivity and thickness were calculated using data and theoretical approaches from the hydrological literature (see Table 4.1):

- Infiltration is the dominant process when the hydraulic conductivity of the topsoil is greater than $10^{-5}$ m/s and the thickness is more than 100 cm.

- Fast subsurface storm-water flow is the dominant process when the thickness is between 30 and 100 cm and the conductivity is greater than $10^{-5}$ m/s; if it exceeds $10^{-4}$ m/s, very fast subsurface flow of more than 50 m/d is to be expected; macropores favor this process.

- Saturated overland flow is the dominant process if we find low permeable layers at depths of less than 30 cm and if the conductivity of the topsoil is greater than $10^{-5}$ m/s.

- Hortonian flow occurs rarely (rainfall intensity of 30 mm/h on steep slopes and 50 mm/h on gentle slopes) if the conductivity of the topsoil is between $10^{-5}$ and $10^{-6}$ m/s.

- Hortonian flow occurs frequently (rainfall intensity of 3 mm/h on steep slopes and 30 mm/hr on gentle slopes) if the conductivity of the top soil is less than $10^{-5}$ m/s.
Table 4.1: Determination of the Predominant Flow Process as a Function of the Saturated Hydraulic Conductivity and the Depth to Low Permeability Layers

<table>
<thead>
<tr>
<th>Hydraulic Conductivity (m/s)</th>
<th>Saturated Flow</th>
<th>Very Fast Subsurface Flow</th>
<th>Fast Subsurface Flow</th>
<th>Infiltration and Subsequent Percolation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.E-05</td>
<td>Hortonian Surface Flow</td>
<td>Rarely (only during storm rainfall)</td>
<td>Hortonian Surface Flow</td>
<td>Frequently (also during low intensity precipitation)</td>
</tr>
<tr>
<td>1.E-06</td>
<td>&lt; 30 cm</td>
<td>30-100 cm</td>
<td>&gt;100 cm</td>
<td></td>
</tr>
</tbody>
</table>

This system makes it possible to delineate areas with different flow processes predominate. However, there are often not enough detailed data to distinguish between the six different processes described above. In this case it is sufficient to differentiate between the three processes infiltration, subsurface flow and surface flow. This can often be done on the basis of geological data, information on the soil type and/or direct field observations. For example: Infiltration has to be expected on highly permeable Rendzinas soil on karst rocks; subsurface flow predominates on coarse rock debris covering low permeability formations; surface flow takes place on outcrops of marl and clay stone formations.

The proportion of each of these flow processes depends on the factors vegetation (land use) and slope of the ground surface. In general, forest cover favors infiltration, whereas agricultural areas are more likely to produce surface runoff. The flow velocity of subsurface flow can be estimated using the Darcy equation (except for preferential flow) and is directly proportional to the slope gradient. Hortonian runoff and saturated flow can occur even on very gentle slopes if the precipitation exceeds infiltration or if the topsoil is saturated, but steep slopes favour surface flow and increase its flow velocity.

A system to assess the proportion of lateral surface and subsurface flow was developed, based on the dominant flow process and the factors vegetation and slope. The slope was derived using the contour map of the area. The proportion of lateral flow is expressed by the so-called I’ factor. Its spatial distribution is shown on I’ map. However, for vulnerability mapping in karst areas, it is necessary to distinguish whether this flow occurs inside or outside the catchment area of a sinking stream as well as to take into account the distance of the evaluated site to the stream. With respect to groundwater vulnerability, the most dangerous situation is lateral flow close to a swallow hole or sinking stream, while the least dangerous situation is flow that leaves the system under consideration without sinking or seeping underground. Therefore, the final I map is obtained by intersection of I’-map with a map showing the catchment areas of sinking streams. Five zones are delineated on this “surface catchment map” in order of decreasing risk (Figure 4.4):
Figure 4.4  Topographical Sketch and Geological Profile Illustrating the Five Zones of the “Surface Catchment Map”

a. Swallow holes, the sinking streams and 10 m buffer zones on both sides of these streams.
b. 100 m buffer zones on both sides of the swallow holes and sinking streams.
c. The rest of the surface catchment areas of the sinking streams.
d. Areas outside the catchment of sinking streams but inside the topographic catchment of the (karst) system under consideration; surface and subsurface flow cannot enter a swallow hole but can infiltrate somewhere else, e.g. at the base of a slope or in a closed depression.
e. Areas that discharge by surface or subsurface flow out of the (karst) system under consideration. In that zone, surface and subsurface flow can never reach the groundwater.

The I’ map is intersected with the map of the surface catchment area are according to the scheme presented in Figure 4.5. I-map shows the degree to which the protective cover is bypassed by lateral surface and subsurface flow.
Production of Vulnerability Map

The vulnerability map shows the intrinsic vulnerability and the natural protection of the uppermost aquifer. The map shows the spatial distribution of the protection factor $\pi$, which is obtained by multiplying the P and I factors:

$$\pi = P \cdot I$$

The areas on each of the three maps are assigned to one of five classes, symbolized by five colors: from red for high risk to blue for low risk. Consequently, one legend can be used for all three maps as shown in Table 4.2.
Table 4.2 π-classes for the vulnerability map

<table>
<thead>
<tr>
<th>Color</th>
<th>Description</th>
<th>π - factor</th>
<th>V-Stress (Vulnerability of GW)</th>
<th>Descriptions</th>
<th>P - factor</th>
<th>Protection Cover</th>
<th>Descriptions</th>
<th>I – factor</th>
<th>Degree of Bypassing</th>
<th>Descriptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Red</td>
<td>Extreme</td>
<td>0-1</td>
<td>Very low</td>
<td>1</td>
<td>Very high</td>
<td>0.0 – 0.2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Orange</td>
<td>High</td>
<td>&gt; 1-2</td>
<td>Low</td>
<td>2</td>
<td>High</td>
<td>0.4</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yellow</td>
<td>Moderate</td>
<td>&gt;2-3</td>
<td>Moderate</td>
<td>3</td>
<td>Moderate</td>
<td>0.6</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Green</td>
<td>Low</td>
<td>&gt;3-4</td>
<td>High</td>
<td>4</td>
<td>Low</td>
<td>0.8</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Blue</td>
<td>Very low</td>
<td>&gt;4-5</td>
<td>Very high</td>
<td>5</td>
<td>Very low</td>
<td>1.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Figure 4.6** displays a flow chart for the preparing the PI (π) map. As it can be seen, the production of the π-map requires the intersection and union of several others overlays. Specific values can be deduced from the maps of the study area, based on methods outlined in COST 620.

The P-map was prepared based on COST 620 mathematical equations as shown below. The parameters were identified and the P-map was prepared as a grid map with a 2x2m cell size.

\[ P_{TS} = [T + S \times M + \left( \sum_{i=1}^{n} B_i \times M_i \right)] \times R + A \] (4.1)
The I-map was prepared by combining the I-factor map, which was derived by intersecting land use, slope gradient and dominant flow process evaluated under the surface catchment map. Then I-map was converted into grid map with cell size 2m x 2m.

The PI-map was constructed by multiplying the P-value for each cell with the I-value for the same cell. Hence, the PI-map is a grid map with cell size 2m x 2m.

**Thematic Maps Used for Calculating P-Factor**

The surface and subsurface soil, recharge, lithology and fracturing characteristics of the study area were prepared for the construction of the P-map as recommended by the European approach in COST620. The thematic maps are:

I. Soil Map: Top Soil (T Values) and Subsoil (S Values)

There are only two different types of soils in the study area: Grumusols and Terra Rossas, Brown Rendzinas and Pale Rendzinas. Top soil values (T value) and Subsoil values (S value) were determined based on the characteristics of these types of soil.

Unfortunately, very little information is available about the top soil and subsoil characteristics in the study area such as effective field capacity, soil texture, and hydraulic characteristics. Therefore, some assumptions based on the local soil experts were used for determining the T and S values. Field capacity values were measured for the soil types in the study area. For each soil type, the estimated/measured effective field capacity and its corresponding T value were assigned as shown in Table 4.3.
### Table 4.3 Top Soil Effective Field Capacity and Corresponding T Values

<table>
<thead>
<tr>
<th>Soil type</th>
<th>Measured / Estimated FC (mm/m)</th>
<th>Weighted Value (T)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Terra Rossa, Brown Rendzinas and Pale Rendzinas</td>
<td>446</td>
<td>750</td>
</tr>
<tr>
<td>Grumusols</td>
<td>460</td>
<td>750</td>
</tr>
</tbody>
</table>

The same soil map was used for determining the S-value. Based on the sub-soil types, the corresponding S values were determined as shown in Table 4.4. For each sub-soil type, the thickness (M) of each sub-soil type was estimated based on previous studies, topography and slope. It should be realized that the difference in S-value indicates the relative degree of variation of each soil for groundwater pollution protection.

### Table 4.4 Sub-Soil Types and Corresponding S Values

<table>
<thead>
<tr>
<th>Soil type</th>
<th>Sub-soil type</th>
<th>Weighted Value (S)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Terra Rossa, Brown Rendzinas and Pale Rendzinas</td>
<td>Clay</td>
<td>500</td>
</tr>
<tr>
<td>Grumusols</td>
<td>Clay</td>
<td>500</td>
</tr>
</tbody>
</table>

II. Geology Map and Topographic Map: Lithology and Fracturing (L and F) Values

Using the geological map of the West Bank, the outcropping geological formations for Tulkarm city were obtained. Using cross sections of the wells located in the city, the following parameters were identified:

1. Stratigraphical column in the study area.
2. Depth of each geological formation.
4. Depth to groundwater level.
4. Lithology of each geological formation.
5. The degree of fracturing, joining in each geological formation.
6. Main aquifers in the study area and their types (confined, unconfined).

It should be understood that the Lithology (L) and Fracturing (F) values refer to the unsaturated geological layers. Hence, knowing the depth to groundwater level, topographic elevation and the depth of each geological formation leads to identifying the thickness (M -parameter). Now according to equation 4.1, we have

\[
B = L \times F
\]

\[
\sum_{i=1}^{n} B_i \times M_i
\]

Where

\[
B = \text{Lithology and Fracturing (L and F) Values for the main unsaturated geological formations in Tulkarm city.}
\]

The value of (A) was determined based on the outcropping formations. If the aquifer is confined, then A=1500 otherwise A=0.

The geology Map (outcropping geological formations) of Tulkarm city is shown in Figure 4.8. This map was used to assign the B, M and A parameters for each outcropping formation.
Table 4.5 Lithology and Fracturing Values

<table>
<thead>
<tr>
<th>Period</th>
<th>Typical Lithology</th>
<th>Lithology Value (L)</th>
<th>Fracturing Value (F)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quaternary</td>
<td>Nari (surface crust) and alluvium gravels and fan deposits</td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td>Eocene</td>
<td>Reefal limestone, Nummulitic limestone and chalk</td>
<td>5</td>
<td>0.5</td>
</tr>
<tr>
<td>Senonian</td>
<td>Marl, chalk and chert</td>
<td>20</td>
<td>25</td>
</tr>
<tr>
<td>Turonian</td>
<td>White limestone, stilolites dolomite and thin bedded limestone</td>
<td>5</td>
<td>0.5</td>
</tr>
<tr>
<td>Upper Cenomanian</td>
<td>Karstic dolomite, dolomite, chalky limestone</td>
<td>5</td>
<td>0.3</td>
</tr>
</tbody>
</table>

III. Geology and Rainfall Maps: Ground Water Recharge Condition R Values

Recharge values were determined based on rainfall-recharge equations adopted and used in SUSMAQ project in the West Bank. These equations were applied depending on outcropping formations in the study area.

When the geological formations that form the main aquifers are outcropping, the following Rainfall-Recharge equations are applied. The R values are shown in Table 4.6.

\[
R = \begin{cases} 
0.6 \ (P - 285) & \text{if } P > 700 \ mm \\
0.46 \ (P - 159) & \text{if } 700 \ mm > P > 456 \ mm \\
0.3 \ (P) & \text{if } 456 \ mm > P 
\end{cases}
\]

where:

\[
R = \text{Recharge from rainfall in mm/yr} \\
P = \text{Annual rainfall in mm/yr.}
\]
Table 4.6  Groundwater Recharge Estimation for Different Mean Annual Rainfall and Corresponding Recharge Values (R)

<table>
<thead>
<tr>
<th>Mean annual rainfall (mm)</th>
<th>Recharge (mm/yr)</th>
<th>R value</th>
</tr>
</thead>
<tbody>
<tr>
<td>500-550</td>
<td>157-180</td>
<td>1.5</td>
</tr>
<tr>
<td>550-600</td>
<td>180-200</td>
<td>1.5</td>
</tr>
</tbody>
</table>

When the geological formations that form the main aquitard are outcropping, it is assumed that 2% of mean annual rainfall to be recharged. Hence, \( R = 1.75 \)

Finally, the P-map was prepared based on COST 620 mathematical equations as shown below.

\[
P_{TS} = \left[ T + S.M + \left( \sum_{i=1}^{n} B_i \times M_i \right) \right] \times R + A
\]

The value \( P_{TS} \) was calculated for each cell by using the previous described parameters maps, Hence, the P-map (Figure 4.9) is a grid map with cell size (2m X 2m) where each cell has its own value for \( P_{TS} \).

Figure 4.9  Protective Cover (P-map) for Tulkarm city
Thematic Maps Used for Calculating P-Factor

The soil, land use, contour, and drainage characteristics of the study area were prepared for the construction of the P-map as recommended by the European approach in COST620. The thematic maps are:

I. Soil Map: Determination of Dominant Flow

The same digital soil map which was used for identifying the T and S values was used in determining the dominant flow. The dominant flow process is assessed on the basis of the top soil permeability and the presence of low permeable layers. For some soil types, values of permeability have been estimated, for the rest types the determination of dominant flow was based on the local soil and geological experts.

The hydraulic conductivity of the following soil types was obtained from the HWE database:
- Terra Rossa $2.78 \times 10^{-7}$ m/s
- Grumusols $6.94 \times 10^{-9}$ m/s

The dominant flows for the different soil types were both estimated Hortonian surface flow, as shown in Table 4.7.

<table>
<thead>
<tr>
<th>Soil Type</th>
<th>Dominant Flow</th>
<th>Flow Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Terra Rossa, Brown Rendzinas and Pale</td>
<td>Hortonian Surface Flow</td>
<td>F</td>
</tr>
<tr>
<td>Rendzinas</td>
<td>Hortonian Surface Flow</td>
<td>F</td>
</tr>
<tr>
<td>Grumusols</td>
<td>Hortonian Surface Flow</td>
<td>F</td>
</tr>
</tbody>
</table>

II. Contour Map: Determination of Slope

Using a contour map for Tulkarm city, with a 10m interval (as shown in figure 4.10), a slope map for the region was created. This slope map was then categorized into three classes, as it is outlined in the PI-method.

The contour map of the study area and the derived slope map, on a 2x2m grid, are shown in the following figures.
Figure 4.10  Contour map with a 10m interval for Tulkarm city

Figure 4.11  Slope map for Tulkarm city
III. Land Use Map: Field/Meadow/Pasture Conditions (I’ Factors)

The landuse map of Tulkarm city (figure 4.12) was classified according to COST 620 into one type of landuse: Field/Meadow/Pasture.

Forest and Vegetation Condition

The I’ factor in the forest land use condition is derived depending on slope and dominant flow process as recommended by the PI method as shown in Table 4.8.

<table>
<thead>
<tr>
<th>Dominant Flow Type</th>
<th>Slope 0 – 3.5 %</th>
<th>Slope 3.5 – 27 %</th>
<th>Slope &gt; 27 %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type F</td>
<td>0.8</td>
<td>0.4</td>
<td>0.2</td>
</tr>
</tbody>
</table>

Field/Meadow/Pasture Condition

Similarly, the I’ factor in the field/meadow/pasture land use condition is derived depending on slope and dominant flow process as recommended by the PI method as shown in Table 4.9.

<table>
<thead>
<tr>
<th>Dominant Flow Type</th>
<th>Slope 0 – 3.5 %</th>
<th>Slope 3.5 – 27 %</th>
<th>Slope &gt; 27 %</th>
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<tr>
<td>Type F</td>
<td>0.6</td>
<td>0.2</td>
<td>0.0</td>
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</table>
The final I’-map was prepared by intersecting the following thematic maps 1) slope map, 2) land use map and 3) dominant flow process. The I’-map is shown in Figure 4.13.

IV. Drainage Map: Surface Catchment Map

The surface catchments map which shows the sinking streams (the sinking wadis in our case) and their catchments was created on the basis of a digital drainage map showing all wadis. The 10 m and 100 m zones were created with the buffer command (by using GIS) and the catchment of the sinking wadis were identified based on the topography of the study area. Figure 4.14 shows the surface catchment map.
Finally, the I-map, which shows the degree to which the protective cover is bypassed, is obtained by intersecting the I' map (showing the intensity of lateral flow) with the surface catchment map (showing the sinking wadis and their catchments). Table 4.10 shows the I-factors.

<table>
<thead>
<tr>
<th>Surface Catchment Map</th>
<th>I' Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>a 10 m buffer on both sides of sinking wadis</td>
<td>0.0 0.0 0.0 0.0 0.0 0.0</td>
</tr>
<tr>
<td>b 100 m buffer on both sides of sinking wadis</td>
<td>0.0 0.2 0.4 0.6 0.8 1.0</td>
</tr>
<tr>
<td>c Catchment of sinking wadis</td>
<td>0.2 0.4 0.6 0.8 1.0 1.0</td>
</tr>
</tbody>
</table>

The final I-Map was converted into grid map with cell size (2m x 2m), so as to calculate the PI map by multiplying each cell in the I-Map with the same cell in the P-Map.

The I-grid Map is shown in Figure 4.15.
Protecting Trans-boundary Groundwater Sources from Pollution

Vulnerability Map

The protection factor $\pi$ (Figure 4.16) was calculated by multiplying the P and I factors. The range of values for $\pi$ was subdivided in five classes of natural protection and vulnerability respectively.

Vulnerability Map of Tulkarm city

Figure 4.15  Map of the Parameter I of the PI Method

Figure 4.16  Vulnerability map of Tulkarm city
From the final PI-map, 4% of the study area is classified as extreme, 38% as high, 28% as moderate, 17% as low and 13% as very low. Hence, Tulkarm city is classified as high-to-moderate vulnerability.

**Figure 4.17** portrays the overlay process of the P and I maps which produced the final PI (π)-Vulnerability map.

### 4.1.2 Hazard Assessment and Mapping

An ‘environmental hazard’ is formally defined as “an event, or continuing process, which if realized, will lead to circumstances having the potential to degrade, directly or indirectly, the quality of the environment”. A hazard presents a risk when it is likely to affect something of value. Hazard Mapping is the preparation of hazard maps, and follows a 7-step work plan (**Figure 4.18**), starting from an Inventory of Hazards and leading to the eventual production of Hazard Maps.
Figure 4.17 Overlay process of P and I maps producing the final PI-Vulnerability map
Step 1: Definition and Inventory of Hazards

A hazard assessment considers the potential degree of harmfulness for each type of hazard. It is determined by both the toxicity and the quantity of harmful substances, which may be released as a result of a contamination event. To classify hazards, a systematic registration of different hazards needs to be based on clear criteria. Such criteria could be the time and duration a hazard is posed, the type of human activity or the nature of the harmful substances.

Step 2: Hazard Data Requirements

Assessing the potential degree of harmfulness for each type of hazard requires information on the following:
- process or nature of activity (production, storage, etc.)
- type of harmful substances
- amount of substances which can be released
- age and status of installations and plants

Step 3: Rating and Weighting of Hazards

In order to come up with a reliable assessment of a hazard, all the necessary details of the influencing factors have to be determined. These include the amount and harmfulness or toxicity of the possibly involved substances as well as an assessment of all factors influencing the likelihood that a release may occur, such as maintenance or security measures.

Weighting Procedure- The main criteria for weighting different hazards is the toxicity of relevant substances associated with each type of hazard as well as their properties regarding solubility and mobility. These determine the weighting coefficient or the “harmfulness of a hazard to groundwater (H)”. Using the hazard mapping approach proposed by COST 620, weighting values are listed in Table 4.11 and vary between 10 (lowest hazard) and 100 (highest hazard).

Ranking Procedure- For a comparison between hazards of the same type, all the different factors influencing the degree of harmfulness have to be considered. The

Figure 4.18: Work plan for the preparation of the hazard map
differences in harmfulness within each hazard category will be mainly due to the variable quantity (Qn) of harmful substances, which can be released into the underground.

In order to ensure a fair balance with the average weighting values, these weighting values should be slightly changed by multiplying them with a ranking factor between 0.8 and 1.2 in order to indicate low or high amounts respectively of toxic substances compared with the general average, i.e. low (0.8), medium (1.0) and high (1.2).

Likelihood of groundwater contamination- The technical status, level of maintenance, surrounding conditions and security measures surrounding the pollution sources are also important factors when assessing the probability that a contamination of groundwater may occur. Thus, a reduction factor is introduced. \( R_f \) is a coefficient which provides an assessment of the probability for a contamination event to occur. If no information on the above mentioned factors is available, then \( R_f = 1 \). Otherwise, positive information concerning the reduction of the likelihood can be used to reduce the Hazard Index. Theoretically the reduction factor may range from 1 to 0. When the \( R_f \) value is set to zero, it is considered that there is no risk of groundwater contamination, while a factor of 1 means that there are no reasons known to reduce the likelihood of pollution.

Calculation of the Hazard Index (HI)- The hazard index describes the degree of harmfulness of each hazard. For its calculation the following formula is recommended:

\[
HI = H \times Qn \times Rf
\]

Where: \( HI \) is the hazard index, \( H \) is the weighting value of each hazard as assigned in Table 3.3, \( Qn \) is the ranking factor (0.8 to 1.2) and \( Rf \) the reduction factor.
### Table 4.11: Hazard Weighting Values

<table>
<thead>
<tr>
<th>No.</th>
<th>Hazards</th>
<th>Weighting Value</th>
<th>map Symbols</th>
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</thead>
<tbody>
<tr>
<td>1.1</td>
<td>Infrastructural development:</td>
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<td></td>
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<td>1</td>
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<td>Urbanisation without sewer systems</td>
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<td>sewer farm, and waste water irrigation system</td>
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### Table 4.11 (cont.): Hazard Weighting Values

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</tbody>
</table>
According to the resulting Hazard Index, five Hazard Index Classes are defined and assigned a color for presentation on the maps. As shown in Table 4.12, the colors representing the potential degree of harmfulness of the different hazards are assigned according to the resulting Hazard Index. Starting from blue, representing no or a very low hazard level, and gradually increasing till reaching red, which is the obvious color to depict very high hazard levels.

Table 4.12: Hazard Index and Hazard Index Classes

<table>
<thead>
<tr>
<th>Hazard Index</th>
<th>Hazard Index Class</th>
<th>Hazard Level</th>
<th>Colour</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 - 24</td>
<td>1</td>
<td>no or very low</td>
<td>blue</td>
</tr>
<tr>
<td>&gt; 24 - 48</td>
<td>2</td>
<td>low</td>
<td>green</td>
</tr>
<tr>
<td>&gt; 48 - 72</td>
<td>3</td>
<td>moderate</td>
<td>yellow</td>
</tr>
<tr>
<td>&gt; 72 - 96</td>
<td>4</td>
<td>high</td>
<td>orange</td>
</tr>
<tr>
<td>&gt; 96 - 120</td>
<td>5</td>
<td>very high</td>
<td>red</td>
</tr>
</tbody>
</table>

Step 4: Graphical Interpretation

The hazards are represented on the map by means of symbols of different colour to indicate their potential degree of harmfulness as derived from the calculation of a Hazard Index (see Step 3). The mapping is performed using a Geographic-Information-System.

Step 5: Mapping Techniques

The integration of the data required for the purpose of hazard mapping will be performed using a Geographic-Information-System (GIS). GIS provides a means of representing the real world through integrated layers of spatial information.

Step 6: Data Evaluation

The 'Data Evaluation', can be linked to several tasks, including:
- Data quality
- Data integration
- Output evaluation; and
- Data sensitivity
Each of these tasks should be performed not only in relation to the hazard maps, but also in respect of vulnerability and risks maps.

Step 7: Production of Hazard Map

The final step in the work plan concerns the actual production of the hazard map. The hazards maps which will be prepared include both 'unclassified', i.e. showing only the relevant geographical location information, and 'classified' (based on a hazard index computation) hazard maps.
Classification, Rating and Weighting of Hazards in the Study Area

The hazards within the Tulkarm city were identified according to the hazard inventory proposed by COST 620, and mapped on topographic maps. All information on the infrastructure, such as roads and sewage networks were provided by the Tulkarm municipality. All the information pertaining to the various pollution sources within the city borders were gathered during through field visits to the study area.

Classification of hazards-

According to their spatial extension, three types of hazards were distinguished:

1- point source hazards
2- line source hazards
3- diffuse hazards

The most common point hazards in Tulkarm were identified as olive mills, quarries, gasoline stations, dumpsites, and wastewater treatment plants. These sources were mapped using GIS, as shown in figure 4.19.

Line hazards in Tulkarm city include main, regional, local roads as well as drainage and sewage wadis (figure 4.20).
Diffuse hazards (figure 4.21) result from urbanisation (leaking sewer pipes), areas served by cesspits, and agricultural lands.
Table 4.13 provides a detailed description of the contaminants for all the pollution sources considered

### Table 4.13: Description of contaminants for pollution sources and their effects on groundwater

<table>
<thead>
<tr>
<th>Pollution Source</th>
<th>Description of Contaminants</th>
</tr>
</thead>
</table>
| Olive Mill                       | • Olive mill wastewater is a serious environmental problem, due to its high organic COD concentration, and because of its high resistance to biodegradation due to its high content of biomass-inhibiting growth, mainly phenolic compounds.  
• Olive mill wastewater also typically contains polysaccharides, lipids, proteins, and a number of monocyclic and polymeric aromatic molecules, which might exhibit inhibition effects towards some specific anaerobic microorganism populations. |
| Quarry + Stone cutter            | • The wastewater is mainly composed of mud and water and can severely contaminate groundwater with the dissolution of the calcium and magnesium carbonate it contains.  
• Release of oil, grease and solvents may contaminate run-off storm water, groundwater, and soil.  
• Quarries extract the solid rock layer up to 30–40 meters deep, which makes these areas easier for micro-pollutants and oil used by machinery to penetrate through and reach the groundwater resources, taking into consideration cracks due to use of explosives |
| Wastewater Treatment Plant       | • Sludge usually contains concentrated organic matter, nitrogen, inorganic salts, heavy metals, and bacteria.                                                                                                               |
| Gas Station                      | • Oil and gas spilled onto paved areas are easily washed away by water, either from hoses or rainfall -one gallon of oil can contaminate one million gallons of water!  
• Engine and brake residues contain antifreeze, grease, oil, copper, and even asbestos.  
• Engine degreasers contain copper and brass.  
• Lead, oil, and grease are residues of radiator flushing.  
• Oil, grease, and detergents drain from car washing.  
• Engine washing releases aluminum and iron.  
• Brakes are a source of asbestos and cadmium washes from tires. |
Table 4.13 (cont.) Description of contaminants for pollution sources and their effects on groundwater

<table>
<thead>
<tr>
<th>Pollution Source</th>
<th>Description of Contaminants</th>
</tr>
</thead>
</table>
| Roads            | • Contaminants from vehicles and from the road and highway construction and maintenance are washed from roads and roadsides when it rains.  
                  | • As it flows over these surfaces, the water picks up dirt and dust, rubber and metal deposits from tire wear, antifreeze and engine oil that has dripped onto the pavement, and discarded cups, plastic bags, cigarette butts and other garbage. |
| Drainage & Sewage Wadis | • As rainfall runs over the surface of roofs and the ground, it may pick up various contaminants including soil particles, (sediment), heavy metals, organic compounds, animal waste, and oil and grease which all accumulate in wadis. |
| Dumpsites & Landfills | • In the case that no proper sanitary measures have been taken at the site, leachate may form and infiltrate into the subsoil.  
                          | • Leachate is the contaminant-loaded liquid that is formed at the base of the disposal site when infiltrating and percolating rainwater is available in sufficient quantity.  
                          | • The leachate usually contains inorganic components including chlorides, sulfates, carbonates, nitrogen compounds, and metals, and a wide range of organic compounds, and may be enriched with toxic metals and organic compounds. |
| Orchards & Field Crops | • The potential threat to water pollution comes from the intensive use of pesticides which includes high amount of toxic chemicals.  
                          | • The main threat comes, not from spraying, but from poor storage and accidental spillage  
                          | • There are more than 120 types of pesticides are in use by Palestinian farmers, several of which are banned internationally. |
| Cesspits          | • In many villages, as well as some urban areas, the disposal of liquid waste by cesspits is practiced.  
                          | • In most cases, no sanitary precautions are taken, so the waste may infiltrate directly into the soil  
                          | • Liquid waste like urine and human excrements, washing water, etc. is discharged into cesspits and, in the case where liquid levels are high, it may reach the water table and contaminate nearby water wells. |
| Industrial Areas  | • The main Palestinian industries are quarry, textile, leather, dairy and food industry.  
                          | • Most of the industrial waste is discharged into cesspits or directly into the sewage collection networks  
                          | • Industrial waste is especially harmful because it has a high BOD and a high amount of suspended solids, including chemicals and toxic materials |

Calculation of Hazard Index- For the calculation of the Hazard Index (HI), all required coefficients (the weighting factor, H; the ranking factor, Qn; and the reduction factor, Rf) were entered in the form of attributes (columns). The Hazard Index was evaluated with a calculating tool available in the GIS and stored as a separate column. The final database thus includes layers (hazard types) with attribute information stored in tables. The columns of these tables contain spatial information and values for H, Qn, Rf, HI and the Hazard Index Classes.
Weighting factor (H)- The *weighting factor* (H) describes the harmfulness of the hazard to the groundwater. It was determined according to the values proposed by COST 620. In the case of geographically overlapping hazards, the hazard with the highest value was chosen to represent the harmfulness of the hazard at this location.

Ranking factor (Qn)- The *ranking factor* (Qn) ranges between 0.8 and 1.2. It was assessed considering the range of possible technical specifications of each hazard type.

Reduction factor (Rf)- The *reduction factor* considers the probability for a contamination event to occur. For most of the hazards in Tulkarm, no information was available concerning their technical status and level of maintenance and therefore Rf was defined as 1 (no reduction).

Most of the hazard index values vary between two Classes. The hazards in Tulkarm city represent Hazard Index Classes ranging from 1 to 3, therefore very low and low Hazard Levels dominate.

**Graphical representation of the hazard maps**

Graphical representation of the hazard map was done in a GIS, using standardized point, line and diffuses symbols, as proposed by COST 620. The unclassified map (figure 4.22) shows the inventory of hazards in the study area in red, independent of the Hazard Index. The classified hazard map (figure 4.23) shows the mapped hazards in different colors according to the Hazard Index Class, with blue representing ‘No or Very Low’ hazard level and red representing ‘Very High’ hazard level.

![Figure 4.22 Unclassified Hazard Map of Tulkarm city](image-url)
4.1.3 Groundwater Pollution Risk Assessment and Mapping

The term ‘Risk’ is used to describe the probability of suffering harm from a hazard. With regard to groundwater, it refers to the possible contamination as a result from a hazardous event.

The risk of contamination of groundwater depends on three elements:

1. The hazard posed by a potential polluting activity
2. The intrinsic vulnerability of groundwater to contamination
3. The potential consequences of a contamination event

In a karst groundwater protection context, risk assessment requires:

- Identification of potential hazards.
- Analysis of the potential impact of hazards on groundwater. This requires details on the contaminant concentration and quantity.
- Information on the hydrogeological characteristics of geological materials beneath hazards, which influence contaminant movement and attenuation. This is shown by the vulnerability of the groundwater, either by vulnerability maps or vulnerability assessments.

Risk maps show the risk of groundwater pollution of each hazard in relation to resource protection. The risk index is the probability that contaminants with a certain amount and concentration (intensity index) reach the surface of the groundwater. The groundwater and the aquifer characteristics are not included in this type of risk assessment. The risk intensity values are determined with a simple equation:
RII = 1/HI * π

RII = risk intensity index
HI = Hazard Index
π = PI-factor (index for intrinsic vulnerability)

The proposed risk assessment is classified taking into account the classes of the vulnerability and the hazard index (see Table 4.14)

<table>
<thead>
<tr>
<th>π-factor</th>
<th>HI</th>
<th>1/HI</th>
<th>π · (1/HI)</th>
<th>Risk Class</th>
<th>Risk Level</th>
<th>Color</th>
</tr>
</thead>
<tbody>
<tr>
<td>4-5</td>
<td>0.24</td>
<td>&gt; 0.042</td>
<td>&gt; 0.167</td>
<td>1</td>
<td>no or very low</td>
<td>Blue</td>
</tr>
<tr>
<td>3-4</td>
<td>24-48</td>
<td>0.042-0.021</td>
<td>0.167-0.063</td>
<td>2</td>
<td>low</td>
<td>Green</td>
</tr>
<tr>
<td>2-3</td>
<td>48-72</td>
<td>0.021-0.014</td>
<td>0.063-0.028</td>
<td>3</td>
<td>moderate</td>
<td>Yellow</td>
</tr>
<tr>
<td>1-2</td>
<td>72-96</td>
<td>0.014-0.010</td>
<td>0.028-0.010</td>
<td>4</td>
<td>high</td>
<td>Orange</td>
</tr>
<tr>
<td>0-1</td>
<td>96-120</td>
<td>&lt; 0.010</td>
<td>&lt; 0.010</td>
<td>5</td>
<td>very high</td>
<td>Red</td>
</tr>
</tbody>
</table>

Production of Risk Map

The risk map for Tulkarm city (Figure 4.24) was produced by incorporating the vulnerability map constructed with the PI-Method (Figure 4.16) and the hazard map as previously described (Figure 4.23).

This approach of risk assessment implies that hazards even with a low or very low hazard level could produce a “Very High” risk level if the vulnerability is very high. In comparison a hazard with a very high hazard level would produce only a “Moderate” or “High” risk level if the vulnerability is less than very high.

To keep the original spatial information of the linear hazards, in this case the roads were buffered with a 10m radius and the sewage and drainage wadis were buffered with a 100 m radius, which is realistic if we consider the affected surface in the case of contaminant release.

The hazard map was converted to grid map where each cell has its value of (1/HI), then multiplied with the same cell which has its own π-value. Hence, the final Risk Map will be grid map with cell size 2m X 2m as shown in Figure 4.24.
Figure 4.24  Risk Map of Tulkarm city

The results from the risk map of the study area show that about 7.2% of the total area is classified as very high risk, 0.7% as high risk, 68.5% as moderate risk, 11.1% as low risk and 12.5% as no or very low risk. Hence, the study area can be classified as a moderate risk area.

4.1.4 Groundwater flow and contaminant transport model for Tulkarm

Groundwater flow and contaminant transport models were produced for Tulkarm in order to define the regional groundwater flow, and to give quantitative estimates of the groundwater dynamic parameters and of the available groundwater resources. The Western Basin is considered the most important basin that provides reasonable quantities of fresh water for Palestinians and Israelis, and therefore, it should be managed and protected from any potential adverse impacts that cause degradation in its water quality.

Groundwater pollution concerns are the main reasons for developing a local-scale groundwater flow and pollution transport model for the Tulkarm area. Therefore, the model will act as a management tool to support the implementation of the necessary measures to protect and remediate the aquifer systems from any source of pollution, and determine the potential areas that might suffer from water quality problems. A detailed description of the Tulkarm models is provided in Annex 1.
The results of pollution model indicate a general trend and distribution of pollution plume to east from Wadi Zeimar, which is one of the main pollution sources in the region. The spatial distribution of concentration is parallel to the input source. The effects of pollution plume after 300 days cover an area of 9.0 km$^2$, and about 14 km$^2$ after 6000 days of simulation.

Based on the results of the contaminant transport model, a groundwater management plan and protection measures should be formulated in order to enhance and manage the water resources in this renewable and vulnerable aquifer. A comprehensive monitoring program for wadi Zeimar should also be considered on a small period interval basis (i.e. run for each 1 month or less).

4.2 Vulnerability and Hazard Assessment and Mapping for Umm el Fahem

4.2.1 Vulnerability Assessment and Mapping

Umm el Fahem can be classified as a highly vulnerable region, considering that it constitutes part of the recharge plain of the Mountain Aquifer. Also, the majority of outcropping formations are marine sediments composed mainly of highly fractured carbonate rocks such as limestone, dolomite, and chalk. The Umm el Fahem region is also characterized by the existence of several major faults and joints oriented east-westwards and by karstic features. These structures have significant contribution in increasing the recharge rates and consequently the infiltration rates of pollutions to groundwater. Therefore, the Umm el Fahem region is considered as a sensitive area with regards to any source of pollution.

The soil in the Umm el Fahem region is volcanic in origin, and therefore is very porous and full of cracks, which makes the Aquifer very susceptible to contamination. An orthophoto of the study area of the Israeli pilot municipality of Umm el Fahem with a layer that shows the soil sensitivity is shown in the following figure.
Based on the soil sensitivity map, and other characteristics, such as geology, drainage, rainfall, topography, etc., a vulnerability map for the region was determined. This vulnerability map for Umm el Fahem was obtained from the Umm el Fahem municipality. Based on this map, it can be observed that 72.6% of the study area is classified as high vulnerability, 26.5% is classified as medium vulnerability and 0.9% low vulnerability. A re-production of the original vulnerability is provided in figure 4.26.
4.2.2 Hazard Assessment and Mapping

Environmental Hazards

The main environmental hazards in the Umm el Fahem region were identified, and mapped on the orthophoto of the area. These sources of pollution which create environmental hazards were classified as: sewage, agriculture, and business. Following is a description of each of these hazard groups.

Sewage

The sewage hazard map (figure 4.27) builds on the Ortophoto and soil sensitivity map (figure 4.25) and adds a layer that illustrates some of the actual environmental hazards created as a result of existing sewage problems (e.g., pumping station that has broken down and poses a hazard; failure in a sewage line). The legend was derived based on the European Union's COST 620, as used in the course of this scientific paper. It was applied, in this map, to individual (actual) sewage hazards.
Agriculture

The agriculture hazard map (figure 4.28) also builds on the Orthophoto and soil sensitivity map (figure 4.25) and adds a layer that illustrates some of the actual environmental hazards created as a result of existing agricultural problems (e.g., barns, animal farms, fertilizers).
Business

The business hazard map (figure 4.29) also builds on the Ortophoto and soil sensitivity map (figure 4.25) and adds a layer that illustrates some of the actual environmental hazards created as a result of existing businesses, some of which are licensed, some are not, and some have applied for licenses. The types of businesses include: garages, illegal gas stations, food factories, etc.
Environmental Hazards (combined)

This map (figure 4.30) builds on the Ortophoto and soil sensitivity map (figure 4.25), and also combines and adds the previous environmental hazard maps (figures 4.27-4.29), i.e., the sewage, agricultural, and business hazards.

![Combined environmental hazards map](image)

In figure 4.31, a sample of the information that can be gathered on a specific hazard is provided. This is an illustration of figure 4.30 (i.e., all of the previous maps/layers combined) with a window describing all of the information gathered on a particular hazard. This is one of the capabilities and benefits of the GIS software, which allows people to gather information on a particular hazard (as well as on the overall situation).
Due to the complexity of the groundwater systems, and the unknowns regarding the volumes of recharge and discharge as well as pollution concentrations and locations, developing groundwater flow and contaminants transport models for Umm El Fahem area is not feasible at this stage of the study. This could also be attributed to the following main reasons:

1. The Umm El Fahem area is characterized by several complex geologic structures and therefore a detailed conceptual model should be prepared first including all physical features of the study area. The purpose of building a conceptual model is to understand and identify the hydrogeologic behavior of the study area including all characteristics of the groundwater aquifer systems and the factors that control groundwater flow system, and to organize the field data of the modeled area.

2. The available data for this study area is not quiet enough to be used for developing flow and contaminants transport model. More data is needed such as
the historical records data of (rainfall, water level, springs discharge, concentrations of pollution parameters…etc). This kind of data is essential for the calibration purposes. Additional data is required on the sources of pollution.

In order to ensure reliable development of a groundwater model for the Umm el Fahem area, a modeling approach should be prepared. The approach proposed for this study will be based on full integration of data collection, management, and the detailed numerical model itself. This integration of field and model simulation results will provide a powerful tool in the comprehensive assessment of the behavior of the developed models. Integration of all historic and recently available data will ensure that the model will provide a reasonably better estimate of the sustainable yield. The modeling work comprises the following stages:

1. Data collection, compilation, and analysis
2. Conceptual Model
3. Numerical Model
4. Model Calibration
5. Development of Pollution Transport Model

A detailed description of these stages can be found in Annex 2.
CHAPTER 5 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusion

Since Palestine and Israel share a good portion of water resources through transboundary aquifers, wadis and the Jordan River, this project believes that protecting these water resources from pollution generated by municipalities on both sides is an important step for any future agreement between the two sides towards effectively managing these shared water resources.

This report has offered an overview of the sources of groundwater pollution, which are adversely affecting the quality of our shared water resources. The general aim of the Pro-Aquifer project is to address the protection of groundwater resources from pollution, in the context of shared Israeli-Palestinian groundwater from the unique perspective of local municipalities, in an attempt to help municipalities identify polluting activities in their boundaries, as well as develop policy mechanisms and techniques on preventing groundwater pollution. The project has encouraged commitment within the municipalities and the public figures to cooperate and protect shared water resources.

The municipalities of Tulkarm, on the Palestinian side, and Umm el Fahem, on the Israeli side, were chosen as case studies of this project for their hydrological and hydro-geological significance:

- both cities are located on outcrops of aquifers that are sensitive to pollution;
- both cities have significant ecological effects;
- both cities have available data within their municipalities;
- polluting activities at both cities are significant.

The outcropping formations of both cities exhibit mature karst features that allow pollutants to reach water level in a relatively short travel time and also with a high concentration of pollutants.

This report has provided a detailed description of the activities that pollute groundwater in the jurisdictions of the municipalities. As a result, guidelines have been developed for the assessment and measures to alleviate groundwater pollution from Israeli and Palestinian municipalities. The main sources of pollution of both cities include:

- dumping of raw sewage in wadis and cesspits without treatment;
- leakage of raw sewage from sewer pipelines;
- sewage networks cover less than 75% of the served communities in Tulkarm and 85% in Umm el Fahem;
- stone cuttings, garages, building material factories and other wastewater from light industries;
- wastes from cement factories, gas stations, olive mills, slaughter houses, chemical industries, and others;
- of particular concern are those sources of pollution such as automobile service stations and storage of petroleum products, acids, solvents and chemicals, because they are likely to contain toxic chemicals;
- in Tulkarm and Umm el Fahem, the illegal dumping sites have been made without concern for aquifer contamination. Even the legal dumping sites lack proper maintenance.
- wastes from fertilizers and agricultural activities
- wastes from livestock sheds

Table 5.1 describes the recommended mitigation measures which can be implemented to reducing these polluting activities.

The Tulkarm area is located on the north-western strip of the Mountain Aquifer while the Umm el Fahem area is located on a part of the recharge plain of the North-eastern aquifer. The vulnerability for both case studies was assessed using the PI-method (GIS based) because of its suitability to the karst aquifers of the study areas. Results of the vulnerability assessment for the Tulkarm showed that:

- 4% of the study area is of extreme sensitivity
- 38% of the study area is of high sensitivity
- 28% of the study area is of moderate sensitivity
- 17% of the study area is of low sensitivity
- 13% of the study area is of very low sensitivity

As for Umm el Fahem, the results of the vulnerability assessment showed that:

- 72.6% of the study area is classified as highly vulnerable
- 26.5% of the study area is classified as medium vulnerability
- 0.9% of the study area is classified as low vulnerability

Thus, both cities are located in highly vulnerable areas, due to the nature of the region. Sewage flow in the recharge area of the Mountain Aquifer leads directly to pollution of groundwater. Moreover, groundwater in that area is closer to the surface, requiring a shorter period of time for pollutants to percolate and reach it. Unfortunately, it is also the location of some of the most serious pollution spots. So, these areas are particularly vulnerable to pollution from sewage, solid waste, agriculture and other types of pollutants.

The results of the pollution modeling indicate a general significant trend and distribution of a pollution plume because of raw sewage in wadi Zeimar in the Tulkarm area. The pollution plume covers 14 km² in the Tulkarm area after 6000 days of model simulation. This will affect 7 groundwater wells in the area. A conceptual model for the contaminant transport model for Umm el Fahem was developed, but a full pollution model was not carried out due to constraints in the availability of data.
**Table 5.1 Proposed Recommendations and Mitigation/Remedial Measures for Tulkarm City**

<table>
<thead>
<tr>
<th>#</th>
<th>Pollution Source/Issue</th>
<th>Status</th>
<th>Objective</th>
<th>Recommendations &amp; Mitigation Remedial Measures</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Short-Term</td>
</tr>
</tbody>
</table>
| 1 | Uncontrolled waste disposal in areas not designated for such purposes | At present, land disposal of different types of waste and littering are spread all over the area, potentially hazardous to health and environment | Eliminate uncontrolled land disposal | Cleaning up of all areas where accumulation of litter is observed | • Regular monitoring of littering in the area and incidence reporting  
• Raise an awareness level of local population | • Regular monitoring of littering in the area and incidence reporting  
• On-going awareness campaigns  
• Establishment of Key Geographic Indicators for Environmental Hazards database |
| 2 | Auto-repair shops/oil change workshops | Auto-repair shops/oil change workshops and car washes are spread out throughout the city. The residual oil, detergents, are disposed directly in the sewage system and surrounding areas | Eliminate pollution from petrochemicals | Evaluation of conditions at the oil change workshops  
Enforcement of existing laws and regulation | • Regular monitoring and incidence reporting  
• Raise awareness of workshop owners and employees | • Regular monitoring and incidence reporting  
• On-going awareness and education of workshop owners and employees |
<table>
<thead>
<tr>
<th>#</th>
<th>Pollution Source/Issue</th>
<th>Status</th>
<th>Objective</th>
<th>Recommendations &amp; Mitigation Remedial Measures</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>Inadequate sewage system</td>
<td>The current sewage system in many areas consists of cesspits close to residences, regularly emptied and transported by septic tanks.</td>
<td>Eliminate penetration of raw sewage into the environment.</td>
<td>Provision of adequate sewage system. Regular monitoring and incidence reporting. Regular monitoring and incidence reporting.</td>
</tr>
<tr>
<td>4</td>
<td>Olive Mills Wastewater (OMW)</td>
<td>Currently, OMW is collected in collection pits collectively with water used for olive washing and regularly emptied and transported to nearby wadis. There is evidence of leakage of OMW into the environment.</td>
<td>Eliminate possible pollution from OMW. Ensure that the collection pits are in adequate condition.</td>
<td>• Introduction of concept of re-use of water used for olive washing or for irrigation; • Regular monitoring and incidence reporting. • Investigate the feasibility of construction of treatment facilities specifically for OMW treatment • On-going education campaign for mill management and staff</td>
</tr>
<tr>
<td>5</td>
<td>Pomace Storage</td>
<td>Pomace generated through the olive oil production cycle is collected on the open areas for drying. The areas are not provided by the adequate drainage systems which causes leakage of residual liquids into the surrounding.</td>
<td>Eliminate leakage from pomace storage. Provision of adequate pomace storage facilities at the mills, like perforated base with the pipe connection to the OMW collection pit</td>
<td>• Regular monitoring and incidence reporting. • Raise awareness on proper disposal methods. • Regular monitoring and incidence reporting. • On-going awareness campaigns proper disposal methods.</td>
</tr>
</tbody>
</table>
### Recommendations & Mitigation Remedial Measures

<table>
<thead>
<tr>
<th>#</th>
<th>Pollution Source/Issue</th>
<th>Status</th>
<th>Objective</th>
<th>Short-Term</th>
<th>Medium-Term</th>
<th>Long-Term</th>
</tr>
</thead>
</table>
| 6 | Littering              | Litter is mostly removed by municipal services, however burning of litter is widely practiced, which can be the cause of air pollution | Prevent accumulation and burning of the litter | Enforcement of proper waste disposal methods | • Regular monitoring and incidence reporting  
• Raise awareness on proper disposal methods | • Regular monitoring and incidence reporting  
• On-going awareness campaigns for proper disposal methods |
| 7 | Application of fertilizers and pesticides | Currently, fertilizers and pesticides are applied on “when needed” in farmers’ opinion basis; no data is available on the type of pesticides applied | Reduce pollution from pesticides and fertilizers | Identification and recording of current levels and types of pesticides | • Introduction of Integrated Pest Management (IPM) when pesticides are applied when it is no longer feasible not to;  
• Regular monitoring and incidence reporting  
• Investigate the feasibility of introducing organic farming | • Regular monitoring and incidence reporting  
• Enforcement of IPM  
• On-going awareness and education on IPM and organic farming |
5.2 Recommendations

This paper investigates the pollution sources of one Palestinian and one Israeli municipality and how vulnerable the groundwater resources are to these sources of pollution. It is recommended to take more cases of Palestinian and Israeli municipalities and to study their sources of pollution and how they impact on the shared groundwater resources.

In order for any comprehensive and integrated cooperative approaches to be successful, it is recommended to construct a comprehensive GIS database for pollution sources that covers all transboundary municipalities. The assessment of vulnerability to pollution, hazards risk and extension of pollution plumes in aquifers were analyzed in some cases using different tools by Palestinians and Israelis. It is recommended that the same tools are used by both sides in any future cooperation.

Although data availability was an important element to choose the city of Umm el Fahem, when the actual work took place, it was realized that some substantial data and information were still needed to determine the travel time of pollutant plumes in the aquifers underneath Umm el Fahem. It is recommended that reliable data should be available for all transboundary municipalities for future work.

Pollution needs monitoring and real time data in order to alleviate its negative impacts on water resources. It is recommended to investigate one type of pollution (i.e. solid waste) at a Palestinian and at an Israeli area, and to install monitoring equipment/structures to study the degree of pollution and then introduce a solution and use the same monitoring tool in order to see how much pollution can be alleviated on both sides of the transboundary aquifers.

Groundwater pollution modeling for transboundary cities is highly recommended. This will help investigate the degree of spread of pollution on one hand and help investigate the effectiveness of any solution that will be introduced in the future.

This paper will help develop groundwater protection guidelines. Both the results of the research and the groundwater protection guidelines should establish the material for some training courses in this project.
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ANNEX 1

GROUNDWATER FLOW AND CONTAMINANTS TRANSPORT MODEL FOR TULKARM

Numerical simulation of Groundwater Resources in Tulkarm Area- Western Aquifer Basin

Introduction
The Tulkarm area, is a densely-populated area, heavily dependent on more than 67 groundwater wells for various purposes. In 2003, the SUSMAQ-PWA project, funded by DIFD, conducted a large-scale hydrogeological assessment and modeling study over the Western Aquifer Basin. The objectives were to define the regional groundwater flow, and to give quantitative estimates of the groundwater dynamic parameters and of the available groundwater resources. The Western Basin is considered the most important basin that provides reasonable quantities of fresh water for Palestinians and Israelis, and therefore, should be managed and protected from any potential adverse impacts that cause degradation in its water quality. One of these adverse impacts is pollution transport from the untreated wastewater of wadi Zeimar that flows from Nablus City to the Tulkarm area, passing over more than 20 km. The average annual flow of this sewage wadi is estimated to be around 1.86 MCM/yr. There are big concerns regarding groundwater pollution from the untreated sewage water in this wadi by infiltration and percolation mechanisms. These concerns are the main reasons for developing a local-scale groundwater flow and pollution transport model for the Tulkarm area. The local-scale model is developed based on the regional model of the Western Aquifer Basin. The data availability will be the key issue for developing such a model since the hydrogeology and structural geology of the study areas is relatively complex. Therefore, the working team will focus firstly on the data collection and analysis in order to ensure that reliable data will be used in the model.

Objectives
The primary modeling objective of this model is to define, with as much accuracy and reliability as possible, the general characteristics of the groundwater flow system as well as to consequently assess the future transport trends of pollution in the groundwater water system of the Tulkarm area through developing a local-scale pollution transport model. Therefore, the model will act as a management tool to support the implementation of the necessary measures to protect and remediate the aquifer systems from any source of pollution, and determine the potential areas that might suffer from water quality problems.

Previous Studies
All available previous studies (both Israeli and Palestinian literature) were conducted on a regional scale concerning the Western Aquifer Basin (WAB), which is a shared groundwater basin. Many of the publications do not directly address the WAB, but there is a lot of useful information scattered in these references. The project team managed to benefit from these publications by gathering the useful information, analyzing them, and then integrating them in a database for this study. It is worth mentioning that most of the data and information were obtained from the SUSMAQ Project.
SUSMAQ Project (1999-2004)

The overall goal of the SUSMAQ project (1999-2004) was to support the sustainable management and use of scarce water resources in the West Bank and Gaza Strip. The project was led by the University of Newcastle upon Tyne, working with the Palestinian Water Authority (PWA) as the main project beneficiary and other UK project partners. The comprehensive scope of the project ranged from regional climate change and aquifer modeling through to assessments of local water access, livelihoods and institutional arrangements. SUSMAQ was funded by the UK Government Department for International Development (DFID).

Pollution Modelling

Construction of a spatial database of aquifer water quality and pollution sources has indicated key issues including the disposal of untreated sewage from Palestinian villages and Israeli settlements in the West Bank. Numerical modeling provides the capability to simulate pollution hot-spots in support of developing protection measures in the vulnerable karstic aquifers.

Flow Modelling and Hydrogeology

An extensive re-evaluation of geological data and new hydrostratigraphic descriptions of the regional aquifers have provided the basis for conceptual models of the trans-boundary groundwater flow systems and the publication of the first hydrogeological map of the West Bank. Steady-state and transient numerical models have been calibrated against historical data, and are being used within a user-friendly Integrated Management Tool to provide predictions of the impacts of future climate inputs and Palestinian and Israeli groundwater abstractions.

Modeling Program and Pre/Post Processor

The USGS modeling program (MODFLOW) is the most famous and widely tested modeling tool, used strongly around the world. The mathematics and governing theories of MODFLOW, which are based on the finite-difference approach, are capable of fully simulating three-dimensional flow with irregular boundary geometry. Since the modular structure of this program is easy to understand and modify, several related agencies and companies have used it for modeling the aquifer systems of the Western Basin, such as SUSMAQ Project (2004). The GMS program was developed under the supervision of the U.S Army Corps of Engineers and supported by the Department of Defense. This program was used in SUSMAQ project and is used also in this study for flow and pollution modeling. GMS supports the following models:

- MODFLOW: 3D finite difference model
- MODPATH: 3D particle tracking model
- MT3D: 3D contaminant transport model
- SPEED2D: 2D finite element model
- FEMWATER: 3D finite element model

GMS also includes a set of modules that help the model developer with site characterization, model conceptualization, mesh and grid generation, and output post-
processing. For the pollution transport model, MT3D is used in this study since it solves the advection-dispersion equation for multi-species transport through saturated porous media.

Study area
The 292 km² study area is located in north-western part of West Bank. Its natural limits are: the political border of the West Bank to the west and the water divide of the Western and Northeastern basins from the east, while the southern and northern limits are a segment of the Tulkarm district. Flat hillsides, relatively wide areas and flat terraces characterize the topography of the region.

The study area is one of the major western surface water catchments, with altitudes ranging from 100 up to 300 meters ASL. A general location map is presented in Figure 1. The climate of the area is characterized by long, hot, dry summers and moderate cool and rainy winters.

Conceptual Model
Data collection, Compilation, and Analysis
This stage comprises the collection of different types of data, which include the original data for the flow model, such as geological, hydrogeological, topographical, and cross-sections and the time series data, such as rainfall data, wells data, and water-level data. Moreover, the basic data for the aquifer geometry, which includes the top and bottom elevation of each aquifer and the aquifer characteristics, are also needed for model construction. Furthermore, pollution data are needed once the flow model is constructed and a preparation for the simulation of contaminants. In this study, the data will include water quality sampling, location of pollution sources, historical records of pollutants concentration data, etc. The efforts of data compilation will include the local data sources in HWE database as well as the output results of SUSMAQ project.

Geology and hydrogeology
The study area is located in the Western Basin, which is characterized by structural features: the Anabta and Umm El Fahem anticlines. Figures 2 and 3 show the generalized structural and geologic maps of the Western Basin. Furthermore, the study area is characterized by a significant structural system that includes several major faults with east-west trending.

The area lies on the western slopes within the West Bank. The aquifer system can be summarized as follows from top to bottom (see Figure 4):

- Upper Aquifer: Upper Cenomanian–Turonian; Hebron, Bethlehem & Jerusalem, formations.
- Middle Aquitard: Lower Cenomanian; Yatta formation.
- Lower Aquifer: Upper Albian; Beit Kahil formations.

Geology
A brief description of the geologic and hydrogeologic features of the main formations that form the aquifer systems is presented below:
Jerusalem Formation (Turonian)
The Jerusalem formation consists of a series of massive, thick- to- thin bedded limestone to dolomitic limestone and dolomites with a thickness of approximately 70-130 m. The lower part of the Jerusalem formation consists mainly of limestone and dolomite with marl and some chalk, making it sometimes difficult to be distinguished from the underlying Bethlehem formation. Towards the top of the Jerusalem formation, chalk beds with occasional chert bands are common, and the formation is transitional to the overlying chalk facies. The Jerusalem formation has a well-developed karst feature, forms cliff morphology, and is commonly used as a building stone.

Bethlehem Formation (Upper Cenomanian)
The Bethlehem formation consists of limestone, dolomite with chalk, and marl. It is massively bedded with a well-developed karst structure from south to north. In the south it contains chalk, while in the north it is considered a vertical extension of the Hebron formation (an aquifer). The dolomite forms a rugged morphology on gentle slopes. The thickness of the Bethlehem formation ranges between 100 to 115 m.

Hebron Formation (Cenomanian)
The Hebron formation consists mainly of dolomite and limestone that is hard, coarsely or poorly bedded, non-fossiliferous, and it shows significant lithological variation over short distances. The top of the Hebron formation consists of dolomitic limestone that is hard, karstified, and grey in colour whereas the base of this formation consists of hard dolomite and dolomitic limestone. The limestone is more thinly bedded than the dolomite. The Hebron formation has a thickness of 105-260 m.

Yatta Formation (Lower, Cenomanian)
The Yatta Formation consists primarily of interbedded limestone, marl, chalky marl, and some thin-bedded dolomite.

Upper Beit Kahil Formation (Upper Albian)
The Upper Beit Kahil formation is regarded as the upper part of the Albian. This formation consists mainly of interbedded dolomite and chalky limestone with intercalations of calcite massive limestone near the base. The formation is dolomite, which is massive, blocky, and blue-gray, weathered with fine chert nodules. The massive unit at the top forms a well-defined feature. At the outcrop, it is characterized by stratification and extremely geometric jointing. The thickness of the Upper Beit Kahil formation ranges between 160-190 m.

Lower Beit Kahil Formation (Upper Albian)
This formation consists of thick to thin-bedded limestone, and marly limestone with shale parting that becomes more massive upwards in the section. The limestone appears medium-soft, creamy or pink and semi-crystalline. The total thickness of this formation ranges between 215-260 m.
**Hydrogeology**

The main aquifer system found in the study area is the Upper Aquifer. The hydrologic characteristics of this aquifer are presented below, including the flow system behavior and water levels.

*The Upper Aquifer*- The Upper Aquifer is represented by the formations of the age of Turonian (Jerusalem formation) and Cenomanian (Bethlehem and Hebron formations) and consists of the following aquifers:

*Turonian Aquifer*- The Turonian aquifer is part of the Upper Aquifer but can be classified as a distinct local aquifer if the formation beneath it acts as an aquitard as is the case in some areas in the eastern and southern parts of the West Bank. The Turonian aquifer is considered a fairly good aquifer especially where the saturation thickness is in tens of meters. For example, the aquifer is of good thickness and extent in the Tulkarem area (approximately 130 m thick). The water quality of this aquifer is generally good but in some areas there is an evidence of deterioration because of sewage and agro-chemical pollution.

*Cenomanian Aquifer*- The formations of this aquifer are the Bethlehem and Hebron formations. The aquifer is an important regional source of water supply for domestic use. The Cenomanian Aquifer has high recharge values. It is heavily exploited in the areas near Tulkarm and Qalqilya because the aquifer is at a shallow depth in this area but it is at an intermediate depth in the Bethlehem and Hebron areas. The well yields range from 40-400 m³/hr with depths less than 400 m with some exceptions. The water level in this aquifer is rarely more than 200 m below ground surface. Water quality in the Cenomanian Aquifer is generally good with values of 30-150 mg/l of chloride.

A detailed description of the geology of the area may be obtained from the Physical Setting and Reference Databook (SUSMAQ-PWA, 2004). The Upper Aquifer is the main source of water supply in this area. Groundwater flow in the Upper Aquifer is generally towards the west with average gradient of 0.3. The Upper Aquifer is characterized by relatively moderate values of transmissivity.
Figure 1: Generalized Structure Map
Figure 2  Generalized Geological Map
Figure 3  Western Aquifer Basin
Figure 4 Generalized Stratigraphic section in the Study Area

Model Domain and Boundaries

The model boundaries and domain will be adapted based on the structural modified cross-sections of the study area, which show the lateral extent and outcropping of geologic formations, and groundwater direction. For this purpose, all available cross-sections, geological maps, and structural maps for the entire area will be used to define the study area boundaries.

Model Layering and Vertical Discretization

The study area is a local part of the Western Basin, which was subjected to intensive previous geological studies that show different stratigraphic units within the proposed area. This area includes aquifers as permeable units and aquitards as impermeable units. However, since most of the existing wells tap into the Upper Aquifer System, the study area will be comprised of the following geological units:

The Jerusalem, Bethlehem, and Hebron Formations of Turonian and Upper Cenomanian age, which are mainly composed of well-bedded and fractured limestone, dolomitic limestone, and marly limestone. This unit represents the Upper Aquifer, which is considered to be confined.

The Yatta Formation, of Lower Cenomanian age, which is composed mainly of marls and marly limestone. This unit is considered an aquitard.
Based on the above layering systems, the vertical discretization of the entire area can be designed to consist of the following 2 layers:

- The first layer, which will simulate the Upper Aquifer
- The second layer, which will simulate the Yatta Aquitard

**Water Budget**

A groundwater budget is an accounting or analysis of a groundwater system’s inflows and outflows. In steady-state conditions, inflows equal outflows and there is no change in aquifer storage.

**INFLOW COMPONENTS**

- **Recharge from Rainfall**

Recharge estimation of the study area is important in order to have a clear picture of the Water Budget, which will be used as an integral step towards the determination of the sustainable yield of the aquifer. The following equations, which were considered in the SUSMAQ, will be used to provide a rough estimation of the recharge values in the study area:

\[
R = \begin{cases} 
0.8 (P - 360) & \text{if } P > 650 \text{ mm} \\
0.534 (P - 216) & \text{if } 650 \text{ mm} > P > 300 \text{ mm} \\
0.15 (P) & \text{if } P < 300 \text{ mm}
\end{cases}
\]

Where:

- \( R \) = Recharge from rainfall in mm/yr
- \( P \) = Annual rainfall in mm/yr.

To minimize time and effort, the recharge values used in this local-scale model of Tulkarm area were obtained from the calibrated values of the regional Western Basin model. The recharge values for model cells were ranged from 0.002 to 0.1 m/day, this giving a total input recharge of 67 Mcm/yr. This value will be refined during calibration.

**OUTFLOW COMPONENTS**

- **Abstraction from Wells**

Pumping data were complied for 2000-2004 for the study area. The average abstraction rates of 2000-2004 are considered in this model to represent the steady-state since the water level is characterized by relatively low fluctuation during this time period.

The average well abstractions from the Upper Aquifer reach about 15.7 Mcm/yr.

- **Subsurface Outflow**

This component represents the rate of subsurface outflow towards the west that leaves the model domain through its western boundary. The inflow rate can be evaluated based on water levels in wells by applying Darcy’s law for confined aquifers. The subsurface
outflow was estimated to be around 42.8 Mcm/y. This estimation will be refined during model calibration.

**Aquifer Parameters**

The main aquifer parameters that are used in this model are hydraulic conductivity ($k$) and vertical conductance. In nature, these parameters are varied for every zone in the model. The values are based on available pumping tests and studies and verified during model calibration.

Experience has shown that the zone concept is the most practical method to specify aquifer parameters because of the sparseness of field data. These zones may vary within reliable limits during the calibration process. The ($k$) values ranged from 10 to 25 m/day.

**Flow and Contaminant Transport Model**

**Development of Flow Model**

The conceptual model will be transferred into numerical model automatically with the help of GMS module (MODFLOW), which will start running the model. The local-scale model domain was constructed based on the regional-scale model of the Western Aquifer Basin conducted by SUSMAQ- PWA. The grid is represented by 108 rows and 91 columns, which combined form 9,828 cells oriented in an east-west and south-north direction respectively. The smallest cells in the grid are 10m by 10 m and the largest cells are 1000m by 1000 m.

The model boundaries were selected as follows:
- North and South boundaries – considered to be no-flow boundaries as they are oriented parallel to ground water flow (west to east)
- West boundary – no-flow boundaries since it represents the water divide
- East boundary – Drain boundary based on computed heads from the regional model

Layer data for the local-scale model, including aquifer hydraulic properties, were imported and interpolated from the regional model, and were subsequently adjusted and refined during calibration.

The steady state calibration represents the water-level conditions before well-development in the study area. But since there is no data measurements for such conditions, data for hydrological years 2000-2004 were used to validate the steady-state period. This period was chosen because the fluctuation in water-level was relatively minor and the groundwater system was at or near a steady-state condition. The simulating water-level in the aquifer for steady-state conditions will not be straightforward since the aquifer is characterized by several complex structures and connections with other strata. The annual average data for water level and well abstractions for the assigned period were used in this calibration. Meanwhile, several representative observation wells were selected as target points for model calibration. These observation wells were selected based on that they provide a wide aerial and vertical distribution and assumed that they have reliable water level measurement.
At the end of the calibration process, the simulated hydraulic conductivity was characterized by low-range values from 10 to about 25 m/day as depicted in figure 5. The simulated water table shows that 2 observation wells are less than 2 meters of difference. The distribution of water simulated by the flow model in the aquifer system is shown in figures 6 and 7. Under such conditions, ground-water-flow directions should be predominantly downward to the western sides of the study area. The simulated water budget of the aquifer system was analyzed to determine if the indicated sources and sinks of water were consistent with the conceptual hydrogeologic model. Table 1 presents the water budget at the end of the steady state simulation.

Table 1: Simulated Water Budget

<table>
<thead>
<tr>
<th>Inflows (Mcm/y)</th>
<th>Outflows (Mcm/y)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Direct Recharge: 65.0</td>
<td>Wells: 15.7</td>
</tr>
<tr>
<td>Wells: 0.0</td>
<td>Lateral flow to west: 49.3</td>
</tr>
<tr>
<td><strong>Total</strong>: 65.0</td>
<td><strong>Total</strong>: 65.0</td>
</tr>
</tbody>
</table>

Figure 5  Simulated Hydraulic Conductivity of the Study Area
Figure 6  Side View of Simulated Water level in Steady-State Conditions

Figure 7  Plan View of Simulated Water level in Steady-State Conditions
Development of Contaminant Transport Numerical Model

Once the model is calibrated against steady state condition, its can be used for contaminant simulation. This stage is considered the most important part since it simulates the transport behavior of pollutants within the aquifer system. The pollution model will be launched automatically after steady-state simulation with the help of GMS module (MT3D). Flow and transport are better understood in the saturated zone than in the unsaturated zone, so transport in the saturated zone is modeled and assumed to be represented by single porosity media. The model simulations are run for chloride as a conservative contaminant from wastewater wadi flow of Zeimar. The pollution model is run for 6000 days (about 16.4 year) to represent the spatial distribution of chloride plume within the aquifer system.

Pollution Sources

Both Palestinian communities and Israeli settlement activities contribute to the potential groundwater pollution that affect the Western Aquifer Basin which is lying over a very sensitive area and can be easily affected by any type of pollution which in turn adversely affects the study area. The main potential groundwater pollution sources affecting the study area, can be summarized in the following:

- Wastewater “Wadi Zeimer”
- Solid Waste Dumping sites
- Agriculture Activities

Wadi Zeimar is the main source of pollution in the Tulkarm area. It the western outlet discharges of Nablus City that passes more than 23 Km to the western side of Tulkarm. This study will assess the impact of the untreated wastewater of Wadi Zeimer on the groundwater system of the Tulkarm area.

Wastewater infiltration from the wadi to the groundwater usually contains high contaminant concentrations of Chloride, BOD, TSS, and Bacteria. The following table shows the analysis results of Wadi Zeimar wastewater in 2003.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Wastewater Collection Sites in the West Bank</th>
</tr>
</thead>
<tbody>
<tr>
<td>BOD (ppm)</td>
<td>570</td>
</tr>
<tr>
<td>TSS (ppm)</td>
<td>1285</td>
</tr>
<tr>
<td>Chloride (ppm)</td>
<td>3019</td>
</tr>
<tr>
<td>Nitrate (ppm)</td>
<td>0.71</td>
</tr>
<tr>
<td>Nickel (ppm)</td>
<td>0.000</td>
</tr>
<tr>
<td>Cadmium (ppm)</td>
<td>0.022</td>
</tr>
<tr>
<td>Chromium (ppm)</td>
<td>0.011</td>
</tr>
<tr>
<td>Zinc (ppm)</td>
<td>0.425</td>
</tr>
</tbody>
</table>

Setting of parameters

The main parameter that is tested during the pollution model is the chloride, with concentration of 3019 ppm in the untreated wastewater of Wadi Zeimar. The aquifer properties that control the movement and distribution of pollutants through groundwater
are hydraulic properties which control the flow field and additional properties affecting the advective and dispersive movement of pollutants transport are porosity and dispersivity (in the transverse and longitudinal directions relative to flow).

According to available literatures review, Table 3, the longitudinal dispersivity was set to be 30 m for the aquifers that were categorized as fractured to karst ones, while the ratio of transverse and vertical dispersivity to longitudinal dispersivity is set as 0.2. The porosity values were ranged from 0.3 to 0.4 for fractured to karstic limestone aquifer.

Table 3: Dispersivity Values in literature

<table>
<thead>
<tr>
<th>Scale</th>
<th>Dispersivity (m)</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solution channels</td>
<td>4-7</td>
<td>Seiler et al. (1989)</td>
</tr>
<tr>
<td>Fissures</td>
<td>≤60</td>
<td>Seiler et al. (1989)</td>
</tr>
<tr>
<td>Fractured Carbonate Aquifer</td>
<td>38.1</td>
<td>Grove and Beetem (19971)</td>
</tr>
<tr>
<td>Fractured Carbonate Aquifer</td>
<td>15</td>
<td>Claasen and Cordes (19975)</td>
</tr>
<tr>
<td>Karstic Aquifer</td>
<td>60</td>
<td>Bredehoeft and Pinder (1973)</td>
</tr>
</tbody>
</table>

Model Simulations

The results of pollution model indicate a general trend and distribution of pollution plume to east from Wadi Zeimar. The spatial distribution of concentration is parallel to the input source. The effects of pollution plume after 300 days cover an area of 9.0 km², and about 14 km² after 6000 days of simulation. The modeled groundwater velocities in the recharge zones of the aquifer are sufficient to carry pollutants by advective process.

The simulated plume of chloride shows also a concentration ranged from 41 to 624 ppm after 300 days, and therefore 4 wells will be affected by pollution plume. Meanwhile, the simulated plume of chloride concentration ranges from 91 to 1368 ppm after 6000 days and about 7 wells will be affected by the pollution plume. Figures 8 and 9 show the plan view simulations of the plume distribution within the aquifer system after 300 days and 6000 days, respectively. Figure 10 shows the side view simulation of plume after 6000 days.
Figure 8: Chloride Concentration After 300 days
Figure 9: Chloride concentration after 6000 days
Conclusion and Recommendations

This flow modeling has improved the understanding of the water regime and assesses pollution transportation in the Tulkarm area. At the end of this stage, several points can be considered for conclusion and recommendations as following:

Conclusion

- The model was well constructed and calibrated against steady-state conditions; a maximum error (difference) of 2 meter was reached in the two observation wells.

- The calibrated hydraulic conductivity ranged from about 10 to 25 m/day. These values reflect the nature composition of the aquifer that consists mainly of fractured limestone and correspond with the previous modeling efforts and literatures.

- The calibrated model shows that around 65 MCM/y is entering the aquifer system as a net recharge from rainfall, while the same amount is leaving the system through several outlets.
• The model reflects the original groundwater flow pattern within the Aquifer, most flow trends are toward the west part of the study area.

• Wadi Zeimar is considered as one of the most important sources of pollution in the Tulkarm area. The chloride parameter has been selected as a tracer with initial concentration of 3019 ppm.

• The results of the pollution model indicate a general trend of pollution plume to the east from Wadi Zeimar. The effects of this pollution plume will reach to considerable areas; within 300 days, the plume will occupy about 9.0 km², while it will reach to more than 14 km² after 6000 days.

• The simulated plume of chloride has concentration ranging from 41 to 624 ppm after 300 days, so 4 wells will be affected by pollution. Meanwhile, the simulated plume of chloride ranges from 91 to 1368 ppm after 6000 days and about 7 wells will be affected by the pollution plume.

Recommendations

• According to the steady-state model results, more calibration should be conducted to have more accurate results. This calibration will include a detailed variation in specific parameters in order to improve the model results.

• Model updating in the near future must be a priority when new reliable data become available. The updating must be emphasized on pollution data as a first priority.

• More investigations should be carried out with field reconnaissance for the structural and geological features of the aquifer system.

• A groundwater management plan and protection measures should be formulated directly based on the final results of this model in order to enhance and manage the water resources in this renewable and vulnerable aquifer.

• In addition, a comprehensive monitoring program for wadi Zeimar should be considered at small period interval basis (i.e. run for each 1 month or less). This monitoring program should consider mainly the most important pollution parameters such as Chloride, Nitrates, TSS, etc.
Groundwater Resources in Umm el Fahem Area

Background

Due to the complexity of the groundwater systems, and the unknowns regarding the volumes of recharge and discharge as well as pollution concentrations and locations, developing groundwater flow and contaminants transport models for Umm El Fahem area is not feasible at this stage of the study. This could be referred also to the following main reasons:

1. Umm El Fahem area is characterized by several complex geologic structures and therefore a detailed conceptual model should be prepared first including all physical features of the study area. The purpose of building a conceptual model is to understand and identify the hydrogeologic behavior of the study area including all characteristics of the groundwater aquifer systems and the factors that control groundwater flow system, and to organize the field data of the modeled area.

2. The available data on this study area is not quiet enough to be used for developing flow and contaminants transport model, more data is needed such as the historical records data of (rainfall, water level, springs discharge, concentrations of pollution parameters…etc). This kind of data is highly needed for calibration purposes, as well as more data is required on the sources of pollution.

MODELING APPROACH

However, in order to ensure reliable development of a groundwater model for the Umm el Fahem area, a modeling approach should be prepared. The approach proposed for this study will be based on full integration of data collection, management, and the detailed numerical model itself. This integration of field and model simulation results will provide a powerful tool in the comprehensive assessment of the behavior of the developed models. Integration of all historic and recently available data will ensure that the model will provide a reasonably better estimate of the sustainable yield. The modeling work comprises the following stages:

1) Data collection, compilation, and analysis
2) Conceptual Model
3) Numerical Model
4) Model Calibration
5) Development of Pollution Transport Model

Each of these stages is described in more detail below.
Data Collection, Compilation, and Analysis
This stage covers different types of data and maps, such as geological, hydrological and topographical maps. Other types such as rainfall/runoff data, wells data, springs data, water heads, and aquifer parameters will be included. The approach proposed here will involve a significant effort to take full advantage of existing data sources, including previous studies covering the aquifer systems in the Umm el Fahem Area. Northeastern Basin conducted by Newcastle Project (DFID Project). It includes the integration of previous work, such the data from Geological Survey and Hydrological Service of Israel. Different types of data and maps will be reviewed and updated whenever new data becomes available.

Conceptual Model
This stage mainly comprises defining the model boundaries and domain, and model layering.

Model Boundaries and Domain
The boundaries and domains of the aquifer systems in the Umm el Fahem Area can be understood based on the hydrogeological features in the region. For this purpose, at least 4 cross-sections should be developed for the study area, two from north to south and two from east to west.

The cross sections should be developed based on the available geological Israeli Maps. The locations of the sections should be selected carefully to reflect changes in the geology and the locations of structures, wells, and springs. At boundaries the cross sections should be extended to cover parts of the next basin to check the boundary location.

Model Layering and Vertical Discretization
The study area is a local part of the Mountain Basin, which was subjected to intensive previous geological studies that show different stratigraphic units, which were identified within the proposed area. These include aquifers as permeable units and aquitards as impermeable units. However, the study area is comprised of the following geological units:

- The Eocene Formation, which consist of massive chalky limestone intercalated by thin bands of chert. This unit is considered as a shallow aquifer systems.
- The Jerusalem, Bethlehem, and Hebron Formations of Turonian and Upper Cenomanian age, which are composed mainly of well bedded and fractured limestone, dolomitic limestone, and marly limestone. This unit represents the Upper Aquifer, which is considered to be confined.
- The Yatta Formation, of Lower Cenomanian age, which is composed mainly of marls and marly limestone. This unit is considered as an aquitard.
- The Upper Beit Kahil Formation of Cenomanian age, which is composed mainly of fractured dolomitic limestone and dolomite. This unit represents the Lower confined Aquifer.
Based on the above layering systems, the vertical discretization of the entire area can be designed tentatively to consist of 4 layers as following:

1. The first layer will simulate the Shallow Aquifer
2. The second layer will simulate the Upper Aquifer
3. The third layer will simulate the Yatta Aquitard
4. The fourth layer will simulate the Lower Aquifer

There is very little drilling data on either the Upper or Lower Aquifer, and only a few wells tap these aquifers.

Because of the complex structural geology of the area, it is clear that it is not possible have a model layer which represents each of the geological formations listed above. Indeed, there is no rationale for having layers for each of the geological formations, because in many cases, there is no water level data to calibrate the model. In general, if there is not a significant amount of discreet groundwater elevation data to calibrate to for a particular hydrostratigraphic unit, it is not necessary or advisable to create a model layer for that unit. In some geographical areas, only two model layers may be warranted because there is not enough existing groundwater elevation data to calibrate the model.

The aquitard layer of the Yatta Formation (very low permeability) will not be simulated as layer, but its effect will be simulated by the leakance effect between the layers and the aquifers.

**Hydraulic Stresses**

The hydraulic stresses include two types: discharge stresses, such as abstraction from wells and spring flow, and recharge stresses, such as direct recharge from rainfall, recharge from wadi runoff, and return flow from water supply networks, sewerage systems, and irrigation. Some of these components are measurable, such as well pumping rates and spring flow. Other components will be estimated in the preliminary stage and these estimates will be verified from the water balance in the calibration stage. This is important in calculating the water balance of the area and the steady state calibration.

**Modeling Program and Pre/Post Processor**

The USGS modeling program (MODFLOW) is the most famous and tested modeling program used around the world. The mathematics and governing theories of MODFLOW that are based on finite-difference approach is capable of fully simulating three-dimensional flow with irregular boundary geometry. In other hand, the Groundwater Modeling System (GMS) software would be the most feasible processor and was developed under the supervision of the U.S Army Crops of engineers and supported by the Department of Defense. GMS supports the following models:

1. MODFLOW: 3D finite difference model
2. MODPATH: 3D particle tracking model
3. MT3D: 3 D contaminant transport model
4. SPEED2D: 2D finite element model
5. FEMWATER: 3D finite element model
GMS also includes a set of modules that help the model developer with site characterization, model conceptualization, mesh and grid generation, and output post-processing.

**Numerical Model**

This stage includes the transformation of conceptual model to numerical model in terms of model run and calibration by trial and error technique. The conceptual model will be transferred into numerical model automatically with the help of GMS module (MODFLOW) and start running the model.

GMS Modflow includes a debugging tool to check the model before running. This helps the user to identify the errors and correct them before the run. The running time usually depends on the complexity of the model (number of layers, grids level of refinement, etc.).

As a result of the successful running of the model, the following variables can be evaluated: water head at each layer, expected drawdown with time, flow direction, and water budget at one cell or group of cells or the whole model. These results can be displayed numerically or graphically.

**Model Calibration**

The calibration process will be applied against Steady-State Condition only. This stage compares computed heads and the measured heads for each layer. The aquifer parameters and boundary conditions will be modified until an acceptable match between both values is achieved. The proposed study team will integrate any new data that become available from Israeli wells, or newly drilled wells in the study areas in the calibration.

**Development of Contaminant Transport Numerical Model**

This stage is considered as the most important part since it simulates the transport behavior of pollutants within aquifer system. The pollution model will be launched automatically after steady-state and transient-state simulations with the help of GMS module (MT3D). All information’s regarding sources of pollution in the proposed area will be collected and compiled from different sources; this will includes also any necessary field activities for water quality sampling and analysis.