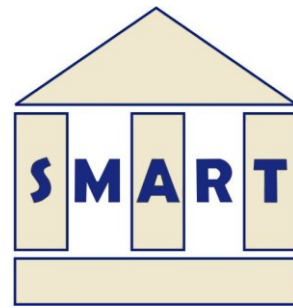


**Integrated Water Resources Management  
in the Lower Jordan Rift Valley**

**Sustainable Management of Available  
Water Resources with Innovative Technologies**



**BMBF IWRM R&D Programme**

Funding No.: 02WM1079-1086 and 02WM1211-1212

**SMART – IWRM**

**Methods for an integrated management of  
sanitation systems and groundwater protection**

**Deliverable No. 508 (part 1 of 2)**

Submitted by Palestinian Water Authority

**Date 30.06.2014**

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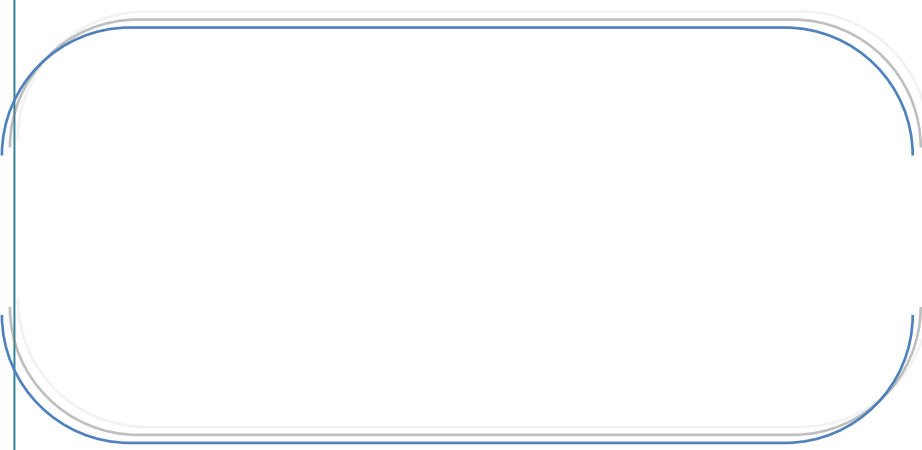
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# Generating Vulnerability Map for West Bank Implementing the P-I( $\pi$ ) Method

**Ashraf Dweikat**



2012

An-Najah National University  
Special Topics in Environmental Sciences  
Generating Vulnerability Map for West Bank  
Implementing the P-I Method

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**Ashraf Dweikat**

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## Preface

### *Background*

Water is the common name applied to the liquid form (state) of the hydrogen and oxygen compound H<sub>2</sub>O. Pure water is an odorless, tasteless, clear liquid. The water or hydrologic cycle explains interactions between the atmosphere, hydrosphere, and lithosphere. It's a major driving force on our planet. Its movement also has a direct effect on the atmosphere. In addition, water makes up 50 to 90 percent of the weight of living things<sup>1</sup>. This is why water is considered as a key component in determining the quality of our lives. Today, people are concerned about the quality of the water they drink, although water covers more than 70% of the Earth, only 1% of the Earth's water is available as a source of drinking. Unfortunately our societies continue to contaminate this precious 1% of water.

However, water is known as a natural solvent. Before this drinkable water reaches the consumer's tap, it comes into contact with many different substances, including organic and inorganic matter, chemicals, and other contaminants. Many public water systems treat water with chlorine to destroy disease-producing contaminants. Although disinfection is an important step in the treatment of potable water, the taste and odor of chlorine is objectionable.

In recognition of the need for effective and efficient methods for protecting ground water resources from future contamination, scientists and resource managers have sought to develop techniques for predicting which areas are more likely than others to become

---

<sup>1</sup> Protoplasm is a solution of water and fats, carbohydrates, proteins, and salts. Water transports, combines, and chemically breaks down these substances. Water also aids the metabolic breakdown of proteins and carbohydrates. Water is one of the most essential elements to good health -- it is necessary for the digestion and absorption of food; helps maintain proper muscle tone; supplies oxygen and nutrients to the cells; rids the body of wastes; and serves as a natural air conditioning system.

contaminated as a result of activities at or near the land surface. Once identified, those areas could then be subjected to certain use restrictions or otherwise targeted for greater attention aimed at preventing contamination of the underlying ground water resources.

The concept that some areas are more likely than others to become contaminated has led to the use of the terminology "ground water vulnerability to contamination." Vulnerability is not an absolute property, but a relative indication of where contamination is likely to occur; no ground water, with possible exceptions such as deep sedimentary basin brines, is invulnerable.

The potential for contaminants to leach to ground water depends on many factors, including the composition of soils and geologic materials in the unsaturated zone, the depth to the water table, the recharge rate, and environmental factors influencing the potential for biodegradation. The composition of the unsaturated zone can greatly influence transformations and reactions. The depth to the water table can be an important factor because short flow paths decrease the opportunity for sorption and biodegradation, thus increasing the potential for many contaminants to reach the ground water.

Conversely, longer flow paths from land surface to the water table can lessen the potential for contamination for chemicals that sorb or degrade along the flow path. Recharge rates affect the extent and rate of transport of contaminants through the saturated zone. Finally, environmental factors, such as temperature and water content, can significantly influence the degradation of contaminants by microbial transformations.

An inventory of the number, type, and intensity of potentially contaminating activities and of the extent of existing contamination of groundwater can serve a twofold purpose for groundwater protection:

It provides government officials, planners, and managers with an understanding of the potential for groundwater contamination needed for successful management programs.

It provides basic data that can be used for the design of the type and location of various controls and of the monitoring programs.

Combining the analysis of existing ground water in Ramallah Al-Bireh district, testing its vulnerability, creating the corresponding map for it, and providing the recommendations based on the study compose the main themes of this project, taking place until May 2009.

The overall aim of the project is to enhance the protection of groundwater in the district of Ramallah Al-Bireh. To achieve that; this project will construct a vulnerability map; another group will construct hazard and risk maps.

## **Objectives**

The specific research objectives are:

To identify the most vulnerable zones (in terms of intrinsic and specific vulnerability) where urban development should be strictly controlled or even prevented for West Bank.

Prepare reflecting maps identifying important characteristics of groundwater underlying West Bank including hydro geological structures, vulnerability, transmissivity, productivity, groundwater quality, and state of pollution.

## **Study Area**

### *Introduction*

Palestine has unique political, economical, and cultural situation due to the presence of complicated political situation, social and socioeconomic issues in addition to the cultural

aspects, specially the west bank which is our study area in this research, The projected number of Palestinians living in the Palestinian Territory at the end of 2011 is 4.2 million, of whom around 2.6 million reside in the West Bank and 1.6 million in the Gaza Strip according to Palestinian Central Bureau of Statistics (PCBS)<sup>2</sup>, with huge challenges that west bank area faces such Israelis colonies and settlements, in addition to the urbanization issues that Palestinian society needs.

## Back ground

### Location

The West Bank has an area of 5,680 kilometers (3,530 mi) and has generally rugged terrain. The climate is mostly desert. The total length of the land boundaries of the region are 404 km. The terrain is mostly rugged dissected upland, some vegetation in west, but barren in the east. The elevation span between the shoreline of the Dead Sea at -408 m to the highest point at Tall Asur 1,022 m. The area of West Bank is landlocked; highlands are main recharge area for ground water aquifers; the western aquifer, Eastern Aquifer <sup>3</sup>.

There are a little natural resources in the area except the arable land, which comprises 27% of the land area of the region. It is mostly used as permanent pastures (32% of arable land) and seasonal agricultural uses (40%).<sup>4</sup> Forests and woodland comprise just 1%, with no permanent crops <sup>5</sup>.

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<sup>2</sup> PCBS website. [http://www.pcbs.gov.ps/Portals/\\_pcbs/PressRelease/palestineEnd2011E.pdf](http://www.pcbs.gov.ps/Portals/_pcbs/PressRelease/palestineEnd2011E.pdf)

<sup>3</sup> Palestinian Water Authority, Water Supply report 2010, published in March 2012.

<sup>4</sup> Ministry of Agriculture Fact sheet about land use, 2008.

<sup>5</sup> Same previous source.

### ***Built up areas***

Political situation divided the west bank into three main areas: area A (3% of the west bank) under fully Palestinian control, area B (27% of west bank) mutual control between Palestinians and Israelis, area C, which includes some Palestinian, built up areas and Israeli settlement and military outposts cover the remaining land. (ARIJ, 1996)

West bank divided into 11 Districts as administrative divisions, those districts are Jericho, Nablus, Qalqiliya, Tulkarem, Tubas, Salfit, Ramallah and al-Birah, Jerusalem, Hebron.

### **Population**

On average, the population density is reaching to more than 466 capita /km<sup>2</sup>, West Bank districts have developed a growing population, affected by the political circumstances. Until the war took place in 1948 most of the city's population has been forced to immigrate to west bank and other countries. The current population West Bank is 2,805,508 inhabitants with a sex ratio of 1.05:1, (PCBS, 2005).

### **Industry**

The West Bank is the larger of the two areas comprising the Palestinian territories it has experienced a relatively high single-digit economic growth rate since 2008, but this rate has been sustained by inflows of donor aid rather than private sector economic activity. After suffering an almost decade-long downturn following the start of the second intifada in 2000, overall standard-of-living measures have recovered to the levels seen in the late 1990s. Despite the Palestinian Authority's (PA) largely successful implementation of economic and security reforms and the easing of some movement and access restrictions by the Israeli

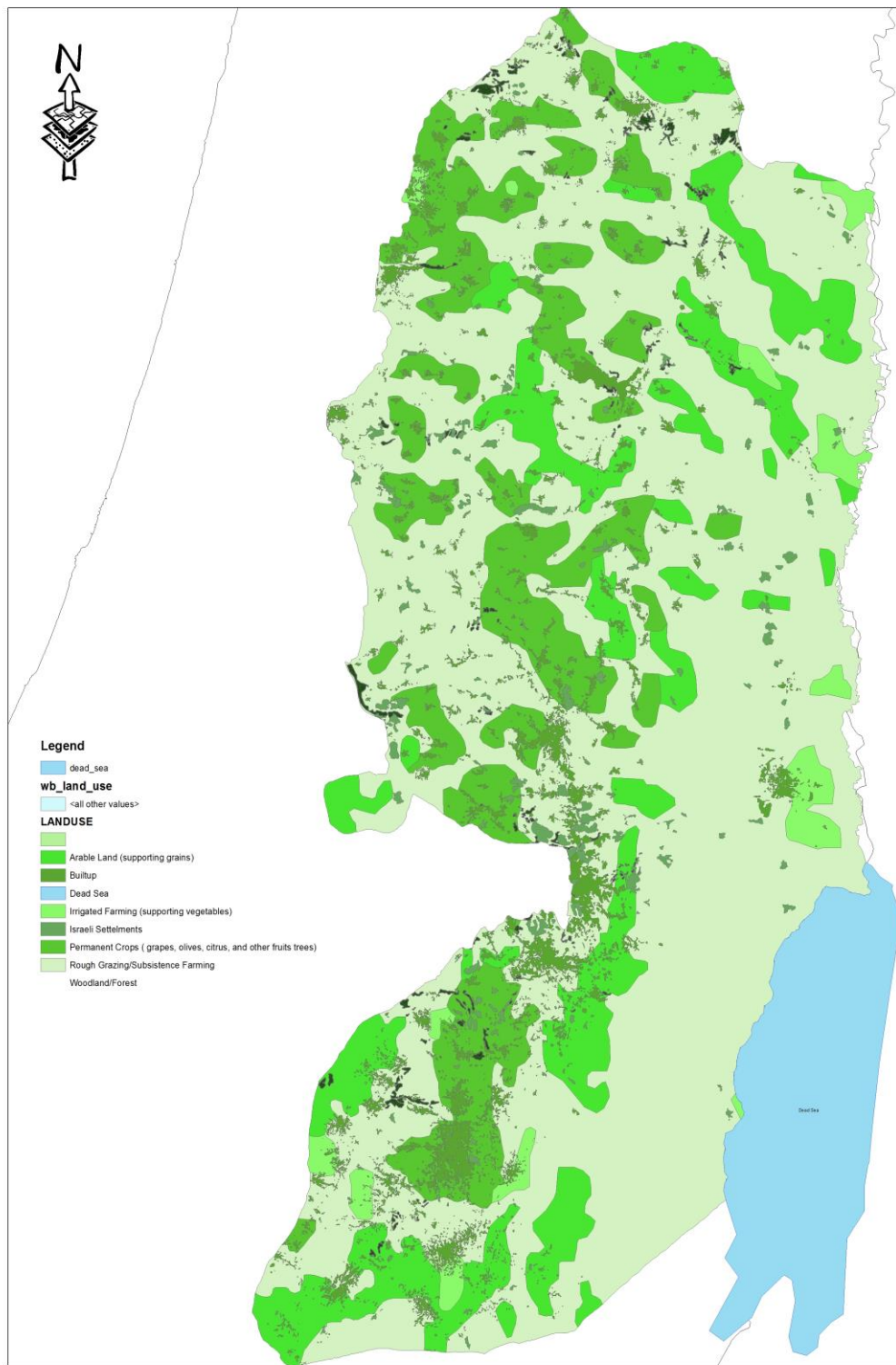
Government in 2010, Israeli closure policies continue to disrupt labor and trade flows, industrial capacity, and basic commerce, eroding the productive capacity of the West Bank economy. Since mid-2007 the PA under President Mahmoud ABBAS and Prime Minister Salam FAYYAD has depended on more than \$3 billion in direct foreign donor assistance to the Palestinian Authority budget. The biggest impediments to economic improvements in the West Bank remain Palestinians' lack of access to land and resources in Israeli-controlled areas, import and export restrictions, and a high-cost capital structure. Absent robust private sector growth, the PA will continue to rely heavily on donor aid for its budgetary needs.

for examp Ramallah Al-Bireh district is not considered an industrial city in general its more directed to the agricultural field, it has tow main industrial area which is approximately 134.2% hectares (0.16% of the land ).(ARIJ,1996)

Currently, most of cites in West Bank is home to a number of industries producing toilet paper, cardboard and cardboard boxes, furniture, consumables, olive oil, soap, aluminum, pharmaceuticals, and many handicrafts. and it is varies from city to city.

## **Cultivated Areas**

For west bank land coverage about 16.9 % of the total area is arable land. Rain fed agriculture is dominant all over the west bank districts in the district, and 18.97% is cultivated for permanent crops .and the rest for other agricultural purposes. We can also say that about 180 Square Kilometer is a irrigated land including Gaza Strip.



Land Use Map of West Bank

**Figure 2-1** Land Use Map in West Bank

## **Settlements**

Settlements utilize a disproportionate part of the available aquifer; in addition they discharge untreated domestic, agricultural and industrial waste into west bank valleys, resulting in significant harm to the environment.

There are 374 settlements and colonization sites all over West Bank , occupying approximately 60% of the West Bank Land, it is estimated that at least 200,000 settlers are living in these settlements. During the past two years, there was a gradual and progressive expansion in the Israeli settlements. (MOS, 2011)

According to the Israeli Human Rights activists, Israeli Jewish settlements in the West Bank area, prevented the expansion of the Palestinian cities and cut it off from the surrounding towns and villages.

## **Traces of Israeli occupation**

Israeli exploitation of water resources accelerated and the water consumption gap between Israelis and Palestinians widened. and as an example in Ramallah Al-Bireh Israel closed several wells and placed several restrictions controlled by means of licensing, application of fixed operation quotas, and refusal of permission to deepen wells, as well as what happen in the other West Bank Districts of Hebron.

Effectively, Oslo II – as in the Interim Agreement - only permitted a relatively small increase in the utilization of water resources by Palestinians as it is clear in article 40 of the mentioned agreement. So the remaining and growing population of Palestine essentially has little control

and restricted access to its national water resources of the city. Palestinian water rights have not been defined even it is recognized in the interim agreement.

## **Geology of West Bank**

The nature and distribution of aquifers and aquitards in a geological system are controlled by lithology, stratigraphy, and structure of the geological deposits and formations.

### *Topography*

The topography of West Bank region is divided into three forms:

- 1- Mountain; considered a rainfall region, it separates between east and west slopes. Its height ranges between 750-1022 meters over sea level.
- 2- East slopes: with ranging decline features. Its height ranges between 250-500 meters over sea level.
- 3- West slopes: has a steep slope. Its height ranges between 20 meters over sea level and 350 meters below sea level.
- 4- Dead Sea and Jordan Valley: its height ranges from 100 meters over sea level to -408 meters below sea level.

The highest point in West Bank district is 1022 m above sea level at Tal A'sur, and the lowest elevation is -408 m below sea level South East corner of West Bank. (ARIJ, 1996)

### *Soil*

West Bank has a variety of soil types according to the diversity of its nature. It's classified as follows:

Upland soil:

- 1- alterrarroza soil: the most common type in the region, which consists of limestone and dolomite in the rocky areas, its red colored or red brown, shallow, used for agricultural.

- 2- Brown forest soil: consists of cretaceous soft rock, contains a thin surface dupalin layer, gray in color, the faded part contain high content of calcareous, exists at shallow depth, its use depends on the amount of lime it contains.

Fertile valleys and plains:

- 1- Brown alluvial soil: exists in plainsat mountainous areas of Nablus, Ramallah, Jerusalem, and mart bin amer, emerged from the ancient mud deposits, brown colored.
- 2- Alluvial soils: has the same characteristic as the first type except for the phenomenon of shrinkage and cracking.
- 3- Colluvial-alluvial soil: exist at mountain of Nablus, Ramallah, Jerusalem composed of various deposits of soil erosion by mountain or sliding soil, usually mixed with gravel and stones, its often brown, use of most agricultural crops.(Ghanem M., 2008)

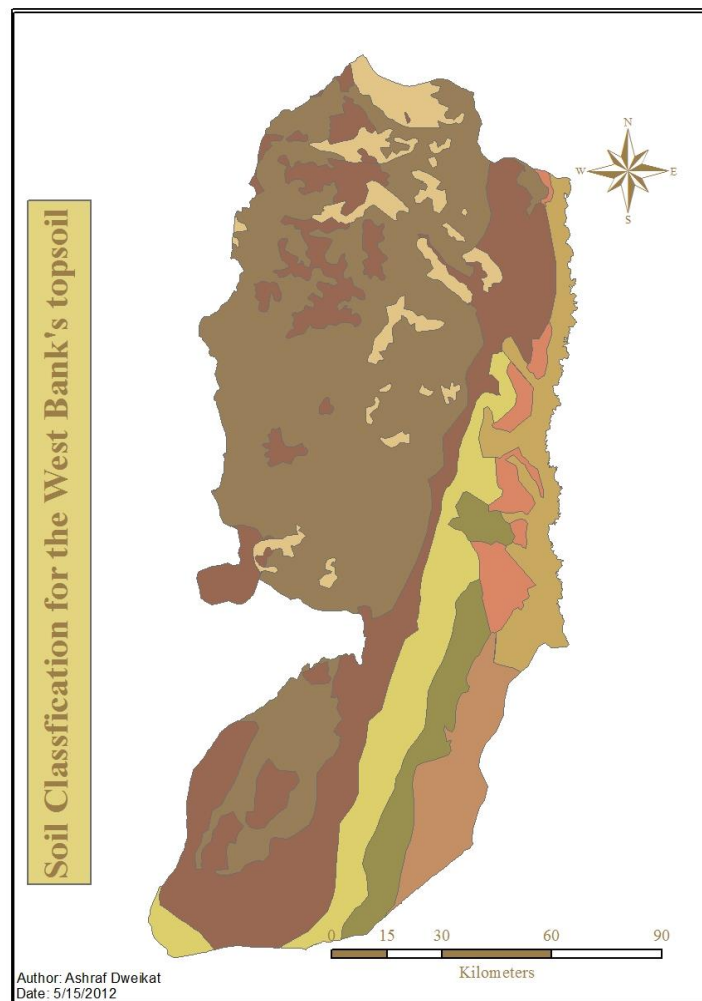


**Figure 2-1** Soil Classification Map of West Bank

Source: PWA, (2012)

### *Aquifers*

Palestine has three main aquifers in the west bank western, eastern, and northeastern. The western (which water flows to the west) has upper and lower aquifers with thicknesses of about 600-900m, although it's the richest basin in the west bank, Israeli forbade Palestinians to dig wells in it, the eastern basin (which water flows towards the east and the southeast and its under the east part. also the north eastern aquifer Basin, and Eastern Basin.

West Bank lies on the three aquifers, first the upper aquifer which consists of the upper Cenomanian (Hebron formations), second the lower aquifer which consist of the Albian lower Beit Kahil formation and sometimes the lower part of Yatta formation.

- **Upper Cenomanian aquifer:**

The Upper Cenomanian aquifer consists of the Bethlehem and Hebron Formations which are mainly interbedded dolomite and chalky limestone (see Figure 2-8). The Aquifer is an important regional source of water supply for domestic uses. The well yields range from 40-400 m<sup>3</sup>/hr. The Aquifer has high recharge values. Its water quality is generally good (30-70 mg/l of chloride). Water levels in the Upper Aquifer are generally higher than in the Lower Aquifer.

- **The Lower Aquifer**

Lower Beit Kahil Formation and to a lesser extent the Upper Beit Kahil Formation and sometimes the lower part of Yatta Formation form the Lower Aquifer, which is a deep confined aquifer across most the West Bank. It is a regional source of drinking water. An individual well yield across the West Bank range from 150-450 m<sup>3</sup>/hr. Water quality is generally good.(Ghanem, M., 2008)

| Period     | Age                        | Graphic log | Typical Lithology                                                            | Formation     | Sub formation | Group                | Symbol | Formation Israel terminology | Hydro-Stratigraphy | Typical Thickness (m) |  |
|------------|----------------------------|-------------|------------------------------------------------------------------------------|---------------|---------------|----------------------|--------|------------------------------|--------------------|-----------------------|--|
| Quaternary | Holocene                   |             | Nari. Alluvium gravels, fan deposits                                         | Alluvium      |               |                      | Qh-a   | Alluvium                     | Local Aquifer      | 0 - 100               |  |
|            | Pleistocene                |             | Thinly laminated marl with gypsum bands and poorly sorted gravel and pebbles | Lisan         |               |                      | Qp-l   | Lisan kurkar group           | Aquitard           | 10 - 200              |  |
| Tertiary   | Neogene                    |             | Conglomerates, marl, chalk, clay and limestone                               | Beida         |               |                      | Tnp-b  | Saqiyeh Group                | Local Aquifer      | 20 - 200              |  |
|            |                            |             |                                                                              |               |               |                      |        |                              |                    |                       |  |
|            | Paleocene (Lower - Middle) |             | Nummulitic reefal limestone                                                  | Jenin         | Jenin 4       | Jenin                | Te-j   | 'Avedat Group                | Aquifer            | 90 - 670              |  |
|            |                            |             | Nummulitic bedded limestone                                                  |               | Jenin 3       |                      |        |                              |                    |                       |  |
|            |                            |             | Nummulitic limestone, chalk                                                  |               | Jenin 2       |                      |        |                              |                    |                       |  |
|            |                            |             | Nummulitic reefal limestone                                                  |               | Jenin 1       |                      |        |                              |                    |                       |  |
|            | Paleocene                  |             | Marl, chalk                                                                  | Khan Al-Ahmar |               | Nablus               | Ka-n   | Mt. Scopus Group             | Aquitard           | 40 - 150              |  |
|            |                            |             | Chalk, marl                                                                  |               |               |                      |        |                              |                    |                       |  |
|            |                            |             | Nummulitic reefal limestone                                                  | Wadi Al-Qit   |               |                      |        |                              | Aquiclude          | 10 - 120              |  |
|            |                            |             | Chalk and chert                                                              |               |               |                      |        |                              |                    |                       |  |
| Cretaceous | Upper                      |             | white limestone and dolomite                                                 | Jerusalem     | upper         | Rama-lah (west bank) | Ko-j   | Bina                         | Upper Aquifer      | 40 - 190              |  |
|            |                            |             | yellow thin bedded limestone                                                 | Bethlehem     | middle        |                      |        |                              |                    |                       |  |
|            |                            |             | dolomite soft                                                                |               | lower         |                      |        |                              |                    |                       |  |
|            |                            |             | Chalky limestone, chalk                                                      |               | lower         |                      |        |                              |                    |                       |  |
|            | Cenomanian                 |             | Karstic Dolomite                                                             | Hebron        |               |                      | Ko-h   | Ammindav                     | Aquifer            | 65 - 160              |  |
|            |                            |             |                                                                              |               |               |                      |        |                              |                    |                       |  |
|            | Lower                      |             | yellow marl                                                                  | Yatta         | Upper         |                      | Ko-y   | Moza                         | Aquitard           | 50 - 125              |  |
|            |                            |             | lime and dolostone, chalk (clay)                                             |               | Lower         |                      |        |                              |                    |                       |  |
|            | Albien                     |             |                                                                              | Upper         | UBK2          | Rama-lah (west bank) | Ka-ubk | Kesaion                      | Lower Aquifer      | 10 - 20               |  |
|            |                            |             | Dolomite limestone with marl                                                 | Beit Kahel    | UBK1          |                      |        |                              |                    |                       |  |
|            |                            |             | Dolomite                                                                     | Lower         | UBK2          |                      |        |                              |                    |                       |  |
|            |                            |             | Karstic limestone                                                            |               | UBK1          |                      |        |                              |                    |                       |  |
| Lower      | Aptian                     |             | marly limestone with limestone                                               | Qatana        |               | Kobar                | Ka-q   | Qatana                       | Aquitard           | 42                    |  |
|            |                            |             |                                                                              | Cin Qinya     |               |                      |        |                              |                    |                       |  |
|            |                            |             | shale                                                                        | Tammun        |               |                      |        |                              |                    |                       |  |
|            |                            |             | shale and limestone                                                          | Ein Al-Assad  |               |                      |        |                              |                    |                       |  |
|            | Neocomian                  |             | marly limestone, sandy                                                       | Nabi Said     |               | Kurnub               | Ka-ns  | Hatira                       | Aquifer            | 20+                   |  |
|            |                            |             | sandstone, volcanics                                                         | Ramali        |               |                      |        |                              |                    |                       |  |
|            | Jurassic                   |             |                                                                              | Tayasir       |               |                      | Kn-r   |                              |                    | 25                    |  |
|            |                            |             |                                                                              |               |               |                      |        |                              |                    |                       |  |
|            | Oxfordian                  |             | Marl interbedded with chalky limestone                                       | Maleh         | Upper         |                      | Jo-um  | 'Arad Group                  | Aquitard           | 100 - 200             |  |
|            |                            |             | Dolomite, limestone with marl                                                |               | Lower         |                      |        |                              |                    |                       |  |

Dolomite

Limestone

megatauna

Flint concretors

sandstone

volcanics

Figure 2-3 Stratigraphical section of West Bank

### *Drainage*

West Bank has 14 catchments systems all over the West Bank Area, seven of them runs from the west part to Mediterranean part (such as wade Saida, wadi el-Shamayah, wade El – Durlb, wade Salaman and wade El- Kabir). and The other system runs from the east to the Jordanian river (such as El-Maquk and el- Ein).

## **Hydrology of the West Bank**

### *Climate*

West Bank has a Mediterranean climate, a rainy cold winter, and hot dry summer. In winter west bank is subject to the harsh rainy south western winds and sometimes to the dry but cold north eastern winds. While we have a desert climate in the southern part of west bank and dead sea area.

### *Humidity*

Humidity is determined through the percentage of water vapour in atmosphere. as an example The mean humidity for Ramallah area 70%, in May the humidity reaches the minimum level that is 48% in November and in February reaches the maximum humidity that is 79.0%. the values of Humidity decreases in winter in Jeinin, Tulkarem, and Hebron, and increased for the same station in summer. whereas station like Nablus increased by 7% in 2009. (PCBS,PMD, 2010)

### *Temperature*

As mention above the west bank is considered as a Mediterranean climate, In winter the weather becomes rainy and reaches low degrees to 5°, in summer the weather becomes dry and sunny with a moderately high temperature of about 30°, the highest temperature is in Jericho with 38°. (PMD,2009)

### *Precipitation*

Rain in west bank starts at late of September until May, maximum precipitation occurs in February (235.2 m<sup>3</sup>). As for the average rainfall, it is around 20 inches or 500 ml a year. In summer it's a sunny dry weather.

West bank has more than 80 rainfall stations distributed allover the area, Ramallah Al-Bireh district has an average annual rainfall of 200-450 mm in the east of the city and 350 – 550 mm in the west. (PMD, 2006)

### *Wind*

Wind velocity is affected by several aspects, most affecting agent is air temperature, the highest wind velocity in Ramallah Al-Bireh according to 2005 statistics was 16.3 km/h in the month with the highest temperature (July), and lowest wind velocity in was 9.7% in November. (PCBS, 2005)

### *Evaporation*

Evaporation in west bank district reaches maximum values between June and September due to the closeness of the sun at this time of the year and the high temperatures.

Evaporation in the district exceeds the rest of the cities due to the high wind velocity, and the height of the city, its highest values at July is 335.2 mm, and lowest values at February is 79.5 mm. (PCBS, 2005)

## **Water resources and demand**

### *Water demand*

The present statistics shows that the population number in west bank 2.3 - without the annexed part of Jerusalem which annexed by Israeli occupation- is affecting the need of water which is approximately 73 L/c/day used for drinking and other domestic uses.

The overall loss of the uncounted-for water rate is about 29% in over west bank, which creates a larger gap between the resources and the demand.

The municipal future water demands comprise the domestic, public, livestock, commercial, and tourist water needs.

### *Water resources:*

Water resources management as defined by the Palestinian Water Law, Article 1, includes the development, improvement, and protection of water resources. This is what PWA along with other local utilities tries to accomplish. The overall natural water resources for Palestinians in the West Bank mostly stretch out in the Mountain Aquifer (containing –based on the Israeli practices- three shared aquifers: the Eastern, the Western and the North-Eastern aquifers). Currently, Palestinians abstract less than 15% of the “estimated potential” of those three aquifers. In 2010, the abstraction of the Mountain Aquifer did not exceed 98 MCM: with 29 MCM from the North-Eastern Aquifer, 25 MCM from the Western Aquifer and 44 MCM from the Eastern Aquifer. However, reduced Palestinian abstraction from all three aquifers over the last decade is due to several reasons; starting with Israeli controls over the available resources, the severe restrictions imposed by JWC and ICA on Palestinian development water projects, and ending with the adverse impact of the drought phenomenon that caused a gradual decrease in rainfall recharge rates into groundwater systems.<sup>6</sup> On the other hand –and with the assurance and support of international reports<sup>7</sup> - Israel abstracts the balance and overdraws on the “estimated potential” by more than 50%. This however does not go along with the Palestinian Water Law –Article 7; “The Palestinian Water Authority shall have full responsibility for managing the water resources and wastewater in Palestine”.

---

<sup>6</sup> Based on the OSLO II interim agreement, Article 40, the allocation of water resources of the three shared aquifers allowed Palestinians to abstract no more than 22 MCM from the Western Aquifer, 42 MCM from the North Eastern Aquifer and 54 MCM from the Eastern Aquifer, however, this is 20 MCM more than the value abstracted in 2010. i.e., Palestinians are not even receiving the quantities specified in the Oslo II agreement.

<sup>7</sup> The World Bank Report for West Bank and Gaza, *Assessment of restrictions on Palestinian Water Sector Development*, 2009

- **Ground water**

ground water is the main Water resources that the west bank depend on, some of these ground water wells owned by Palestinians and most of them under Israeli occupation and control. It supplies the district with largest quantity of water. The geological composition of the wells is Cinomanian upper and lower containing salts No.3 and No.4 and give good water for use when pumping water from the lower class Cinomanian. (PWA, water supply report 2010)

The ground water wells supplying domestic water to the people in the west bank districts are controlled by water supplier and Mekorot and west bank water department and PWA. The total number of groundwater wells in west bank District is 250 wells for domestic and agriculture as shown in Figure 2.3.(PWA,2006)

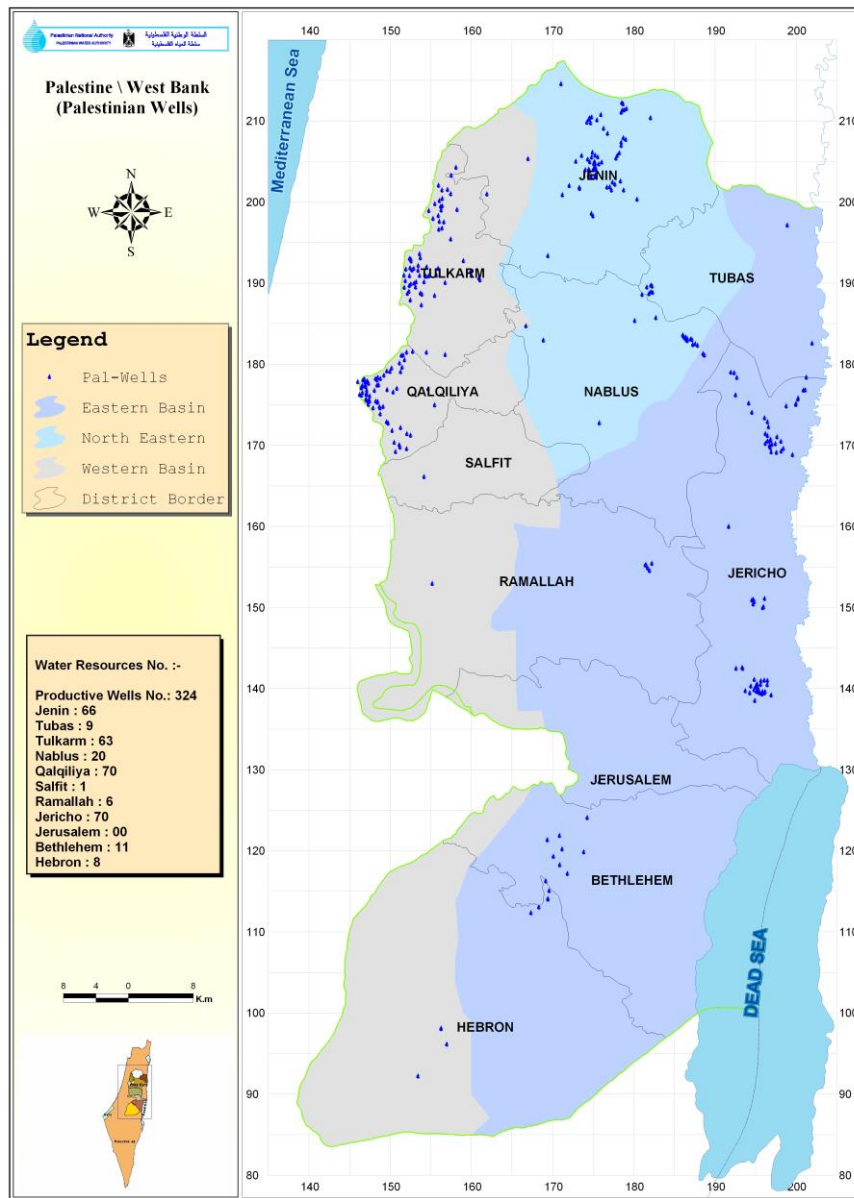


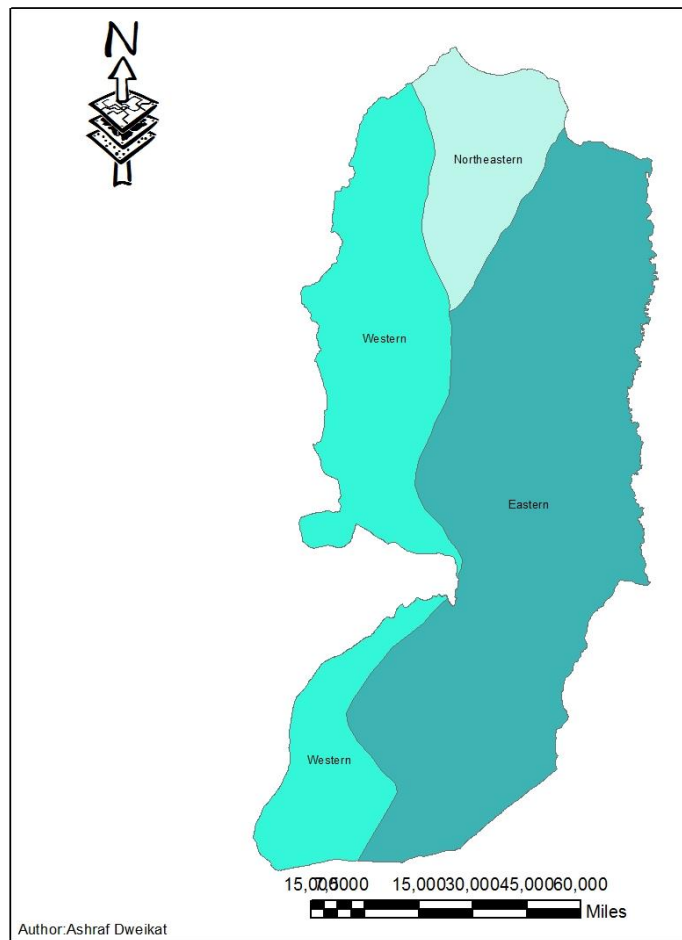
**Figure 2-3** Water Wells and springs in West Bank

Source: PWA, (2009)

Groundwater basins in west bank as shown in figure 2-4, are the western and the eastern as follows:

- The western groundwater basin (Auja Tamasseh sub-basin): This basin underlies approximately 65% of the district and its water flows towards the west.
- The eastern groundwater basin: This basin underlies the eastern part of the district (35%). Its water flows towards the east and southeast. (PWA, 2006)

- North Eastern Ground water Basin: the basin underlines the north Eastern part of west bank.



## West Bank Water Basin

**Figure 2-4** Groundwater basins in West Bank

Source: PWA, (2012)

- **Purchased water**

1. West bank water department: These wells are drilled in the Jordanian government period after Israeli occupation authorities took control over these wells and handed them to Mekerot which is the water resource company in Israel.

2. Israeli water company (Mekeroth): it is considered the main source for purchased water that take from the wells inside the green line or the wells in side the wet bank the statistics shows the amount of purchased water in 2011 was approximately 55.4 Mcm .

- **Springs and wells**

The two major springs in the district are the Auja and Samya springs located in Ramallah and Kafr Malek. Springs are the main source of the water in villages, especially if they were not connected with the network of municipal water distribution. In the territory of Ramallah there are about 78 springs, 38 of them pumps at rate 0.01 liters per second the others give an annual recharge of 11.56 L/sec. They are used mostly for domestic purpose and few of agriculture.(PHG, 2006)

- **Rain water harvesting (Household Cisterns)**

Water collected by two ways, the first is collecting rain in large hole at the earth's surface. Second is by the use of roofs to collect rain water in the winter and then store it in tanks and use it later for non-drinking purposes such as irrigation and cleaning.

## **Water pollution**

### *Introduction to water pollution*

Ground water is the main source of water in west bank because it occurs on the western, north eastern, and eastern aquifers , but the nature of stratigraphic formation are from karstic type which leads to high vulnerability to contamination of ground water.

### *Sources of ground water pollution*

- **Domestic waste water:**

The statistic found that the quantity of domestic waste water reach to (50 – 85) % from the consumption water, it's the most important source that contaminates ground water and effect on its quality, domestic water divided to three types according to waste water collection:

- 1) Connected to sewage system.
- 2) Using uncover age system.
- 3) Drilling holes into the ground for collecting water.

- **Industrial waste water**

1. Gas station: all of them have under ground tanks may lead to leakage from its content to the ground water basins, their number in Ramallah district reaches to 19.
2. Stone cutting: it's an important source of pollution since it discharges large amounts of slurry into wadies which results in increasing sediment loads that pollute the karstic aquifers.
3. Olive mills: there is no accurate data about olive mills but there's 26 olive mills in Ramallah district only that mainly works at the period between October up to December, most of them discharge their "Zebar" into wadies, the improper disposal of the organic content of the waste of olive mills is a major destruction to the environment in general, and ground water in specific.

## Methodology

The Main reference for this chapter is Zwahlen, (2003)

### *Introduction Literature Review*

The highest priority is to protect groundwater which is used for drinking from contaminants, finding a map that describes the danger level of associating a waste water treatment plant in a the different positions of a certain area is the main subject of this project, its called the risk map, its a map that considers the activities that present the risk that threatens groundwater. They are obtained by synthesizing the information presented on two different maps; hazard and vulnerability. In order to get those maps a series of actions are required starting with collecting geographic and hydrologic data, give them a graphical form by the use of certain computer programs and minor calculations.

This chapter is to explain the basis of the work of this project.

### *Definition and concept of Ground water vulnerability*

Vulnerability is the subject of this project that's why it will be discussed in details. Generally this term is defined as the sensitivity of something to any kind of stresses acting upon, earlier in 1968 it was introduced as the protection of physical environment to ground water against contaminants of human activities and nature in general.

Vulnerability is very important since it provides a vital tool to protect karst groundwater; it's also used as a practical tool for land-use planning, protection zoning, and risk assessment. It's connected to planning process and describes various properties in an integrated way. It's also a non measurable property that has two types; intrinsic (natural) and specific. The first type depends mainly on the natural properties of the area and it's a function of the geological, hydrogeological, and hydrological properties of the system which is independent of the nature of the contaminants, but the second type includes in addition the properties of contaminants.

A physical definition of vulnerability reflects aquifers capacity to reduce contamination, its developed through graphical method of cube axis that allows to define vulnerability more clearly has three basic criteria: transfer time, duration and concentration level. This axis is used to define vulnerability classes, based on that when two different points (A and B) are being compared due to vulnerability, A is said to have less vulnerability than B if:

- If the transfer time from A to the target is longer than the transfer time from B.
- If the maximum concentration of a contamination coming from A is lower than the maximum concentration of the same contamination coming from B.
- If the duration of a contamination coming from A is shorter than the duration of the same contamination coming from B.

### *Ground water Vulnerability Model (origin-pathway-target model)*

This is the basic model used for vulnerability; it's divided into three main parts that describes the whole process which are shown in Figure 3-1.

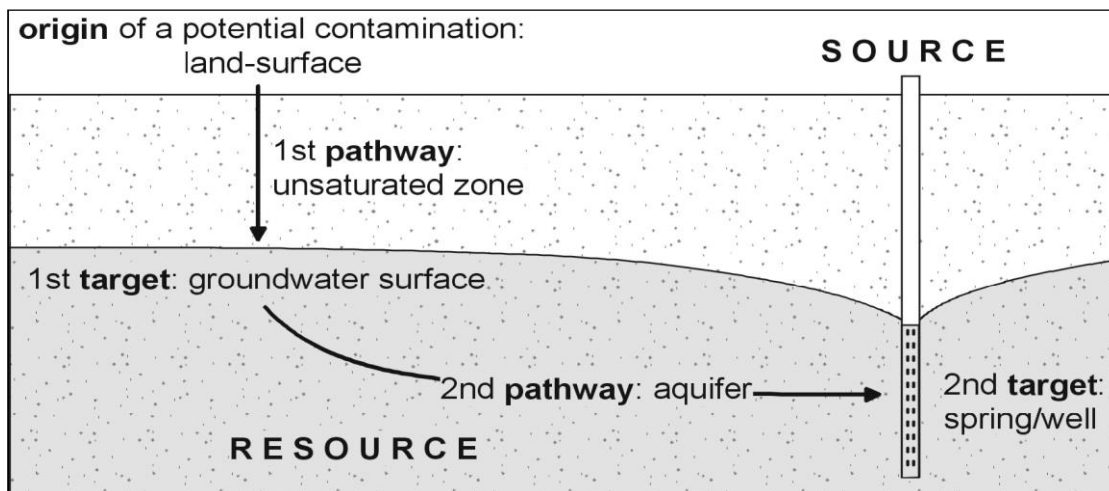


**Figure 3 – 1** The origin-pathway-target model

- The origin is the proposed place of the release of the contaminant, it's usually assumed to be at the land surface. Sources like fertilizers, pesticides, and leakage of sewerage system are the main suspects.
- The path way is the path taken by the contaminant from the source zone (its origin) to the protected zone which is ground water in this case. The pathway may be vertical or horizontal through aquifers.
- The target is the water in the aquifers which has to be protected from contamination.

### *Source and the resource of contaminants*

Distinguishing between resource and source is very important; the source is ground water, resource is what feeds ground water, it is difficult to protect the source without protecting the resource, for resource protection, groundwater surface in the aquifer is the target. The pathway consequently consists mostly of the vertical passage through the layers above groundwater surface or surface of the aquifer. These overlying layers are mostly unsaturated but might be locally saturated. For source protection, the water in the well or spring is the target. The pathway includes mostly horizontal flow in the aquifer (this can be easily noticed from Figure 3-1).

### *Methods and applications of producing vulnerability maps*

There are two types of models that can be used by the GIS program to produce vulnerability maps, these models depend on the nature of the area analyzed, it can be either DRASTIC model or PI (II) model for karst (carbonate) aquifers.

A wide explanation will be listed about the PI method since it's the chosen model in this project because Palestine's aquifers are of karstic type which has especial characteristics:

- A unique and separate hydrogeologic investigation for the karst aquifer is the first step in the process of producing the map since each karstic system has its own properties.
- in the karst aquifer the water table might be discontinuous and not apparent, also an epikarst zone might exist which is difficult to assess since a large portion of it is usually not visible at the surface.
- Usually the higher layers are considered protection for the groundwater but lateral flow must be taken into consideration when having a low permeable layer, since karst aquifers are recharged by infiltration and percolation through the soil or by concentrated point through swallow holes.
- This type of aquifers has intergranular pores those results with triple porosity, fractures, and solution voids. Groundwater is stored in the fractures and the pores which is considered a slow flow for the contaminant, or it flows rapidly through the conduits which act as drains.
- Karst systems have fast and strong hydraulic reactions to hydrologic events, it's usually large and connected over long distances.
- Considering calculations this type of systems is considered anisotropic and heterogeneous which creates higher complexity in the interpolations and mathematical formulas.

The hydraulic property of karst has a large role in migration of the contaminant; the epikarst layer it considers a high conductivity medium, and the existence of dual permeability.

Mineralogical and geochemical properties play an important role for example the carbonate medium that prevented the migration of contaminants such as phosphate that precipitates as apatite, and a heavy metal that can precipitate as carbonate species, generally these carbonate medium is absent from covering soil that residue formations.

Clay has a double mineralogical and geochemical role where the specific surface enables adsorption of nonionic substances (organics and bacteria) and their cationic exchange capacity (CEC) enable retention of cations .these come from the soil covering (residual clay), non karstic covering formations (geological clays) and detrial sediments which are presented in karstic layer that founded in the saturated and unsaturated zones.

Organic matter is founded in top soil and in the filling of the soil of Karren that play two roles; adsorption of organic contaminant and forming of ligands with metals.

EH is generally high in the karst environment that is widely pen to the atmospheric reservoir in this case the heavy metals can precipitate. Finally the temperature plays an important role where the degradation processes are more active at higher temperature.

## **PI method**

The PI method was developed within the scope of COST 620 at the Department of Applied Geology (AGK), University of Karlsruhe. It's a mapping method used to produce intrinsic vulnerability maps based on the GIS approach with special consideration of karst aquifer. It is based on the origin – pathway –target model where the origin is the ground surface; target is groundwater table in the uppermost aquifer; pathway is the layers between ground surface and groundwater table. However, if the resource vulnerability map is intersected with a map showing the flow route in the aquifer towards a spring or well, it can also be used for source vulnerability mapping.

This PI factor is subdivided into five classes ranging between 0-5, if  $\pi \leq 1$  it indicates a very low protection and extreme vulnerability to contamination, if  $\pi = 5$  it indicates a high degree of protection and very low vulnerability.

PI method depends on two factors; protective cover (p factor) and infiltration conditions (I factor), the final protection factor ( $\pi$ ) is a result of 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 P factor describes the protective function of the layers between the ground surface and the groundwater table – soil, subsoil, non karst rock and unsaturated karst rock, its divided into five classes. Form  $P = 1$  for a very low degree of protection to  $P = 5$  for very thick and protective overlying layers.

The I factor describes the infiltration conditions, particularly the degree to which the protective cover is bypassed as a result of lateral surface and subsurface flow in the catchment of swallow holes and sinking streams.

The PI method always takes the groundwater table in the uppermost aquifer as the target since it can be misleading to assign a low vulnerability to an area when the aquifer under consideration is overlain by a higher aquifer – in this case, the higher aquifer needs protection, as a consequence, a higher aquifer is not considered to be protection for the underlying aquifer.

A P-factor of 5 is assigned to areas outside the considered aquifer from which recharge enters the aquifer by surface and lateral surface or subsurface flow; these areas can be subdivided and classified according to different I values. An illustrations of the PI method is shown in Figure 3-2. The P factor takes into account the effectiveness of the protective cover as a function of the thickness and hydraulic properties of all the strata between the ground surface and the groundwater surface. The protective cover consists of up to four layers: 1. topsoil, 2. subsoil, 3. non karst rock, 4. unsaturated

karst rock. The I factor expresses the degree to which the protective cover is bypassed by lateral surface and subsurface flow, especially within the catchments of sinking streams.

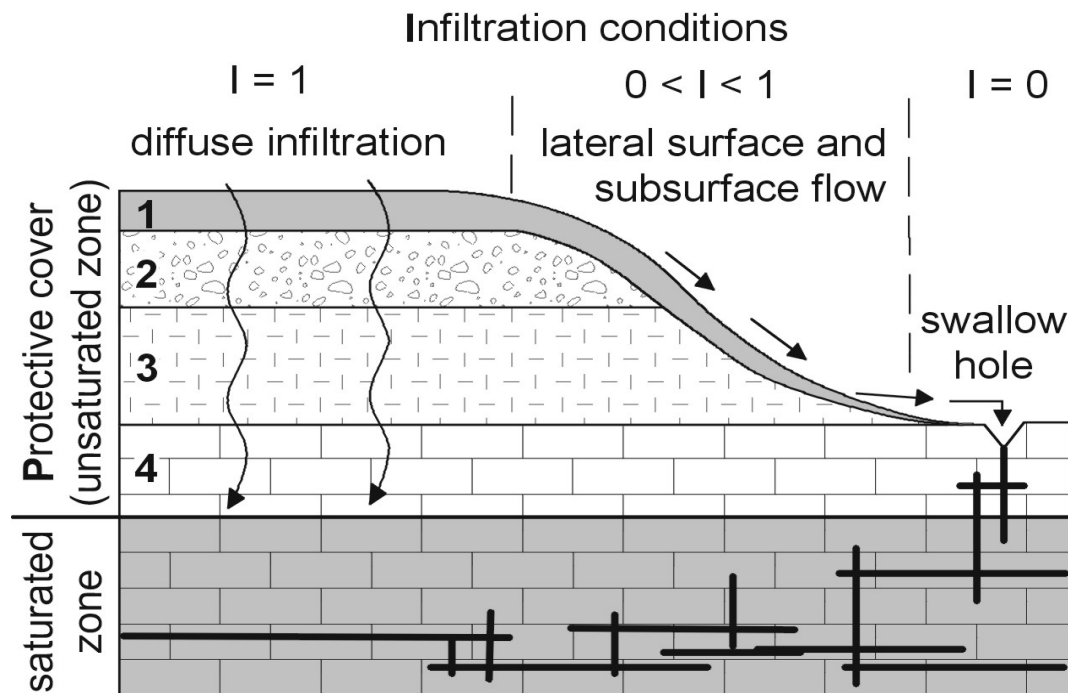


**Figure 3-2** Illustration of the PI method

### *Protective cover factor (P factor)*

This factor is a description of what the aquifers between ground surface and ground water table do to protect the water, it indicates the effectiveness of the protective cover, which might be soil, subsoil, non karst rock, and unsaturated karst rock.

P factor is divided into five classes ranging in between 1 - 5, when  $P = 1$  indicates very low degree of protection, when  $P = 5$  indicates a very thick and highly protective overlying layer, which is the best case.

Using the Arc Map 10 program is basic to find the P-factor, the methodology here is to draw a number of graphs that form different layers of the study area, which depends mainly on the following:

**I. Type of Topsoil(T),**

**II. Amount of Recharge (R),**

**III. Type Of subsoil (S),**

**IV. Lithology (L) and Fracture (F).**

The value of P factor is found using the following steps:

1. First a data of the top soil of Ramallah district is collected, a Figure of the effective field capacity vs. the top soil (T) is drawn using Table 3-1.

**Table 3-1 Top Soil**

| <b>eFC(mm)up to<br/>1meter depth</b> | <b>T</b>   |
|--------------------------------------|------------|
| <b>&gt;250</b>                       | <b>750</b> |
| <b>&gt;200-250</b>                   | <b>500</b> |
| <b>&gt;140-200</b>                   | <b>250</b> |
| <b>&gt;90-140</b>                    | <b>125</b> |
| <b>&gt;50-90</b>                     | <b>50</b>  |
| <b>&lt;50</b>                        | <b>0</b>   |

2. In order to find the recharge for the area, several properties are to be studied: rainfall and precipitation, evaporation and recharge of the area. This all leads to draw the second Figure which is the recharge graph using Table 3-2.

**Table 3-2** Recharge Table

| Recharge(mm/y) | R    |
|----------------|------|
| 0-100          | 1.75 |
| 100-200>       | 1.50 |
| 200-300>       | 1.25 |
| 300-400>       | 1.00 |
| 400>           | 0.75 |

3. After dealing with the top soil, the subsoil is then examined and a Figure of the grain size distribution is drawn against the type of the subsoil, using Table 3-3.

**Table 3-3** Subsoil

| Type of soil grain size distribution | S   | Type of soil grain size distribution                 | S   |
|--------------------------------------|-----|------------------------------------------------------|-----|
| Clay                                 | 500 | Very clayey sand, clayey, loamy silty sand           | 140 |
| Loamy clay, slightly siltyclay       | 400 | silt, very loamy sand                                | 120 |
| Slightly sandy clay                  | 350 | Loamy sand, very silty sand                          | 90  |
| Silty clay, clayey silty loam        | 320 | Slightly clayey sand, silty sand, sand clayey gravel | 75  |
| Clayey loam                          | 300 | Slightly loamy sand,                                 | 60  |

|                                                                                      |     |                                                            |     |
|--------------------------------------------------------------------------------------|-----|------------------------------------------------------------|-----|
|                                                                                      |     | sandy silty gravel                                         |     |
| Very silty clay, sandy clay                                                          | 270 | Slightly silty sand,<br>slightly silty sand with<br>gravel | 50  |
| Very loamy silt                                                                      | 250 | Sand                                                       | 25  |
| Slightly clayey loam, clayey<br>silty loam                                           | 240 | Sand with gravel, sandy<br>gravel                          | 10  |
| Very clayey silt, silty loam                                                         | 220 | Gravel, gravel with<br>breccia                             | 5   |
| Very sand clay, sandy silty<br>loam, slightly sandy loam,<br>loamy silt, clayey silt | 200 | Non-lithified volcanic<br>material(pyroklastied)           | 200 |
| loam ,slightly loamy silt                                                            | 180 | Peat                                                       | 400 |
| Slightly clayey silt, sandy<br>loamy silt, silt, very sandy<br>loam                  | 160 | Sapropel                                                   | 300 |

4. Lithology of the soil layers is drawn in a Figure, fracturing of the stones is drawn in another Figure using Table 3-4, the product of those two Figures give the value of the bed rock factor (B).
5. All the data required for equation of the total protective function is now available which is used as an indicator of the P-factor using Table 3-5.

**Table 3-4** Lithology and fracture criteria

| Lithology                                                           | L  |
|---------------------------------------------------------------------|----|
| Claystone, slate ,marl,<br>siltstone                                | 20 |
| Sandstone, quartzite,<br>volcanic rock plutonite,<br>metamotphite   | 15 |
| Porous sandstone, porous<br>volcanic rock(e.g. tuff)                | 10 |
| Conglomerate, breccia,<br>limestone, dolomitic rock,<br>gypsum rock | 5  |

| <b>Fracturing</b>                                                           | <b>F</b> |
|-----------------------------------------------------------------------------|----------|
| Non-jointed                                                                 | 25.0     |
| Slightly jointed                                                            | 4.0      |
| Moderately jointed, slightly karstified or karst features completely sealed | 1.0      |
| Moderately karstic or karst features mostly sealed                          | 0.5      |
| Strongly fractured or strongly karstified and not sealed                    | 0.3      |
| Epikarst strongly developed, not sealed                                     | 0.0      |
| Not known                                                                   | 1.0      |

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

Eq.3-1 Total Protective Function

**Table 3-5** P-factor

| <b>Score PTs</b> | <b>effectiveness</b> | <b>P-factor</b> | <b>Example</b>             |
|------------------|----------------------|-----------------|----------------------------|
| 0-10             | Very low             | 1               | 0-2 m gravel               |
| 10-100>          | Low                  | 2               | 1-10 m sand with gravel    |
| 100-1000>        | Medium               | 3               | 2-20 m slightly silty sand |
| 1000-10000>      | High                 | 4               | 2-20 m clay                |
| 10000>           | Very high            | 5               | 20 m clay>                 |

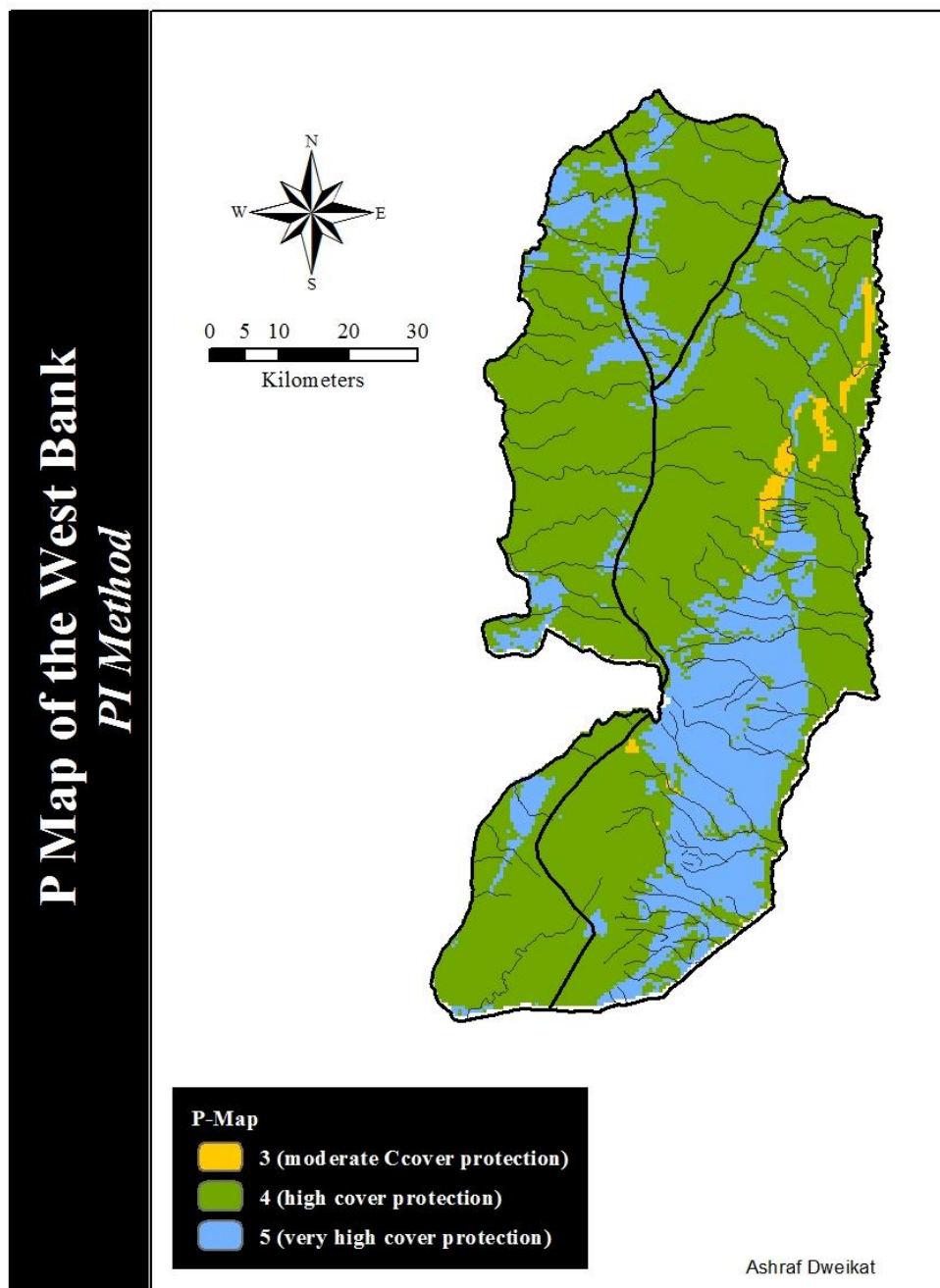


**Figure 3-2** The P-Map of PI method

### *Infiltration factor (I factor)*

#### General concept

It's a description of resistance of the protective cover to the infiltration passing laterally within the catchment of swallow holes and sinking streams, its value depends on the proportion of the lateral flow which is controlled by soil properties, slope and vegetation.

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, it equals 0.0 when the protective cover is completely bypassed by a swallow hole through which surface water directly enters the karst aquifer. 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.

I factor is not precisely defined in terms of hydrology. It is a half-quantitative tool to express the vulnerability of groundwater resulting from bypassing of the protective cover by lateral surface and subsurface flow. The I factor is used for further GIS operations to generate the vulnerability map.

### *Hydrological basis*

The vulnerability of an area to groundwater contamination is dependent on the pathway of a possible contaminant from the ground surface to the groundwater table. As contaminants are usually transported in water, it is necessary to describe the possible flow paths of the water, that's why it has a hydraulic basis, and we can distinguish between three relevant processes: infiltration with subsequent percolation, surface flow, and subsurface flow. Which of these processes predominates depends on both the properties of the site and the characteristics of the rainfall event, as well as the previous precipitation history and the degree of saturation of the soil.

- Infiltration with subsequent percolation:

Diffuse infiltration of rain water from the surface into the soil and the subsequent downward percolation through the soil is the dominant hydrological process if the rainfall intensity is less than the capacity of the soil to absorb the water and if the hydraulic conductivity of the total soil profile is high enough to allow downward movement of the water. Gentle slopes, dense vegetation – especially forest cover – and coarse-textured soils with thick organic horizons and stable peds favor infiltration.

- **Surface flow:**

Surface flow occurs when not all of the rainwater is able to penetrate the soil surface. There are two main types:

1) Hortonian runoff: Hortonian runoff occurs when the intensity of a rainfall event exceeds the infiltration capacity of the topsoil and the surplus rainwater flows away on the surface. The necessary condition for Hortonian runoff is that the intensity of the rain is significantly higher than the hydraulic conductivity of the topsoil. The amount (depth) of surplus water, which is sufficient to produce surface runoff, is dependent on the slope of ground surface.

2) Saturated surface flow: Occurs when a rainfall event is sufficiently long and intense to saturate the soil and exhaust its through flow capacity or if the soil was saturated due to previous pre- capitation and the additional precipitation cannot infiltrate but flows away on the surface. This process is favored when lower permeability layers are present below thin, relatively highly permeable topsoil. The necessary condition for this type of flow is that the total amount of precipitation is more than the effective porosity; similar to Hortonian runoff, the amount of surplus water that is sufficiently high to produce surface runoff depends on the ground surface gradient.

- **Subsurface Flow:**

Subsurface flow occurs when the hydraulic conductivity of the topsoil is high enough for the infiltration of rainwater, while lower permeability layers in or below the soil do not allow the further downward percolation to continue. In this case, the layers above the low permeability zone become temporarily saturated, allowing movement parallel to the slope. The velocity of the subsurface flow is strongly dependent on the slope gradient, the hydraulic conductivity of the topsoil, and on preferential flow paths, two types can be emphasized Subsurface storm water flow in diffuse pathways and Subsurface storm water flow in preferential pathways, both are fast flow process, the first type occurs in very highly permeable soils where the flow velocity depends on the hydraulic conductivity and the slope gradient. The second type occurs in Soil pipes, desiccation fissures, worm holes and mouse holes which are usually dry but become filled with water during intensive rain events, enabling very fast flow.

## **Determination of the I-factor**

hydrological basis discussed above is used to determine this factor, The critical values for hydraulic conductivity and thickness were calculated using data and theoretical approaches from the hydrological literature to calculate infiltration, depending on their values 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; macro pores favour 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/h on gentle slopes) if the conductivity of the topsoil is less than  $10^{-5}$  m/s. Determination of the predominant flow process is shown in Figure 3-3.

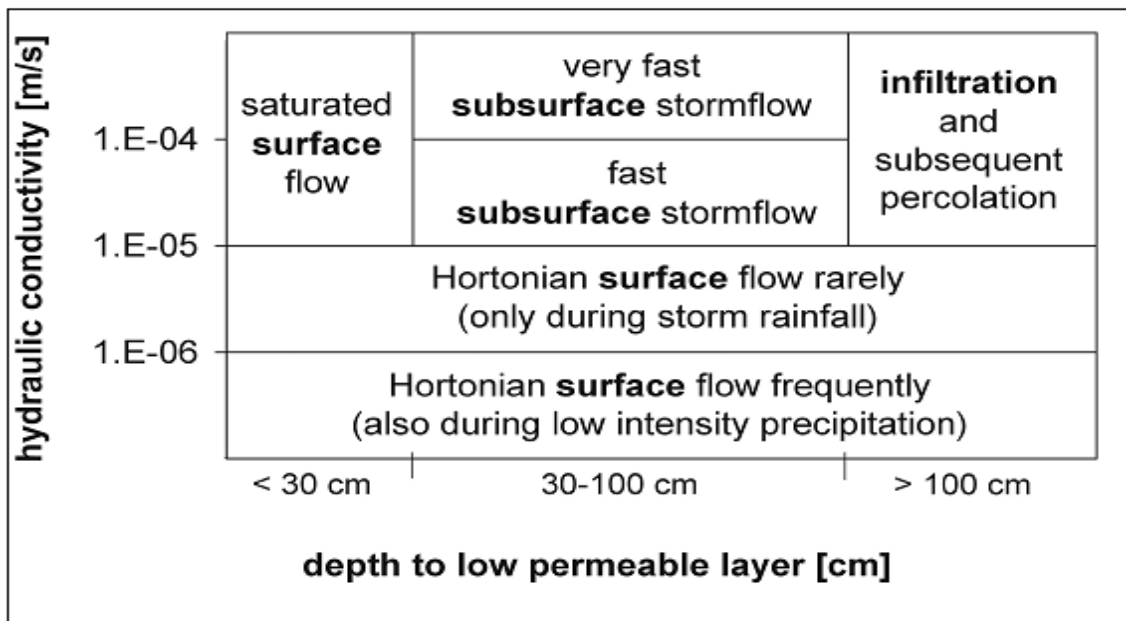


**Figure 3 – 3** Determination of the predominant flow process as a function of the saturated hydraulic conductivity and the depth to low permeability layers.

If it is not possible to distinguish all the six processes, it is often sufficient to differentiate between infiltration, subsurface flow and surface flow. This can be done on the basis of direct field observations and geological data

If there is a lack of data 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.

However, for vulnerability mapping in karst areas, it is indispensable 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 the I' map with a map showing the catchment areas of sinking streams. A topographic sketch and geological profile is shown in Figure 3-4.

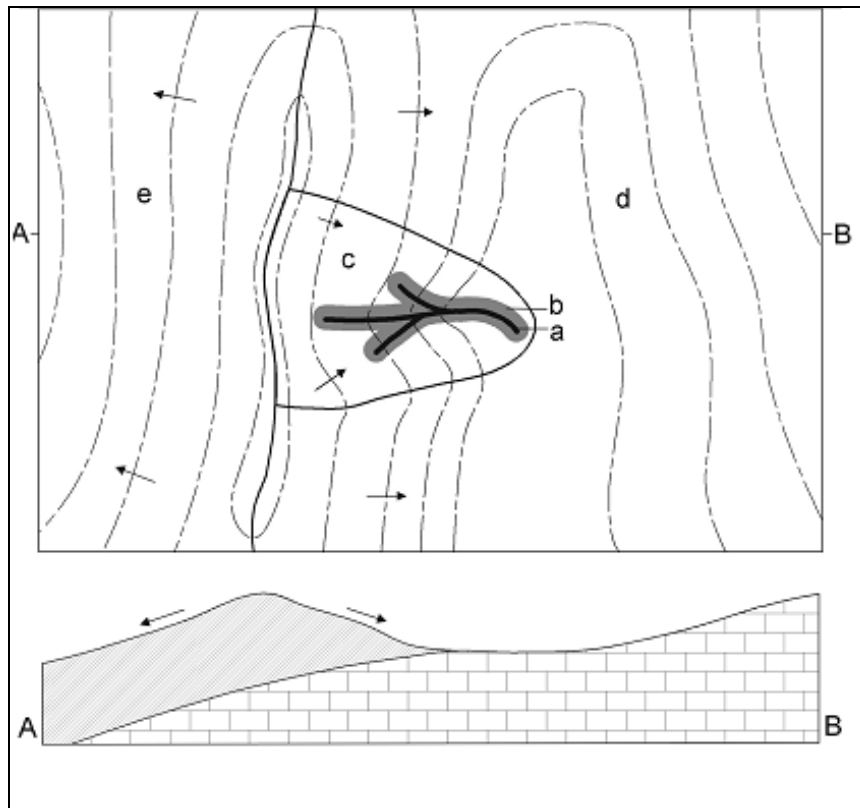


**Figure 3 – 4** Topographic sketch and geological profile illustrating the five different zones of the “Surface Catchment Map”

To decrease the risk five zones are delineated on this “Surface Catchment Map” in the Figure (3-4):

- 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 and the map of the surface catchment area are intersected. Those maps are constructed through the following diagram:

Step one: Determination of the dominant flow process:

|              |         | Depth to low permeability layer |           |         |
|--------------|---------|---------------------------------|-----------|---------|
|              |         | < 30 cm                         | 30-100 cm | >100 cm |
| Saturated    | >10     |                                 | Type C    |         |
| Hydraulic    | >10 -10 | Type D                          | Type B    | Type A  |
| Conductivity | >10 -10 | Type E                          |           |         |
| m/s          | < 10    | Type F                          |           |         |

Step Two: Determination of the I' - factor:

| Forest                |        |       |         |      |
|-----------------------|--------|-------|---------|------|
| Dominant Flow process |        | Slope |         |      |
|                       |        | <3.5% | 3.5-27% | >27% |
| Infiltration          | Type A | 1.0   | 1.0     | 1.0  |
| Subsurface            | Type B | 1.0   | 0.8     | 0.6  |
| flow                  | Type C | 1.0   | 0.6     | 0.6  |
| surface               | Type D | 0.8   | 0.6     | 0.4  |
| flow                  | Type E | 1.0   | 0.6     | 0.4  |
|                       | Type F | 0.8   | 0.4     | 0.2  |
| Field /meadow/ pature |        |       |         |      |
| Dominant Flow process |        | Slope |         |      |
|                       |        | <3.5  | 3.5-27% | >27% |
| Infiltration          | Type A | 1.0   | 1.0     | 0.8  |
| Subsurface            | Type B | 1.0   | 0.6     | 0.4  |
| flow                  | Type C | 1.0   | 0.4     | 0.2  |

|         |        |            |            |            |
|---------|--------|------------|------------|------------|
| surface | Type D | 0.5        | 0.4        | 0.2        |
| flow    | Type E | 0.8        | 0.4        | 0.2        |
|         | Type F | <b>0.6</b> | <b>0.2</b> | <b>0.0</b> |

Step Three: Determination of the I- factor:

| Surface Catchment map |                                              | I' Factor |     |     |     |     |     |
|-----------------------|----------------------------------------------|-----------|-----|-----|-----|-----|-----|
| A                     | Swallow hole, sinking stream and 10 m buffer | 0.0       | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| B                     | 100 m buffer of both sides of sinking stream | 0.0       | 0.2 | 0.4 | 0.6 | 0.8 | 1.0 |
| C                     | Catchment of sinking stream                  | 0.2       | 0.4 | 0.6 | 0.8 | 1.0 | 1.0 |
| D                     | Area discharging inside of the karst area    | 0.4       | 0.6 | 0.8 | 1.0 | 1.0 | 1.0 |
| E                     | Area discharging out of the karst area       | 1.0       | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 |

## Vulnerability mapping

Vulnerability map represents in an integrated manner the main characteristics and properties of the catchment of the contamination resistance, it illustrates the area with different degrees of vulnerability. It is widely used in protection zones, land use planning, and risk assessment. However it has a major disadvantage of giving qualitative approach only.

Vulnerability map is an application of a Geo informatics technology (GIS) where the GIS is an information system which has the capacity to assemble, store, analyze and display information. The regional interactions and interpretation relationships between land, soil & water can be displayed using a GIS.

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 ( $\pi = P \cdot I$ ).

As shown in Table 3-6 the  $\pi$  factor ranges between 0.0 and 5.0, with high values representing a high degree of natural protection and low vulnerability. Small maps of the protective cover and the infiltration conditions are also printed as insets on the vulnerability map so that it can be determined whether the vulnerability of a particular area is due to a thin protective cover or to surface and subsurface concentration of flow. 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.

**Table 3 - 6** Legend for the vulnerability map, the P and the I map

|               | vulnerability map<br>vulnerability of<br>groundwater |               | P-map<br>protective function<br>of overlying layers |          | I-map<br>degree of<br>bypassing |          |
|---------------|------------------------------------------------------|---------------|-----------------------------------------------------|----------|---------------------------------|----------|
|               | description                                          | $\pi$ -factor | description                                         | P-factor | description                     | I-factor |
| <b>red</b>    | extreme                                              | 0-1           | very low                                            | 1        | very high                       | 0.0-0.2  |
| <b>orange</b> | high                                                 | >1-2          | low                                                 | 2        | high                            | 0.4      |
| <b>yellow</b> | moderate                                             | >2-3          | moderate                                            | 3        | moderate                        | 0.6      |
| <b>green</b>  | low                                                  | >3-4          | high                                                | 4        | low                             | 0.8      |
| <b>blue</b>   | very low                                             | >4-5          | very high                                           | 5        | very low                        | 1.0      |

As the information on the vulnerability map is always for the uppermost aquifer, a thick line indicates graphically the presence of aquifers above the main aquifer under consideration.

Dolines that are too small to be classified using the P and I factors are given special treatment: An extreme vulnerability is assigned both to active ponor dolines and to dry dolines that are not filled by sediments. A high vulnerability is assigned to partially filled dolines. In any case, the existence of

dolines serves as an indicator for extensively developed epikarst and for a low degree of protection provided by the unsaturated karst rock. They should be shown on the vulnerability map with the customary symbols.

## Data collection

The main source of the data is the database National Water Information System, Palestinian Water Authority, 2011

### *Introduction*

Based on the approach defined by COST 620 the vulnerability map for the karstic aquifers underlying West Bank Area is obtained by the assessment of the P-map and the I-map using ArcMap 10 .

## Required data

### *Types of soil*

The soil types West Bank is shown in Figure 4-1

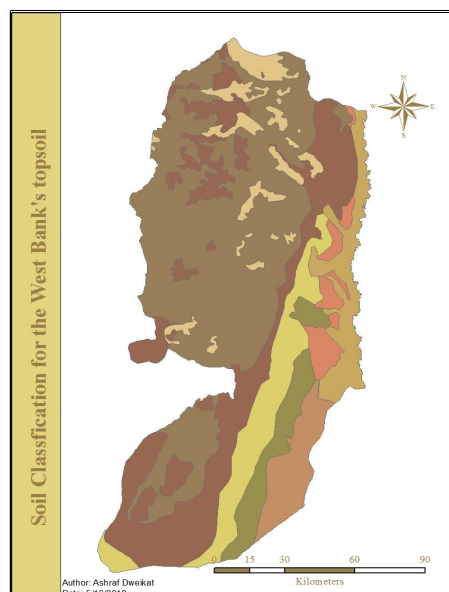


**Figure 4-1** Types of soils in West Bank

#### 4.2.2 Rain fall

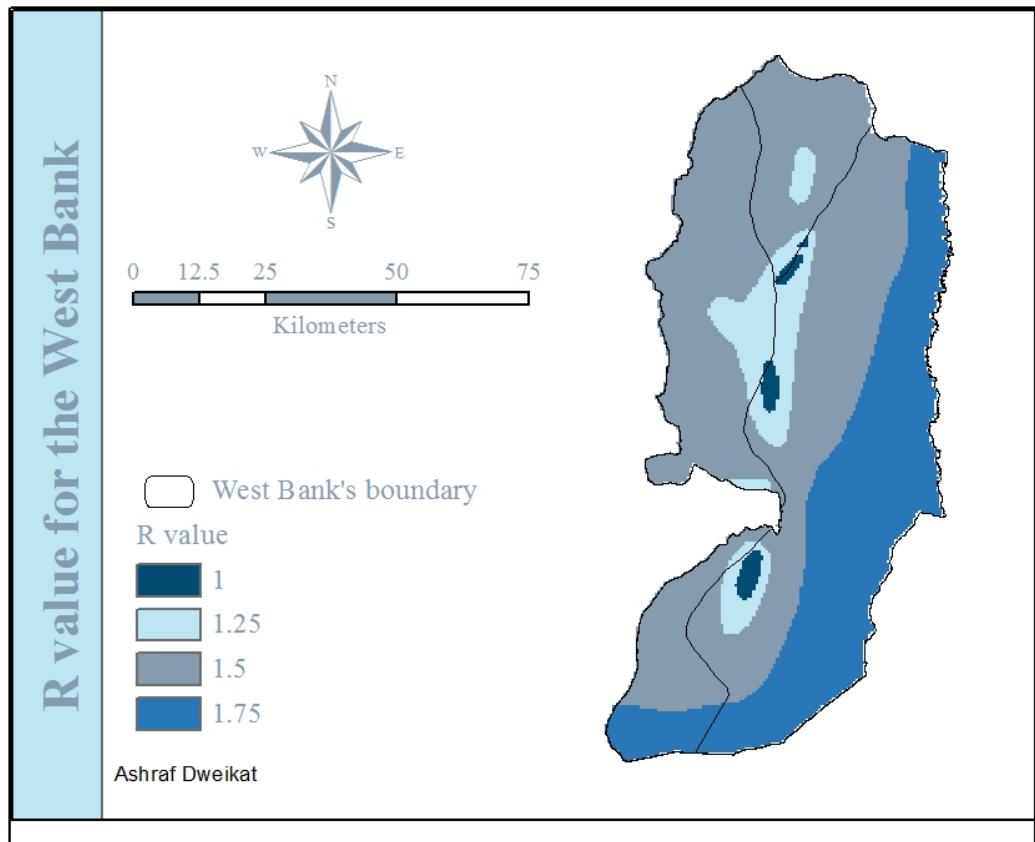


**Figure 4-2** Rainfall distribution in West Bank

## Drainage

The drainage in West Bank is shown in Figure 4-3.

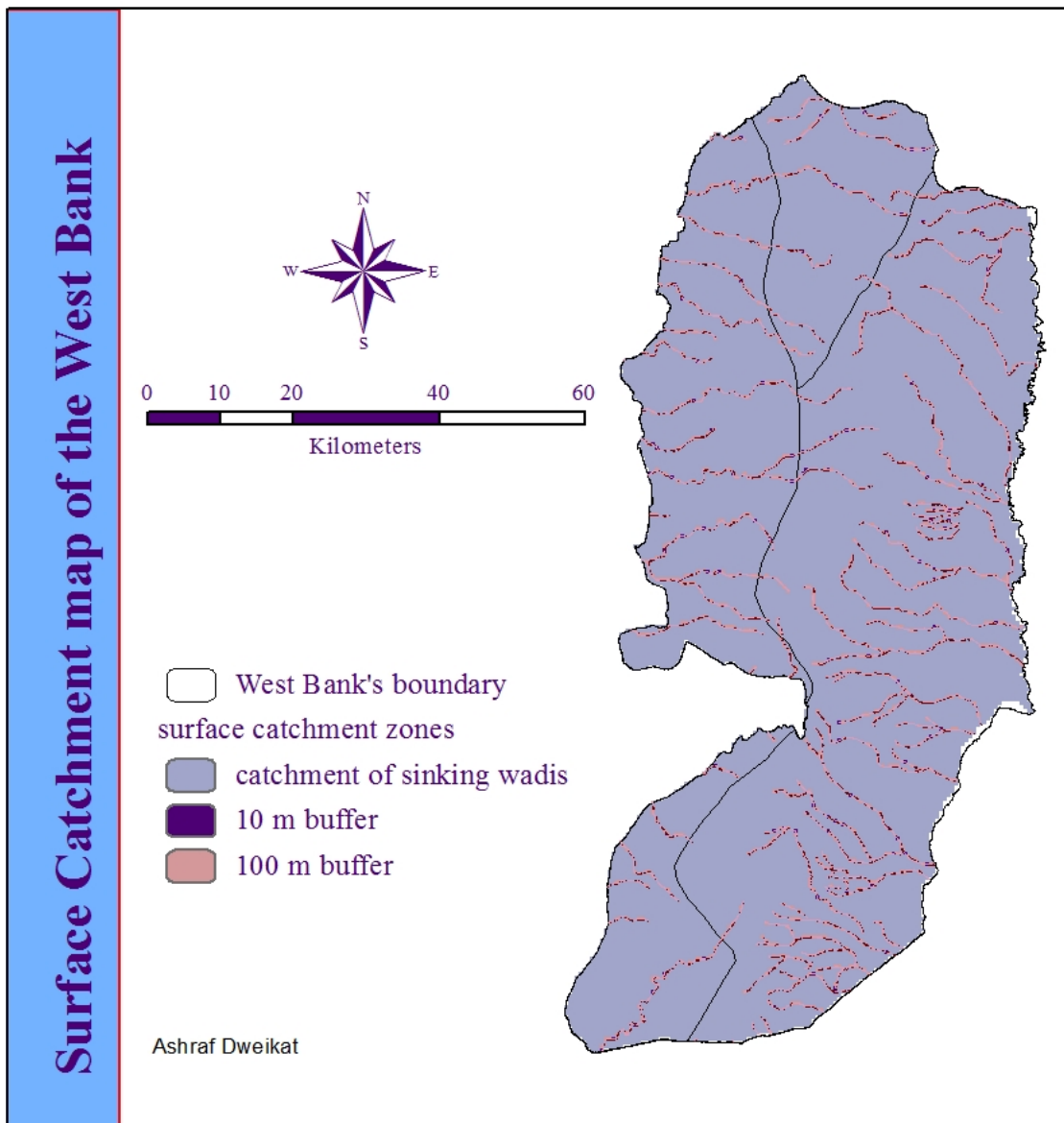


**Figure 4-3** Drainage in west Bank

## Geology

Geological formations in West Bank is shown in Figure 4-4

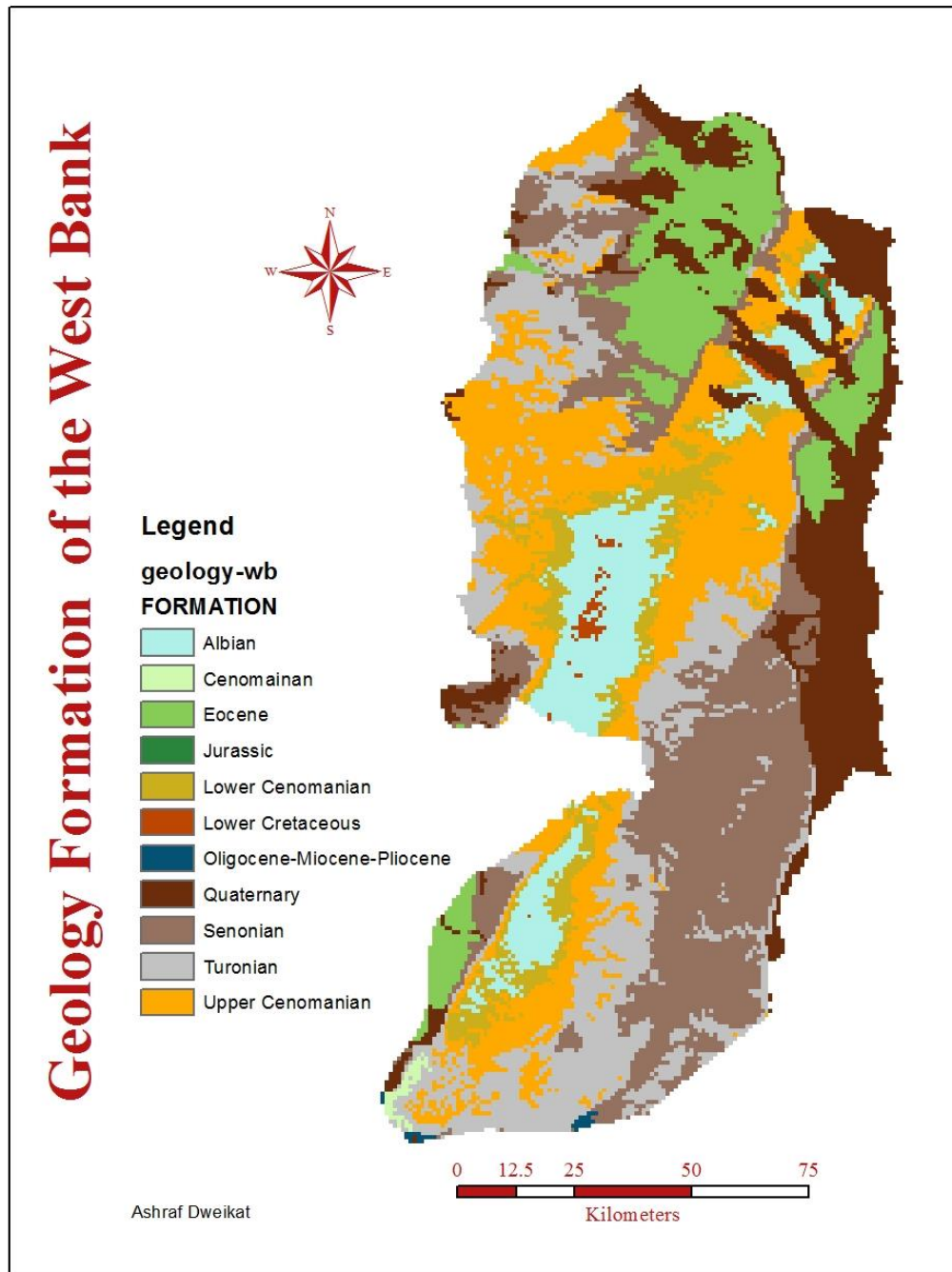


**Figure 4-4** Geology of West Bank

### *Topography*

The topography of west bank is divided to two parts: the eastern slopes and western slopes as shown in Figure 4-5.

# Topographic Map of West Bank

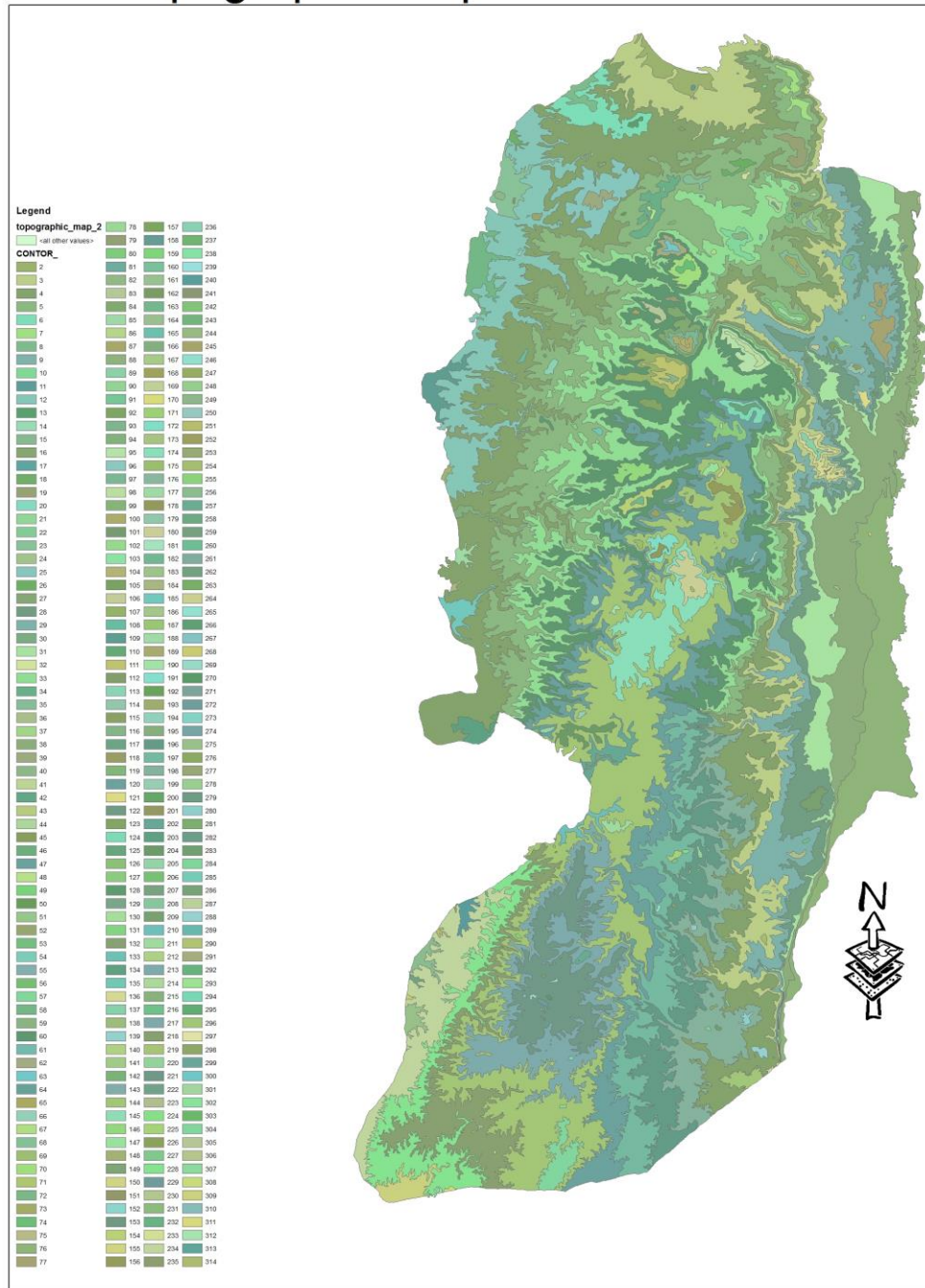


**Figure 4-5** Topography in West Bank

## Springs

Springs in West Bank is distributed as shown in Figure 4-6.

## Springs in West Bank

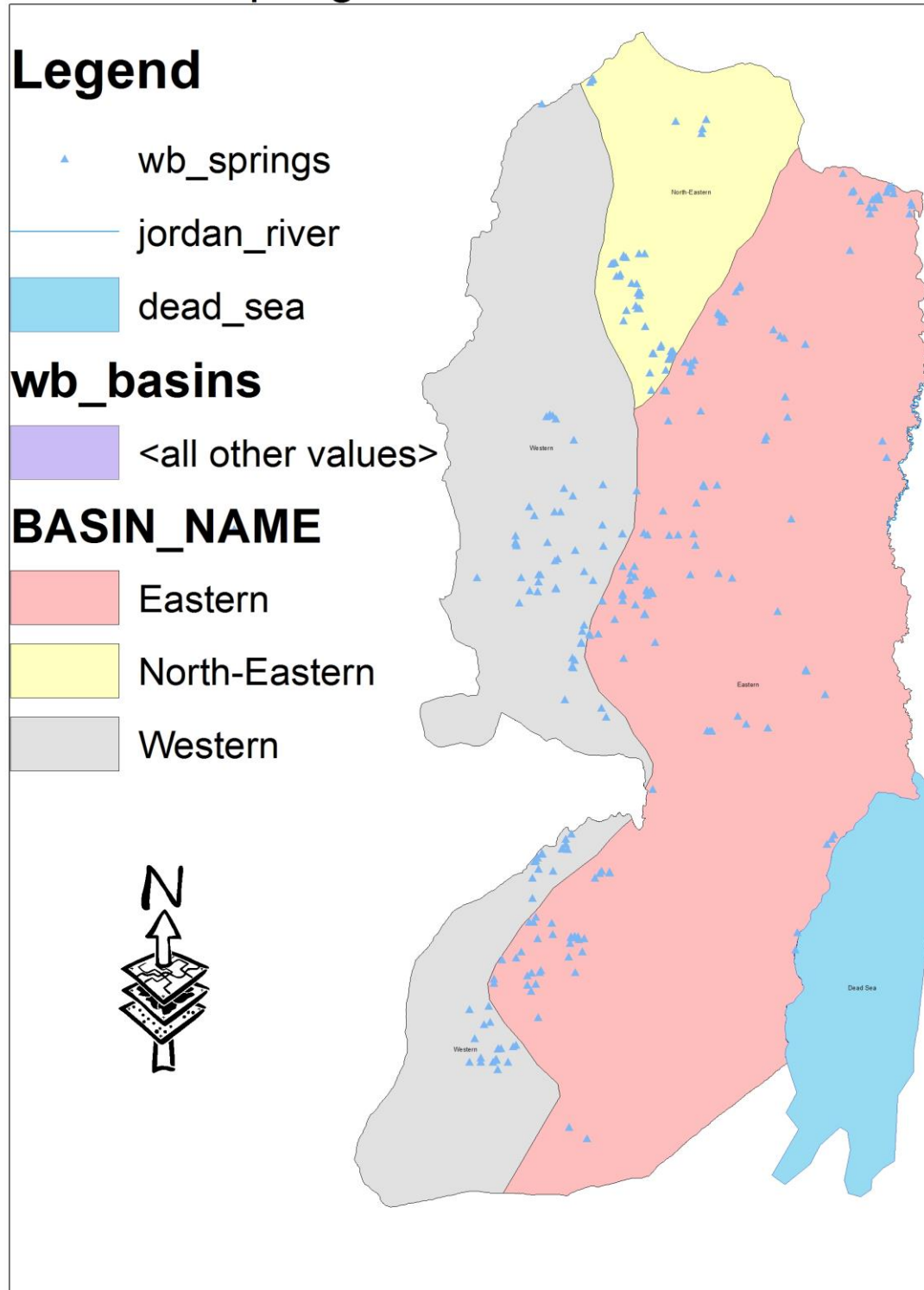


Figure 4-6 Springs in West Bank

Water Wells in West Bank are found as shown in Figure 4-7.

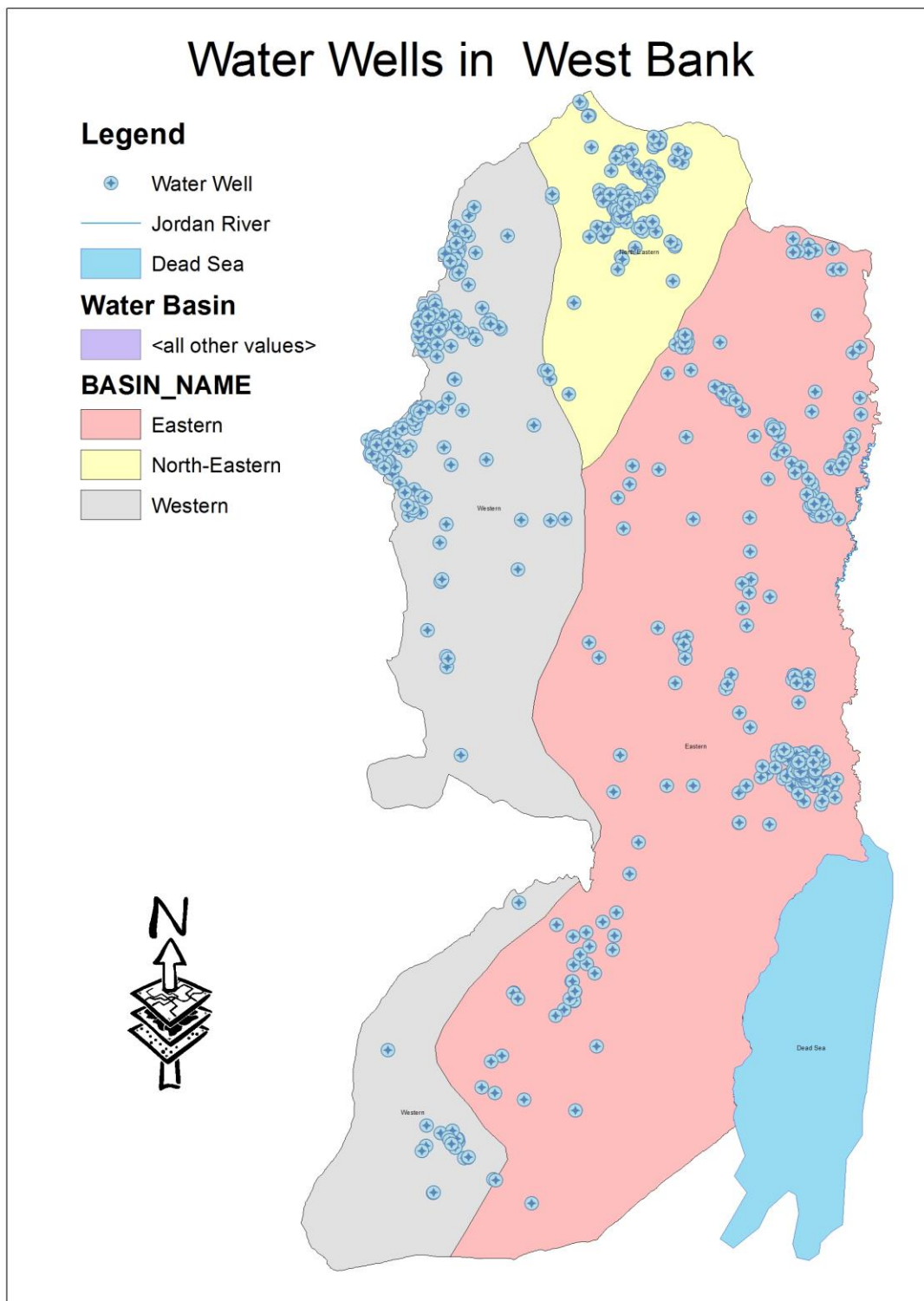


**Figure 4-7** Wells in West Bank

## Wastewater wadis

Sewage that flows in the wadis is considered a minor source for ground water recharge; it exists all over West Bank, as shown in Figure 4-8.

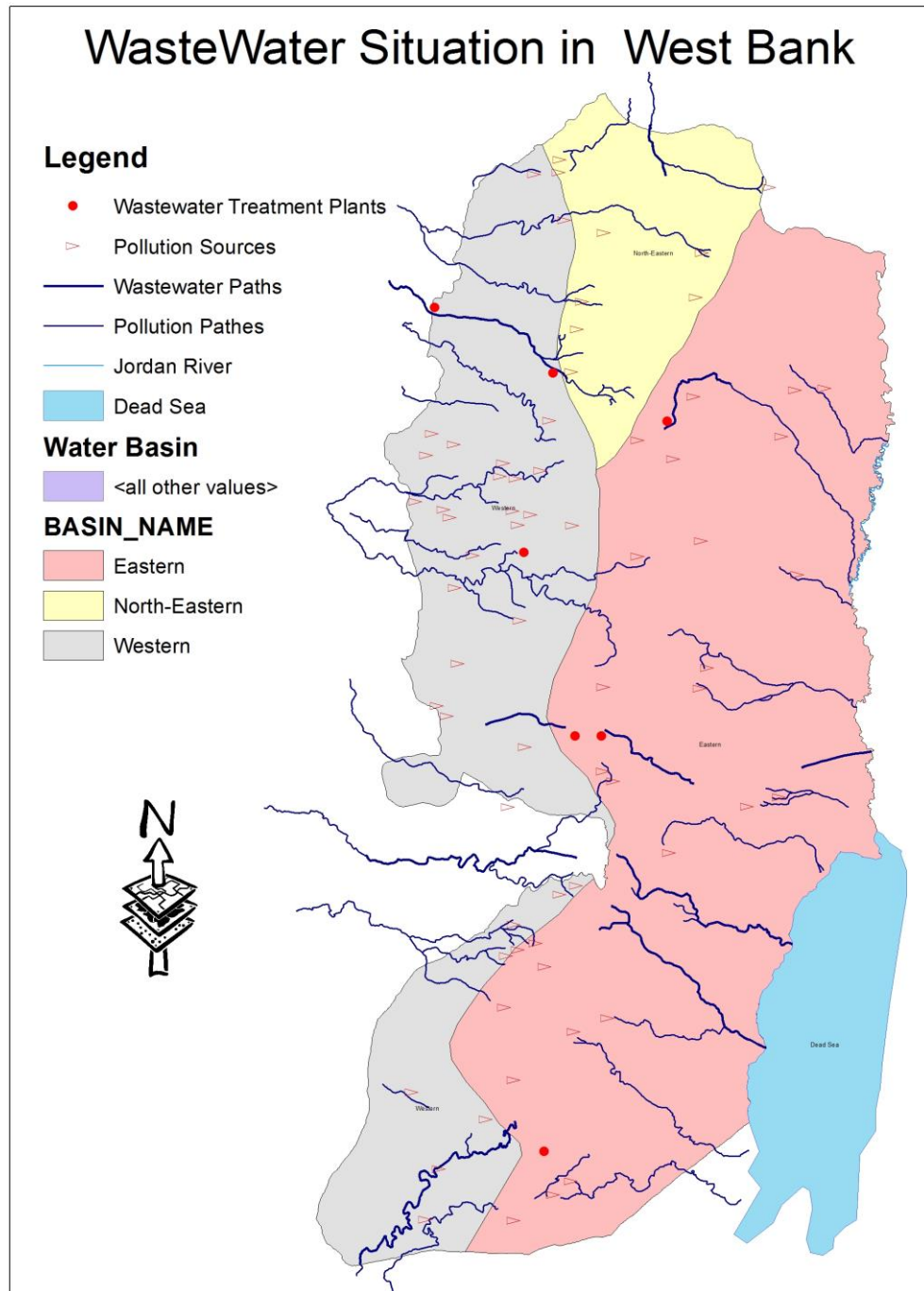


**Figure 4-8** Wastewater situation of West Bank

## Landfill

The Dumpsite over west bank landfill is shown in Figure 4-9.

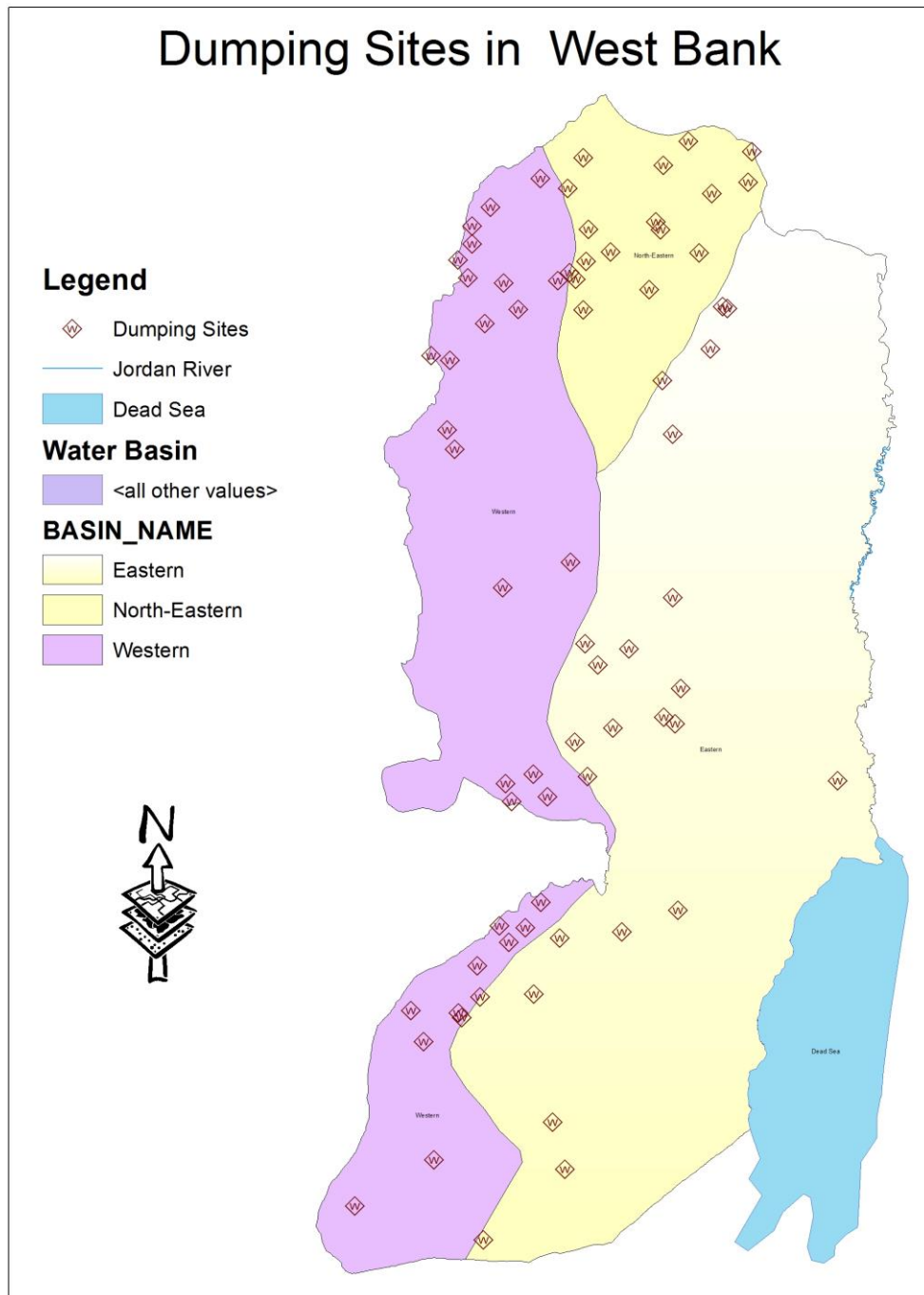
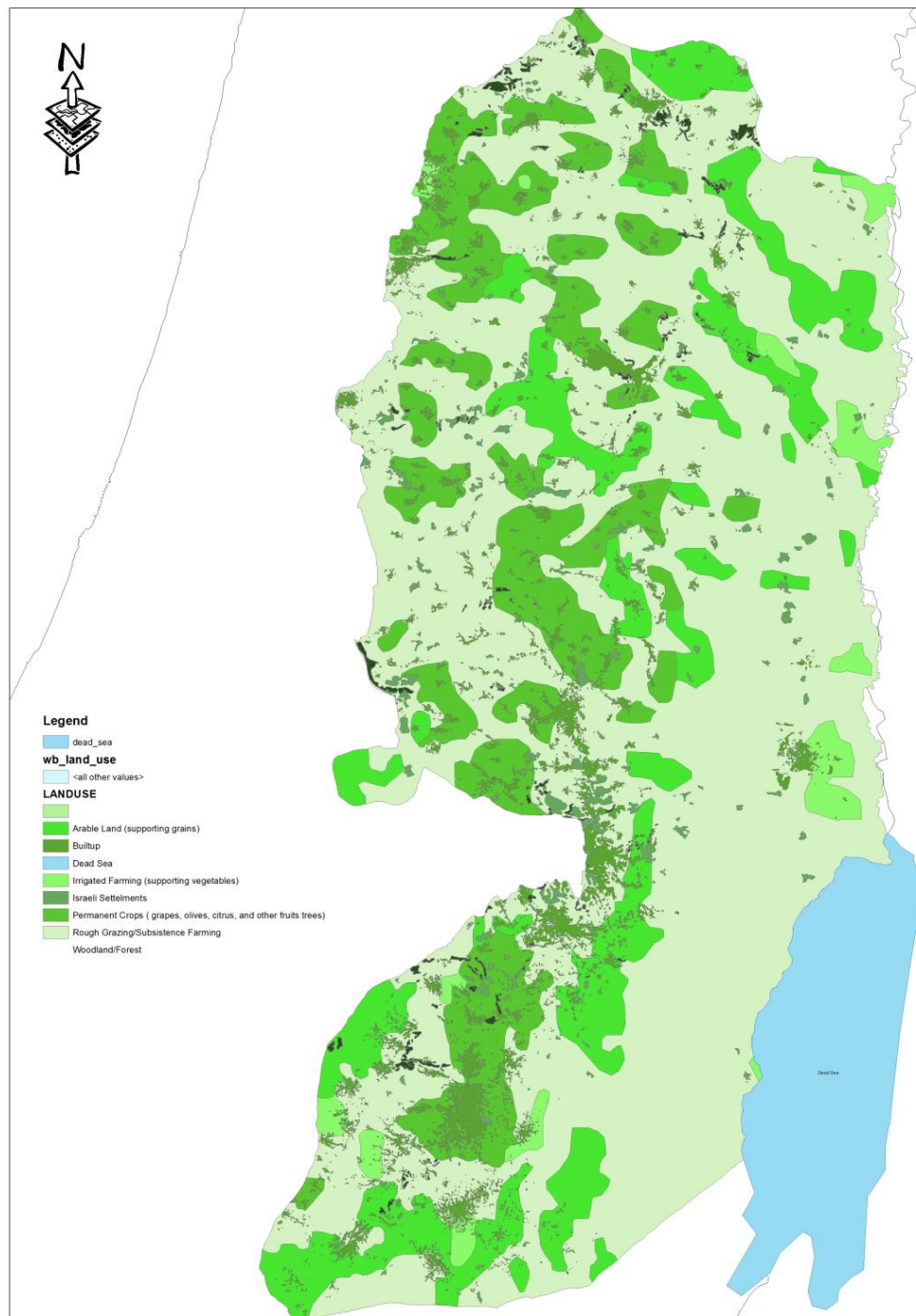


**Figure 4-9** Ramallah Al-Bireh landfills

## Land use

The land use of the district is shown in Figure 4-10.



Land Use Map of West Bank

**Figure 4-10** land use in West Bank

## Data about sources of contamination

### *Dumping site*

Dumping sites in West Bank are distributed as shown in Figure 4-12

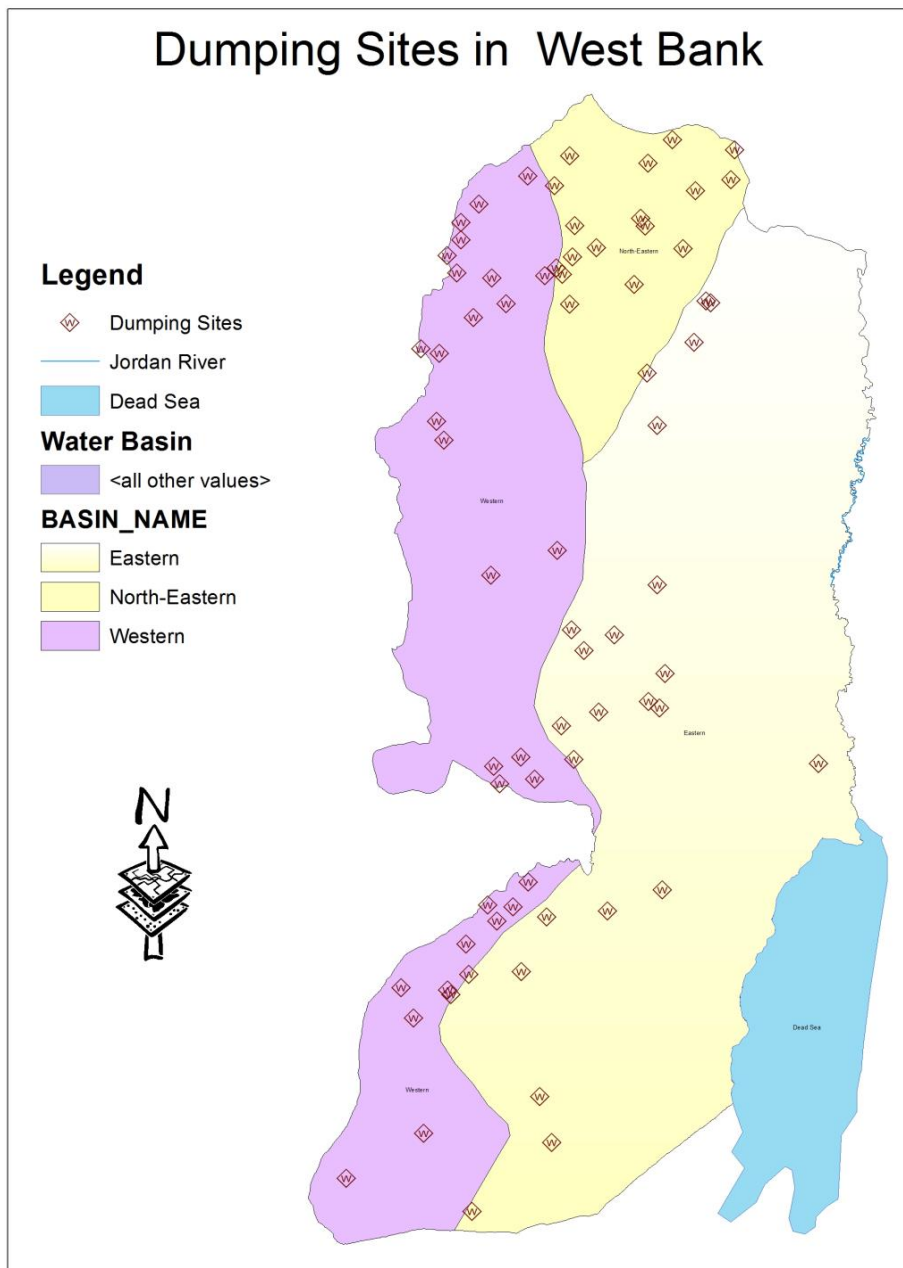


**Figure 4-12** Dumping sites in West Bank

## Construction of Vulnerability map of West Bank

### *Introduction*

In order to produce the Vulnerability map west bank; the following steps were taken:

- The maps and the data listed in chapter 4 using the ArcMap 10 program as a tool were used to produce the vulnerability map.
- As soon as the vulnerability map was produced, the other team used the result with the Hazard map to produce the risk map.

### *P-map*

The P factor as mentioned before describes the protective function of the layers between the ground surface and the groundwater table, soil, subsoil, non karst rock and unsaturated karst rock.

The construction of this map is through a defined procedure of joining several maps that include geological data according to a particular rank, and by using Equation 3-1 to find the protective function that leads to the p-value.

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

Where:

T: Field Capacity for top soil.

S: grain size distribution for subsoil.

R: Recharge into the aquifers.

B: Bedrock

M: Thickness of unsaturated zone.

A: Artesian Pressure.

Each term of Equation 3-1 will be clarified through its relevant data and map in the following sections.

### *Top soil*

West Bank includes several types of soil: Grumusols, Terra Rossa, Brown Rendzinas &Pale rendizinas, Brown Rendzinas &Pale rendizinas, Brown Lithosols &Loessial arid brown soils, Loessial serozems, Brown lithosols &Loessial serozems.

Each one of those types has different capacity to store water within the top soil through a certain period of time; this quality is called effective field capacity (eFC); its value is proportional to the T-value as shown in Table 5-1, and represented graphically in Figure 5.1.

**Table 5-1** Field Capacity for soil found in the Ramallah Al-Bireh District

| Types of soil                                            | eFC[mm]up to 1m depth | Field Capacity<br>(T) |
|----------------------------------------------------------|-----------------------|-----------------------|
| <b>Grumusols</b>                                         | 460                   | <b>750</b>            |
| <b>Terra Rossa, Brown Rendzinas &amp;Pale rendizinas</b> | 446                   | <b>750</b>            |
| <b>Brown Rendzinas &amp;Pale rendizinas</b>              | 334                   | <b>750</b>            |
| <b>Brown Lithosols &amp;Loessial arid brown soils</b>    | 140-200               | <b>250</b>            |
| <b>Loessial serozems</b>                                 | 140-200               | <b>250</b>            |
| <b>Brown lithosols &amp;Loessial serozems</b>            | <b>90-140</b>         | <b>125</b>            |

Source: (PWA, 2010)

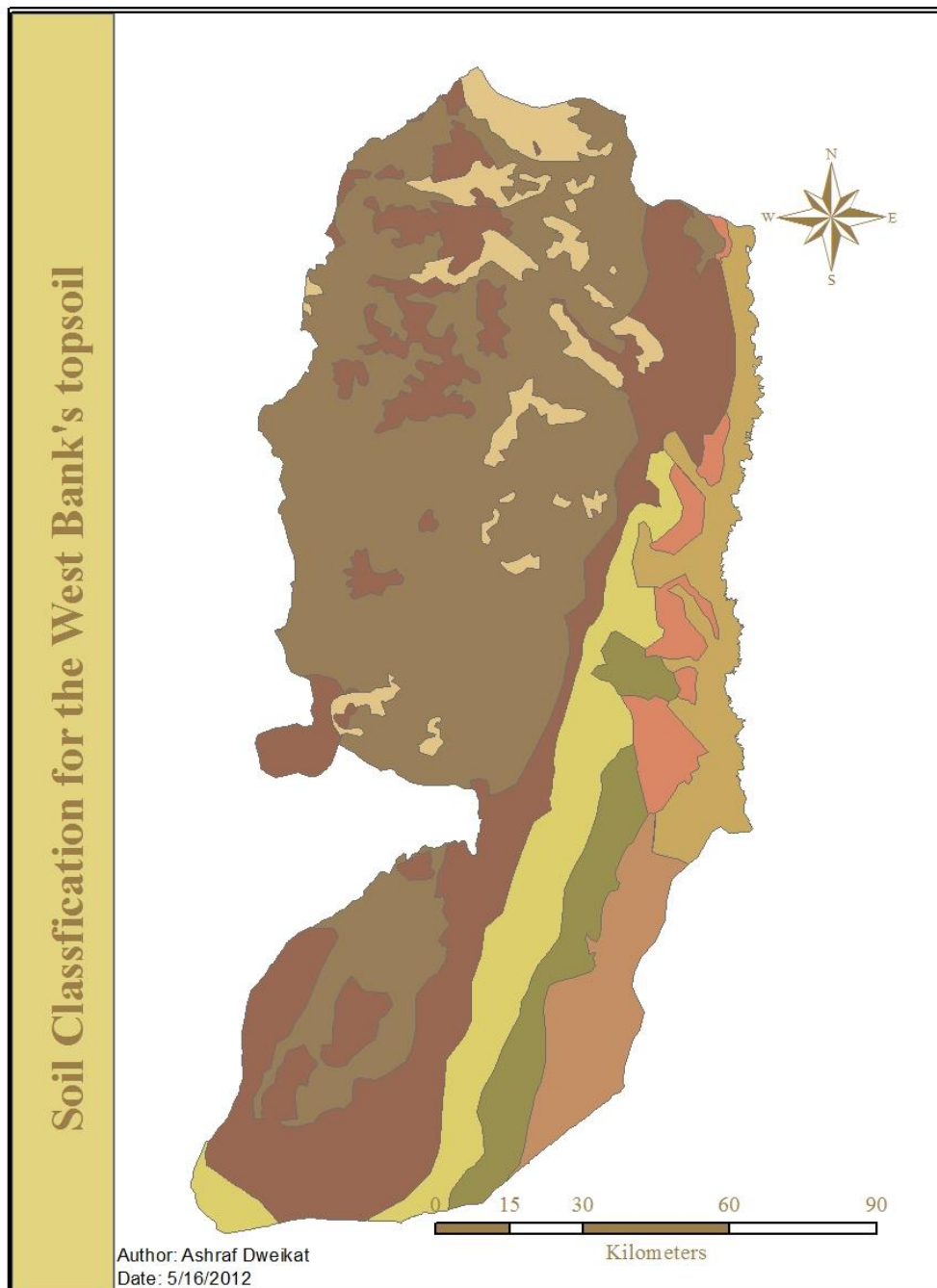


**Figure 5-1** Top soil map

*Sub Soil*

Sub soil is the soil underneath the top soil, after dealing with the top soil, the subsoil is then examined and a figure of the grain size distribution is drawn against the type of the subsoil.

Depending on Table 3-3 the S-value is obtained for each type of soil in the district, and the thickness of the soil is assumed depending on the elevation of the land, for mountainous areas and high elevations in general are assigned a low thickness (starting from 0.5). On the other hand the lowlands are assumed to have higher thicknesses (to the value of 1.5) as shown in Table 5-2, and Figure 5-2 that represent the S-value around the area. Figure 5-3 applies the value of S.M.

**Table 5-2** S.M values for subsoil.

| Types of soil                                           | Type of subsoil "grain size distribution " | S(value)   | Thickness of soil (M) | S.M         |
|---------------------------------------------------------|--------------------------------------------|------------|-----------------------|-------------|
| <b>Grumusols</b>                                        | Clay                                       | 500        | 1.0                   | <b>500</b>  |
| <b>Terra Rossa, Brown Rendzinas &amp;Pale rendzinas</b> | Clayey loam                                | 400        | 0.5                   | <b>200</b>  |
| <b>Brown Rendzinas &amp;Pale rendzinas</b>              | Clay                                       | 500        | 1.5                   | <b>750</b>  |
| <b>Brown Lithosols &amp;Loessial arid brown soils</b>   | Slitly clayey sand                         | 75         | 0.5                   | <b>37.5</b> |
| <b>Loessial serozems</b>                                | Loamy                                      | 400        | 1.5                   | <b>600</b>  |
| <b>Brown lithosols &amp;Loessial serozems</b>           | <b>Sility clay</b>                         | <b>320</b> | <b>1.0</b>            | <b>320</b>  |

Source: PWA, (2007).

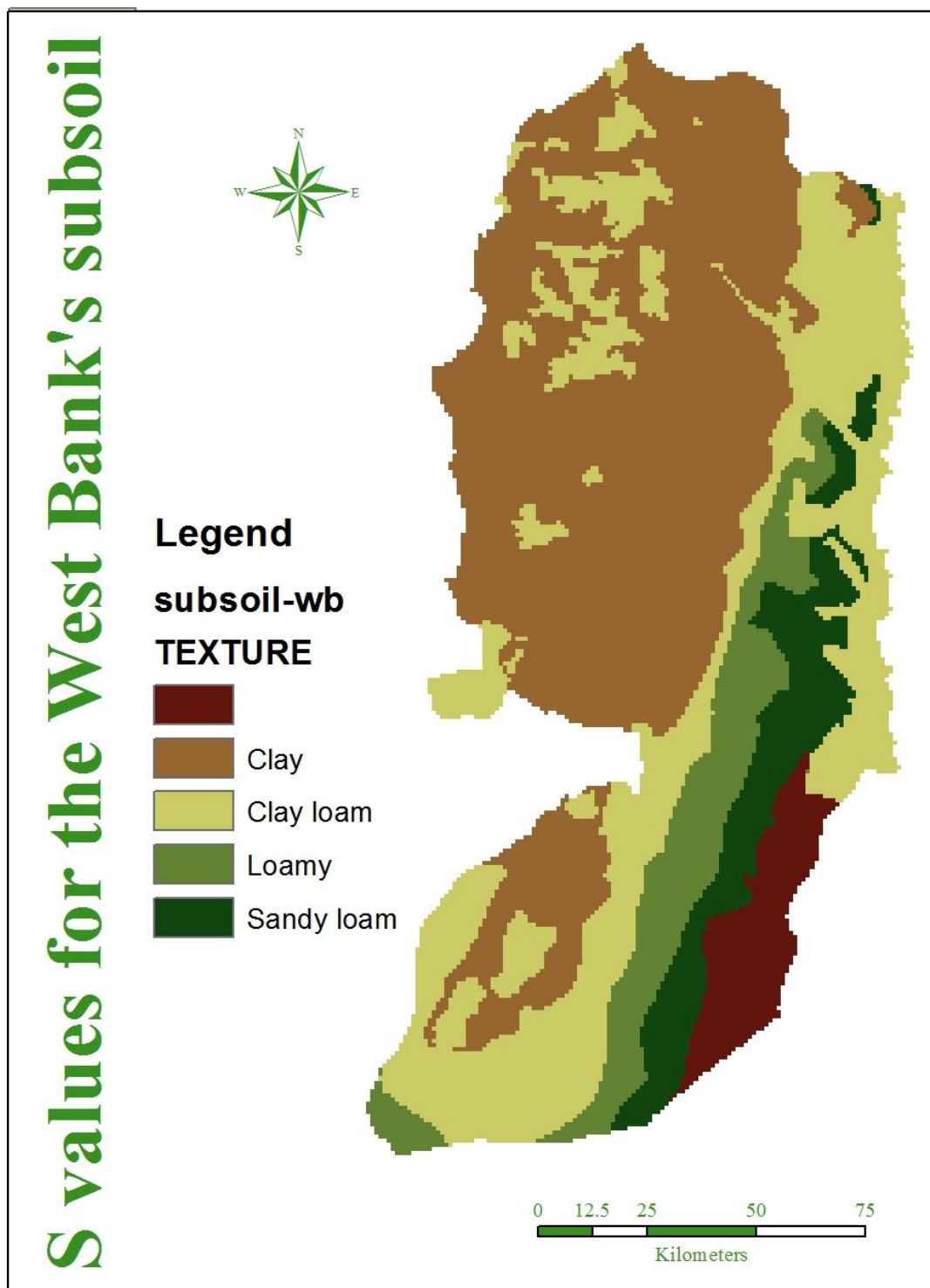


**Figure 5-2 S-value map**

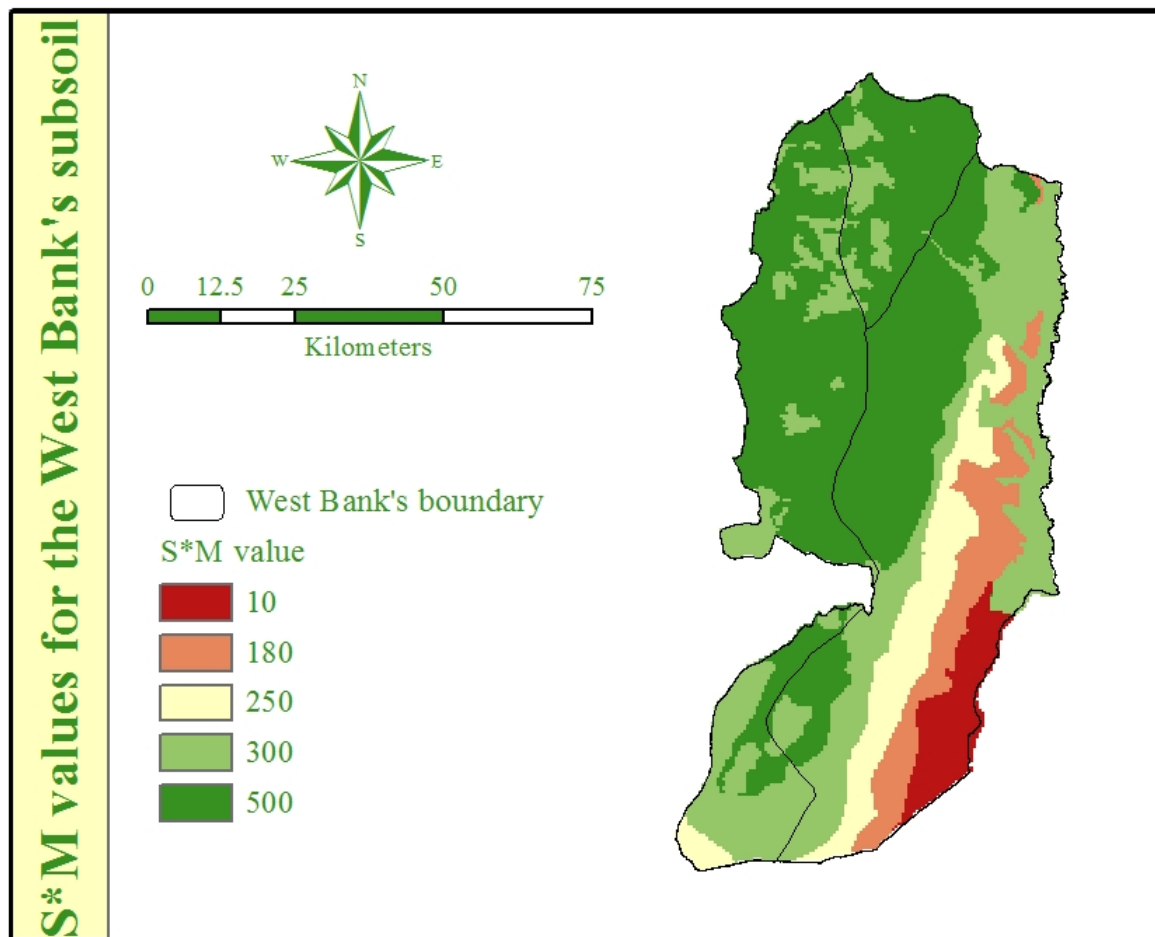


**Figure 5-3** S.M map

### *Lithology and fracture B-factor for West Bank*

Lithology is a geological description of the mineral composition, texture, sediment packing, grain size distribution, and color of the soil layer, value of (F) corresponding to each type of soil is taken from Table 3-4.

Fracture on the other hand is the separation of particles of rocks under the act of stress upon them it can take the shape of a joint or a fault that divides the rock into two or more pieces, its also taken from Table 3-4, the product of those two figures give the value of the bed rock factor (B) and that is shown in Table 5-3, both of (L) and (F) values refer to the unsaturated geological formations.

**Table 5-3** Lithology and Fracturing for geological formation

| Formation        | Lithology                                                     | L  | F    | B=L*F |
|------------------|---------------------------------------------------------------|----|------|-------|
| Quaternary       | Nari (surface crust) and alluvium<br>gravels and fan deposits | 5  | 4.0  | 20    |
| Eocene           | Reefal limestone                                              | 5  | 0.5  | 1.5   |
| Senonian         | Marl, chalk , chert                                           | 20 | 25.0 | 500   |
| Turonian         | White limestone                                               | 5  | 0.5  | 1.5   |
| Upper cenomainan | Karstic Dlomite                                               | 5  | 0.3  | 1.5   |
| Upper cenomainan | Limestone and dolostone                                       | 5  | 0.3  | 1.5   |
| Albian           | Reefal limestone                                              | 5  | 0.3  | 1.5   |

Source: PWA, (2007).

Figure 5-4 shows the bedrock values for different geologic formations.

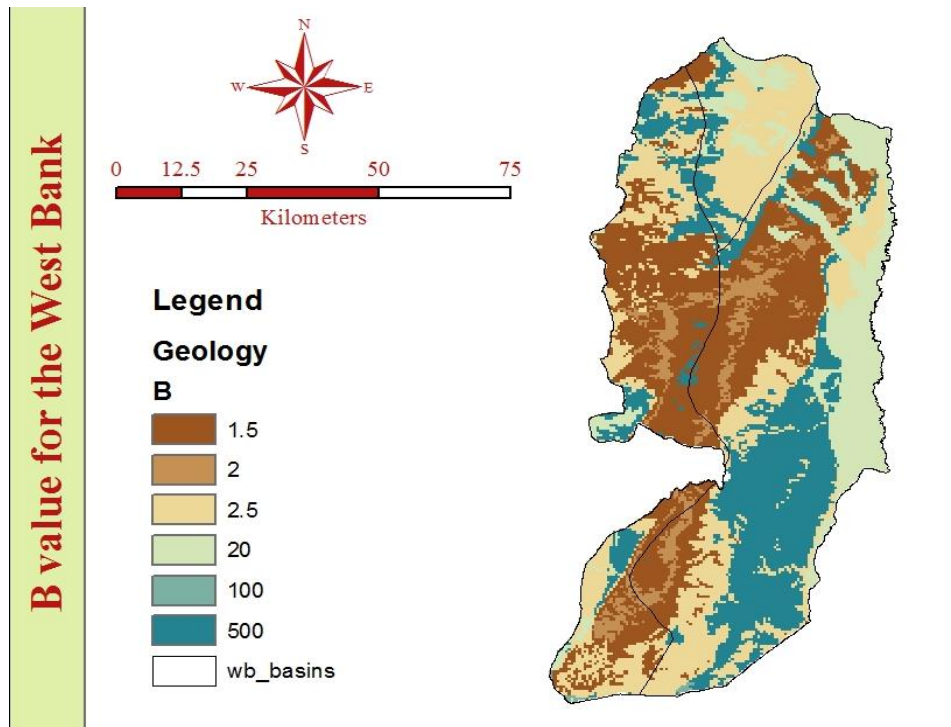


**Figure 5-4 B-factor Map of west Bank**

Through a union between water level and ground level (geology) the uncovered layer is observed and using the cross section of Ramallah Al-Bireh district the map of BM is constructed.

In order to examine the danger degree of pollution on groundwater aquifers, the Stratigraphical section (Figure 2-2) of the district is used to observe the amount of protection upon and underneath the uncovered layer.

When a formation is overlain by an aquitard; then  $\Sigma BM = BM$  (not  $\Sigma bm$ ) where M is the thickness of the formation, the situation is of great danger since the uncovered formation is directly water level, based on the stratigraphical section of the district there are tree formations that apply to this situation (Turonian, Upper cenomaianan, Albian). For the other formations  $\Sigma BM = \Sigma bm$  since the uncovered layer is an aquitard so all the layers are taken until the water surface is reached.

For the Arc-GIS the analysis used to enter the data is by Table 5-4 using the upper matrix analysis in order to enter all the values properly and solve the equation  $BM = \Sigma b_i m_i$ .

Where:

$m_i$  is the thickness of the layer

$b_i$  the bedrock value for this layer.

**Table 5-4** Values of the bedrock factor, and thickness for the various formations

|            | Bedrock |    |    |    |    |    |    | Formation Thickness |     |     |     |     |     |     |
|------------|---------|----|----|----|----|----|----|---------------------|-----|-----|-----|-----|-----|-----|
|            | b1      | b2 | B3 | B4 | b5 | b6 | b7 | m1                  | m2  | m3  | m4  | m5  | m6  | m7  |
| Quaternary |         |    |    |    |    |    |    | 155                 | 380 | 278 | 115 | 330 | 330 | 497 |
| Eocene     |         |    |    |    |    |    |    | 0                   | 380 | 278 | 115 | 330 | 330 | 497 |

|                                    |    |     |     |     |     |     |     |   |   |     |     |     |     |     |
|------------------------------------|----|-----|-----|-----|-----|-----|-----|---|---|-----|-----|-----|-----|-----|
| Senonian                           |    |     |     |     |     |     |     | 0 | 0 | 278 | 115 | 330 | 330 | 497 |
| Turonian                           |    |     |     |     |     |     |     | 0 | 0 | 0   | 115 | 330 | 330 | 497 |
| Upper<br>cenomai <span>na</span> n | 20 | 1.5 | 500 | 1.5 | 1.5 | 1.5 | 1.5 | 0 | 0 | 0   | 0   | 330 | 330 | 497 |
| Lower<br>cenomai <span>na</span> n |    |     |     |     |     |     |     | 0 | 0 | 0   | 0   | 0   | 330 | 497 |
| Albian                             |    |     |     |     |     |     |     | 0 | 0 | 0   | 0   | 0   | 0   | 497 |

Using special analysis on the Arc-GIS the map; the data of Table 5-4 is entered and Figure 5-5 is produced to form the value of BM for Ramallah Al-Bireh district.

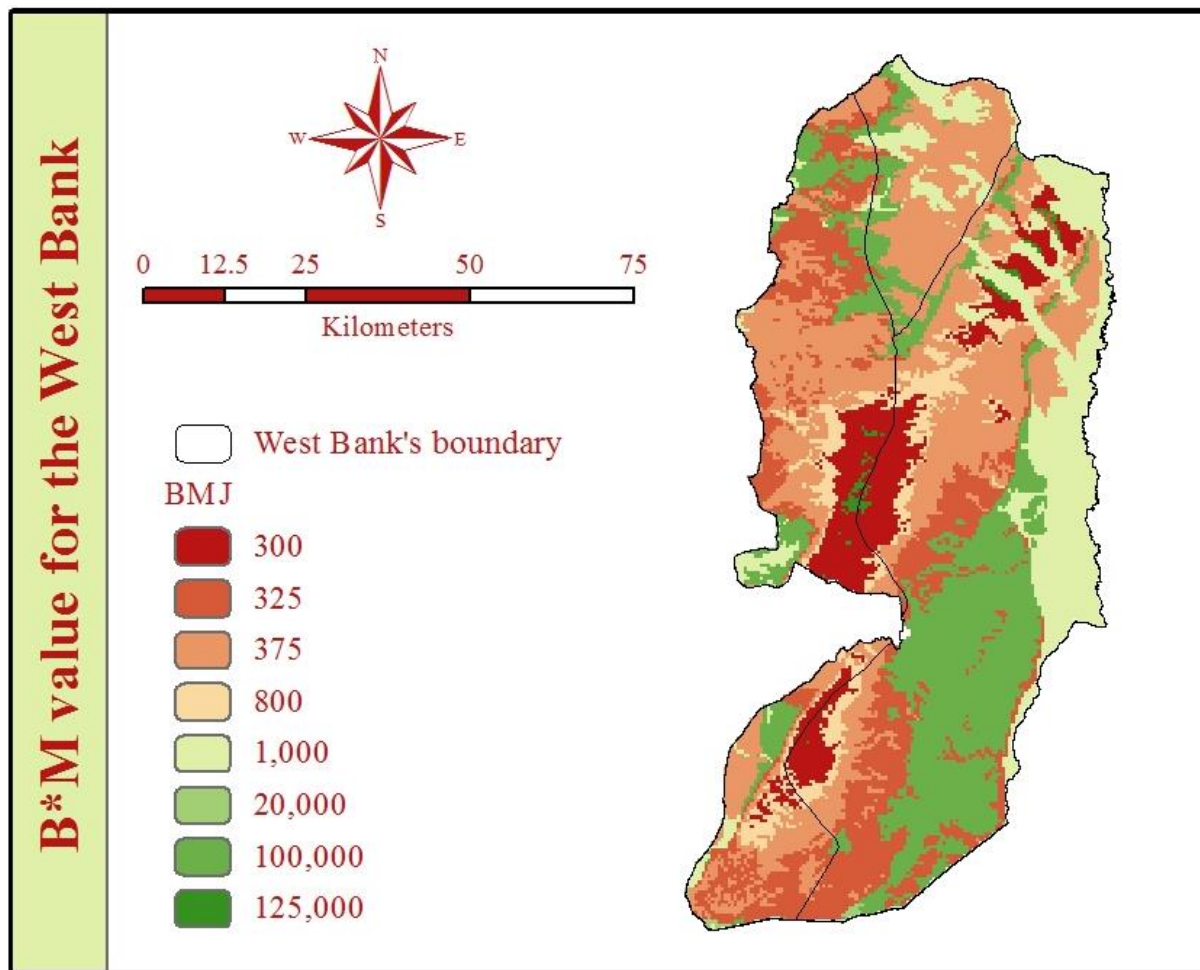


**Figure 5-5** BM value for West Bank

### *Recharge*

Recharge can be direct or indirect, only the direct recharge from the rainfall is considered here because it's the dominant element, the indirect though is neglected. Based on rainfall-recharge equations adopted and used in SUSMAQ project in the west bank, the recharge values were obtained. The following mathematical equations link the annual rainfall (P) with the recharge from the rainfall (R) in mm/yr:

$$R = 0.6(P - 285); \quad P > 700 \text{ mm}$$

$$R = 0.46(P - 159); \quad 700 > P > 456 \text{ mm}$$

$$R = 0.3(P); \quad 456 \text{ mm} > P$$

Table 5-5 shows values of mean annual rainfall (mm) with the corresponding recharge (mm/year) and R-value based on the up mentioned equations.

**Table 5-5** Groundwater recharge estimation for different mean annual rainfall and corresponding recharge values (R)

| Mean annual rainfall<br>(mm) | Recharge (mm/yr) | R-value |
|------------------------------|------------------|---------|
| 200-250                      | 60-75            | 1.75    |
| 250-300                      | 75-90            | 1.75    |
| 300-350                      | 90-100           | 1.75    |
| 350-400                      | 105-120          | 1.5     |
| 400-450                      | 120-135          | 1.5     |
| 450-500                      | 135-157          | 1.5     |
| 500-550                      | 157-180          | 1.5     |

|          |         |      |
|----------|---------|------|
| 550-600  | 180-200 | 1.5  |
| 600-700  | 200-250 | 1.25 |
| 700-1000 | 250-430 | 1.00 |

Source: PWA, (2007).

Or using the ArcMap 10 the R-factor is found as follows:

- I. Creating a union between two maps (geology and rainfall maps), in order to investigate which geological formations in the District are subjected to pollutants then calculating the rainfall recharge.

See Figure 5-6 for Geology and Figure 5-7 for Mean Annual Rainfall in West Bank

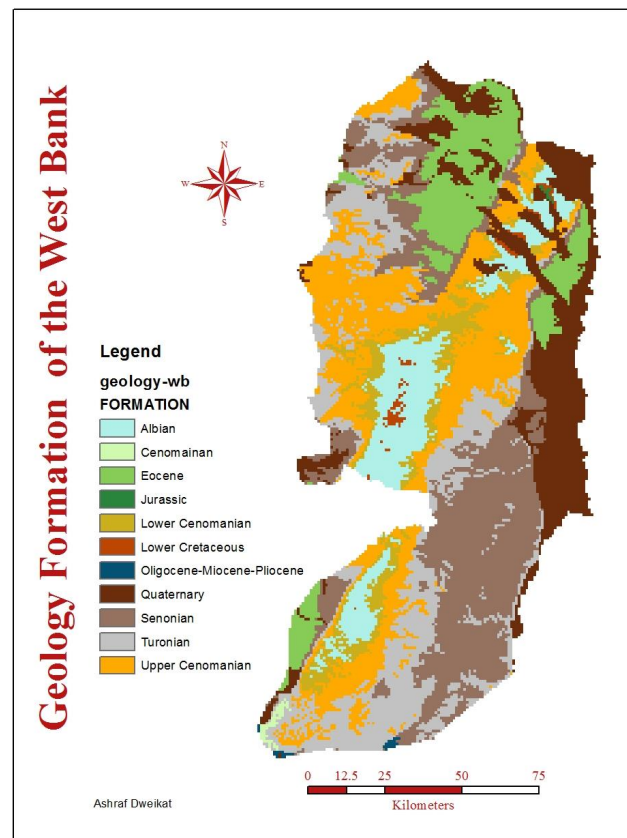


**Figure 5-6** Geology map for West Bank

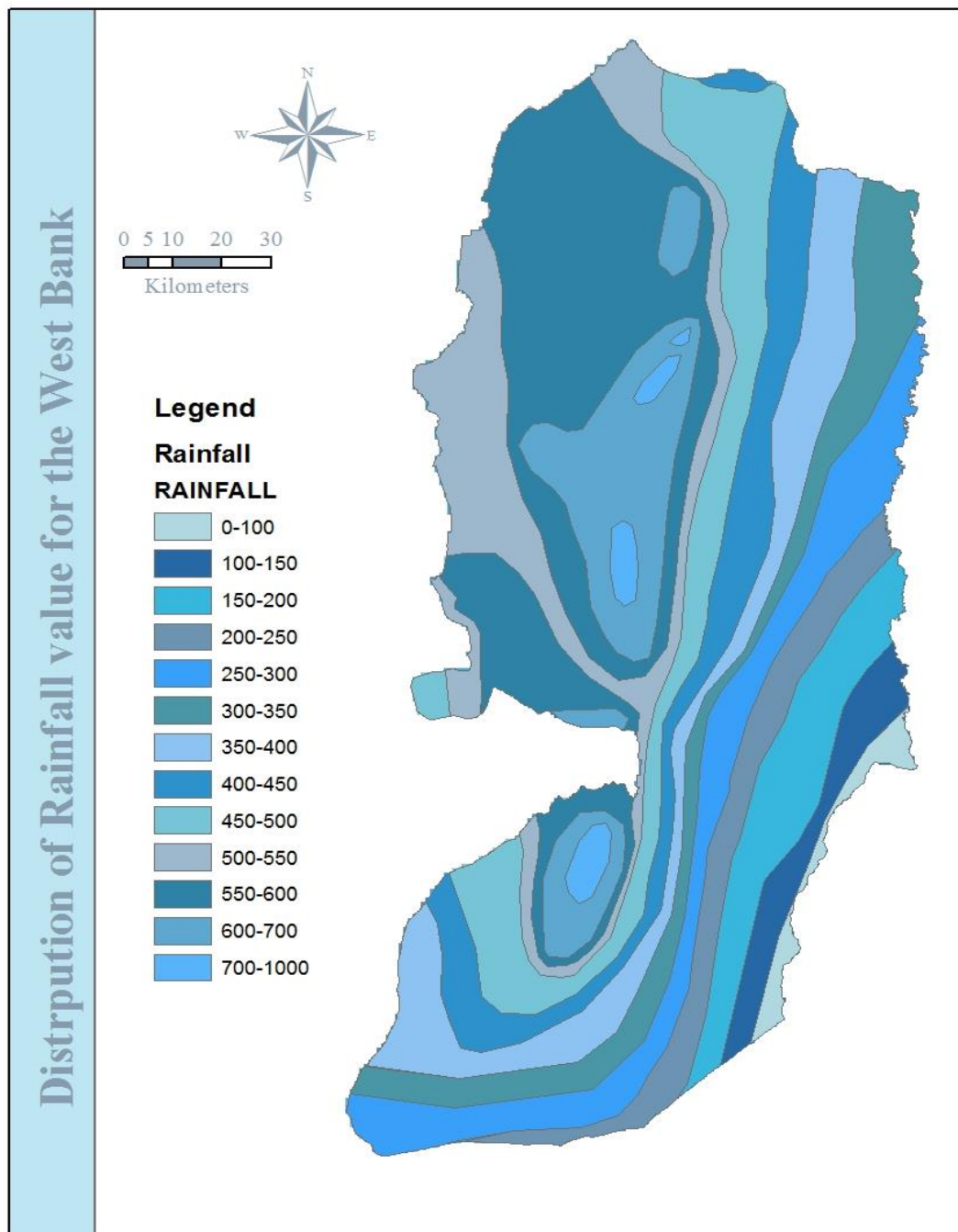


**Figure 5-7 Mean Annual Rainfall map of West Bank**

II. Determining the R-factor based on cost Action 620 as shown in Table 5-4 and Figure 5-8 shows the R-factor for geological formations.

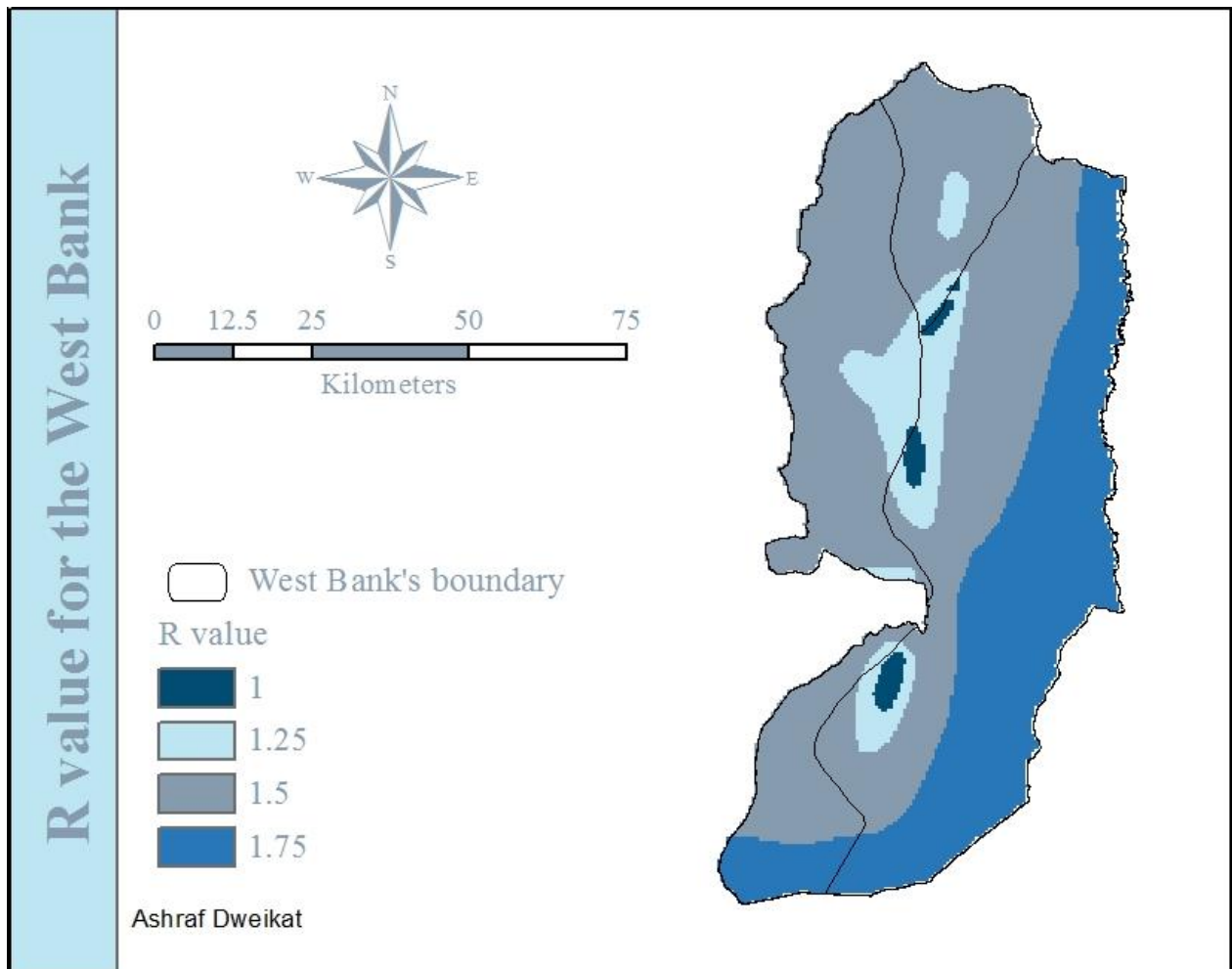


**Figure 5-8** R-value for Ramallah Al-Bireh District

### *Artesian pressure*

Artesian pressure is a measure of the pressure that the soil particles are subjected to, depending on the aquifer they lay on; there are two types of aquifers: confined and unconfined; the confined aquifer is one that lays under high pressure due to its position of laying between two aquitards or impermeable layers which puts it under higher pressures, unconfined on the other hand is the aquifer that is subjected to atmospheric pressure since its considered open.

Each type of aquifers is given a certain value for artesian pressure, the confined is given the value of 1500, the unconfined is assumed to have an A-value of zero, Table 5-6 shows those values. Figure 5-9 shows the distribution of A-values over the area.

**Table 5-6** Types of Formation in Ramallah Al-Bireh District

| <b>Formation</b>        | <b>Type</b>       | <b>A-value</b> |
|-------------------------|-------------------|----------------|
| <b>Lower cenomainan</b> | Confined          | <b>1500</b>    |
| <b>Upper cenomainan</b> | Unconfined        | <b>0</b>       |
| <b>Turonian</b>         | Unconfined        | <b>0</b>       |
| <b>Senonian</b>         | Unconfined        | <b>0</b>       |
| <b>Albian</b>           | Confined          | <b>1500</b>    |
| <b>Quaternary</b>       | Unconfined        | <b>0</b>       |
| <b>Lower cretaceous</b> | Confined          | <b>1500</b>    |
| <b>Eocene</b>           | <b>Unconfined</b> | <b>0</b>       |

Source: PWA, (2009)

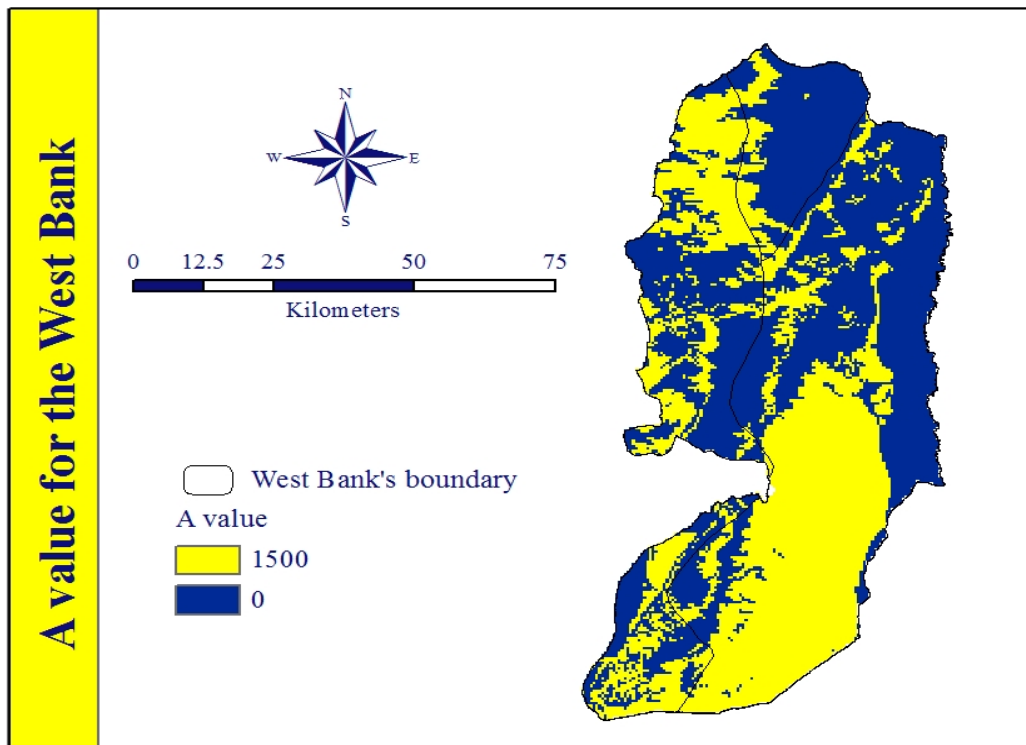


**Figure 5-9** Artesian pressures for the District

*Total protective cover ( $P_{Ts}$ ):*

Implementing the Equation 3-1 and submitting the previous elements in the equation the map of total protective function ( $P_{Ts}$ ) is produced and shown in Figure 5.10

## P-Map of the West Bank *PI Method*

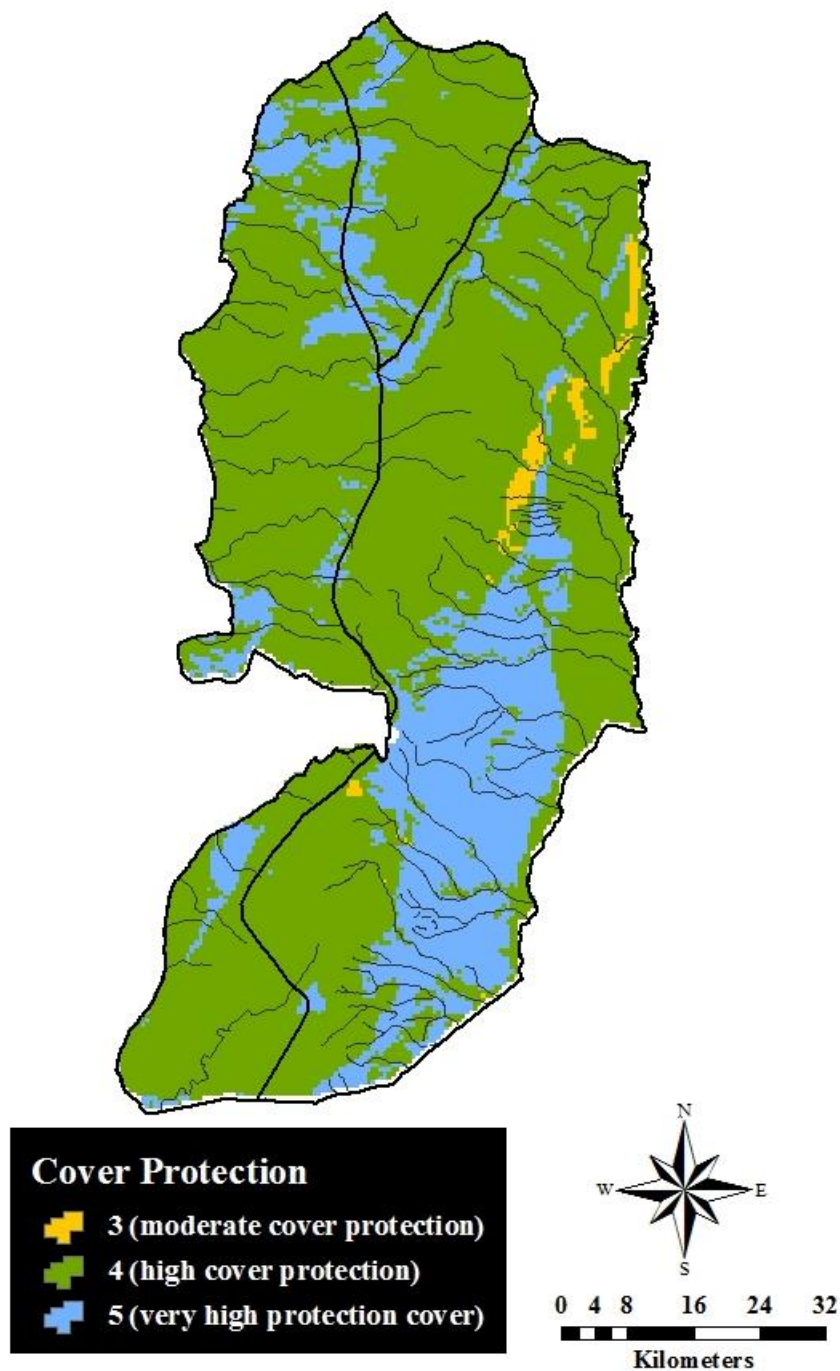


**Figure 5-10** Total protective function (Pts)

Following the procedure mentioned, the P-map using Table 3-5 is constructed and shown in Figure 5-11.

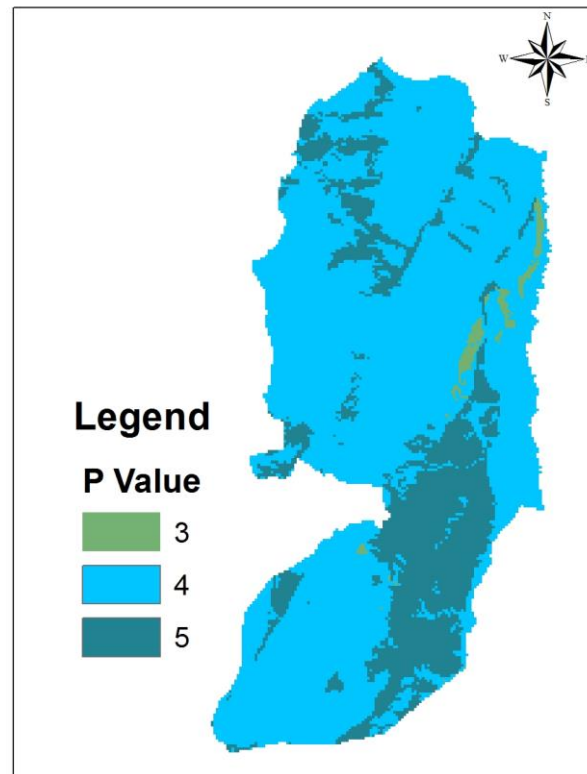
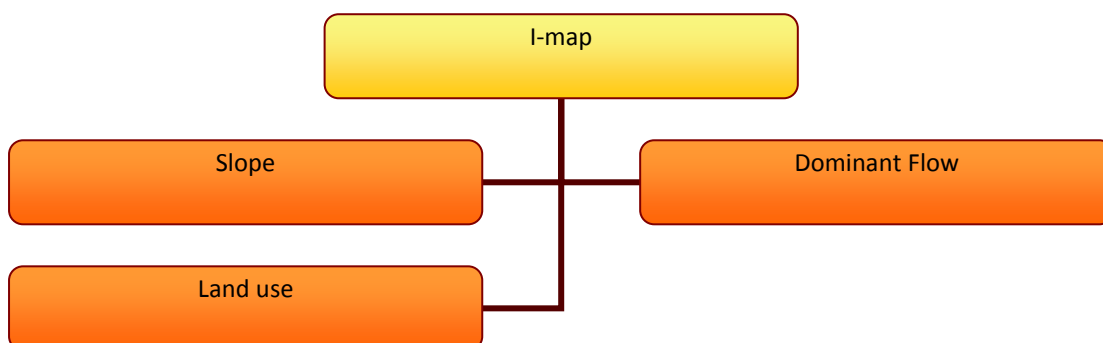


**Figure 5-11** Protective Cover Factor

## I-map

I-map is the second part of the Vulnerability map, this map is constructed by the union of three different maps: slope, land use, and dominant flow. The method used is explained below:



## Slopes

Slope of an area is a measure of its inclination; it directly affects the amount of water percolating inside the ground surface.

The method used to obtain the map of Figure 5-12 (slope map) is as follows:

1. First the contour map is subjected to 3-D analysis on ArcMap 10 program in order to convert the lines and points into triangular areas.
2. Clip both contour map and topography map to remove all the excessive points at the borders.
3. Slope map is produced; it includes all slopes all over the area; but in fact those slopes are divided into three zones (those zones are  $\leq 3.5\%$ ,  $3.5-27\%$ ,  $\geq 27\%$ ) according to European approach COST 620- PI method.

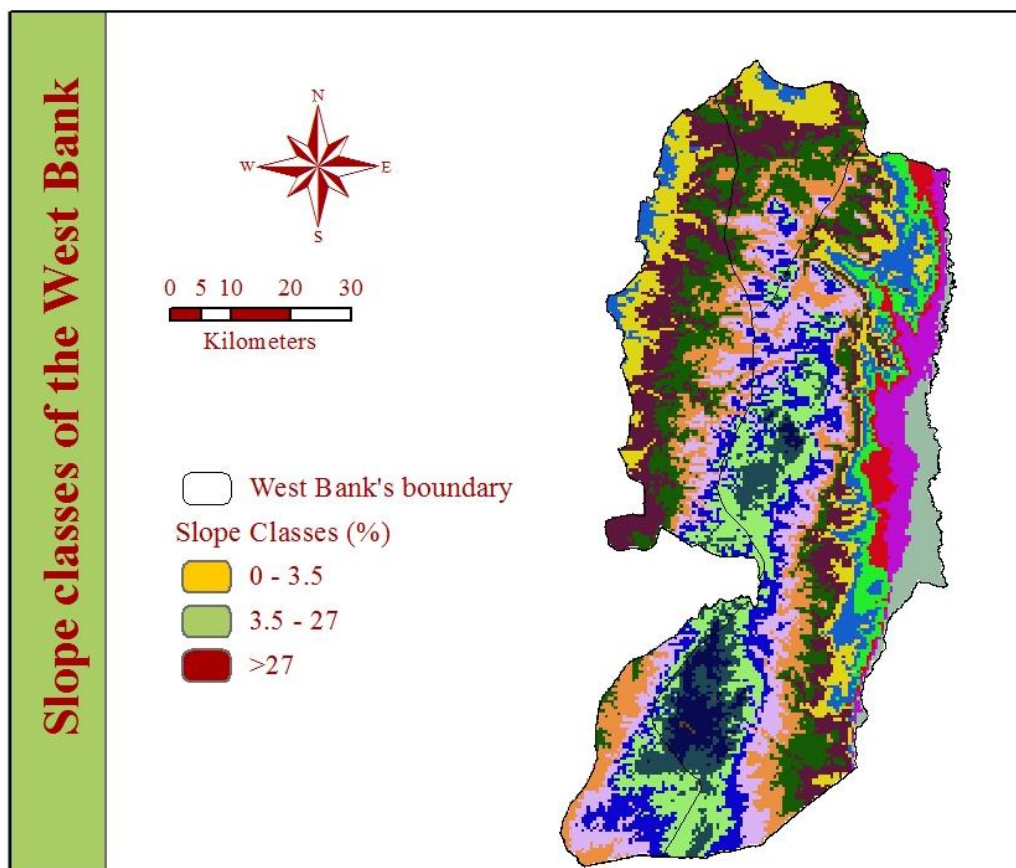


**Figure 5-12** Slopes map

### Dominant Flow

As mentioned before, there are three different types of dominant flow:

- Hortonian surface flow.
- Infiltration and subsequent percolation.
- Saturated surface flow.

Each type of topsoil is assigned a certain type of the dominant flow, based on its hydraulic conductivity and thickness using Table 5-7.

**Table 5-7** Determination of the Predominant Flow Process

| Hydraulic Conductivity (m/s) | 1.E-04 | Saturated surface flow                                                      | Very fast subsurface storm-flow | infiltration and subsequent percolation |
|------------------------------|--------|-----------------------------------------------------------------------------|---------------------------------|-----------------------------------------|
| 1.E-05                       |        |                                                                             | Fast subsurface storm-flow      |                                         |
| 1.E-06                       |        | Hortonian surface flow rarely (only during storm rainfall)                  |                                 |                                         |
|                              |        | Hortonian surface flow frequently (also during low intensity precipitation) |                                 |                                         |
|                              |        | < 30 cm                                                                     | 30-100 cm                       | >100 cm                                 |
|                              |        | Depth to Low Permeable Layer (cm)                                           |                                 |                                         |

Source: PWA, (2006)

There are six different dominant flows but due to the lack of data obtained for the area, the concentration on the three up mentioned types of dominant flow, and they are shown in Figure 5-13.

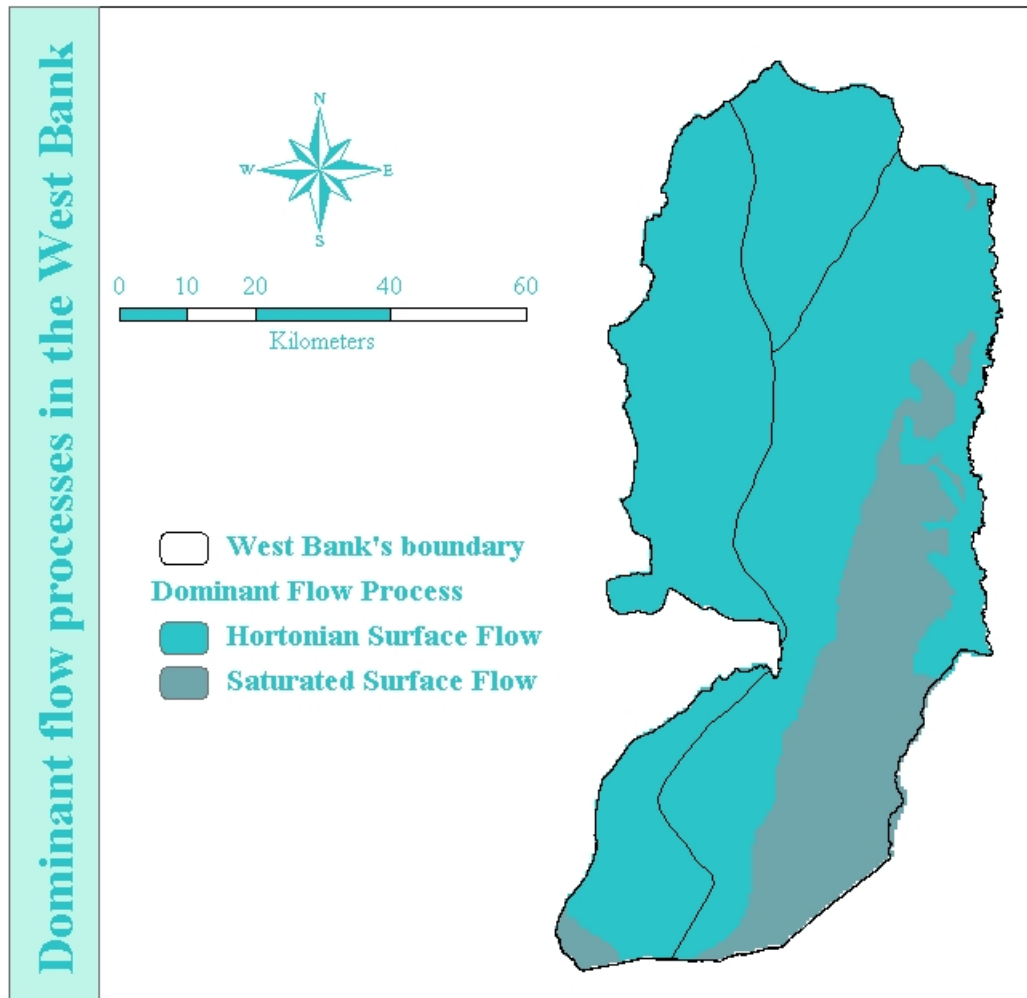


**Figure 5-13** dominant Flow Type for the West Bank

### *Land use map*

The final map needed for the construction of the I-map is the Landuse map. This map is a description of the type of land in the area, it includes several types: field crops, natural forest, olives, orchards, planted forest, sandy soil, and scrublands.

According to COST 620 its classified into two categories only:

1. Forest and vegetation (includes natural and planted forest).
2. Field, meadow, and Pasture (include the rest).

The procedure used for the production of this map is modifying the original Landuse map in Figure 5-14 to a new version with the needed up mentioned categories which is shown in Figure 5-15.

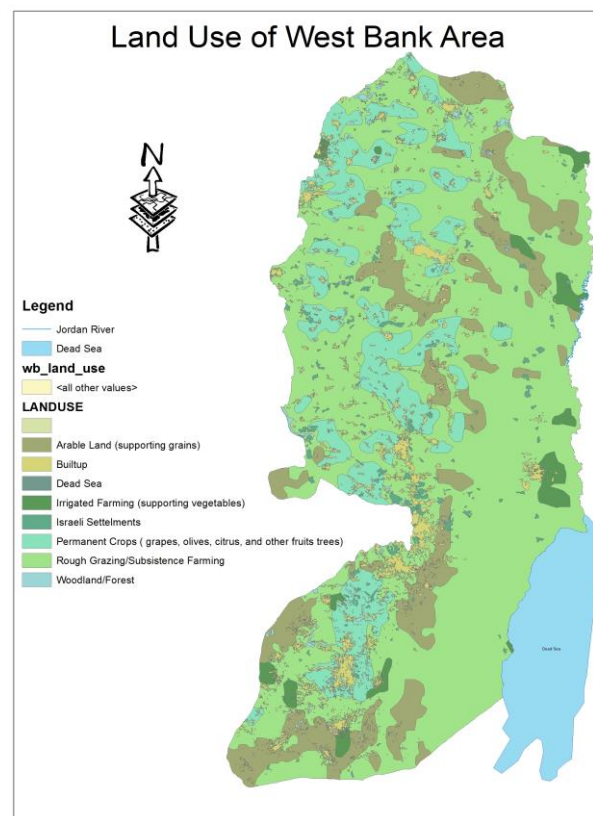


**Figure 5-14** landuse in West Bank with all categories

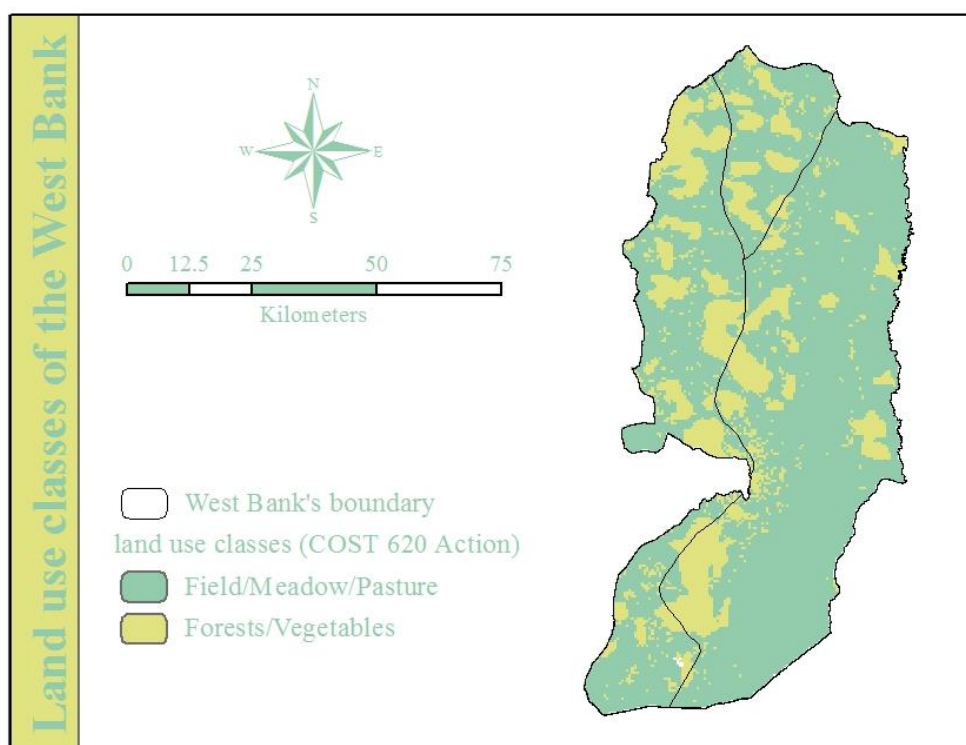


**Figure 5-15** Land use map with the needed categories

A union of the previous three maps and through using Table 5-8; I' map is drawn in Figure 5-16, and then using the method explained in Chapter three, the I-map is drawn in Figure 5.18.

**Table 5.8** Determination of the I' factor.

| Forest              |         |          |        |
|---------------------|---------|----------|--------|
| Slope               | < 3.5 % | 3.5-27 % | > 27 % |
| Type D              | 0.8     | 0.6      | 0.4    |
| Type E              | 1.0     | 0.6      | 0.4    |
| Field/Meadow/Pature |         |          |        |
| Slope               | < 3.5 % | 3.5-27 % | > 27 % |

|        |     |     |     |
|--------|-----|-----|-----|
| Type D | 0.6 | 0.4 | 0.2 |
| Type E | 0.8 | 0.4 | 0.2 |

I' factor

|     |     |     |     |     |
|-----|-----|-----|-----|-----|
| 0.2 | 0.4 | 0.6 | 0.8 | 1.0 |
|-----|-----|-----|-----|-----|

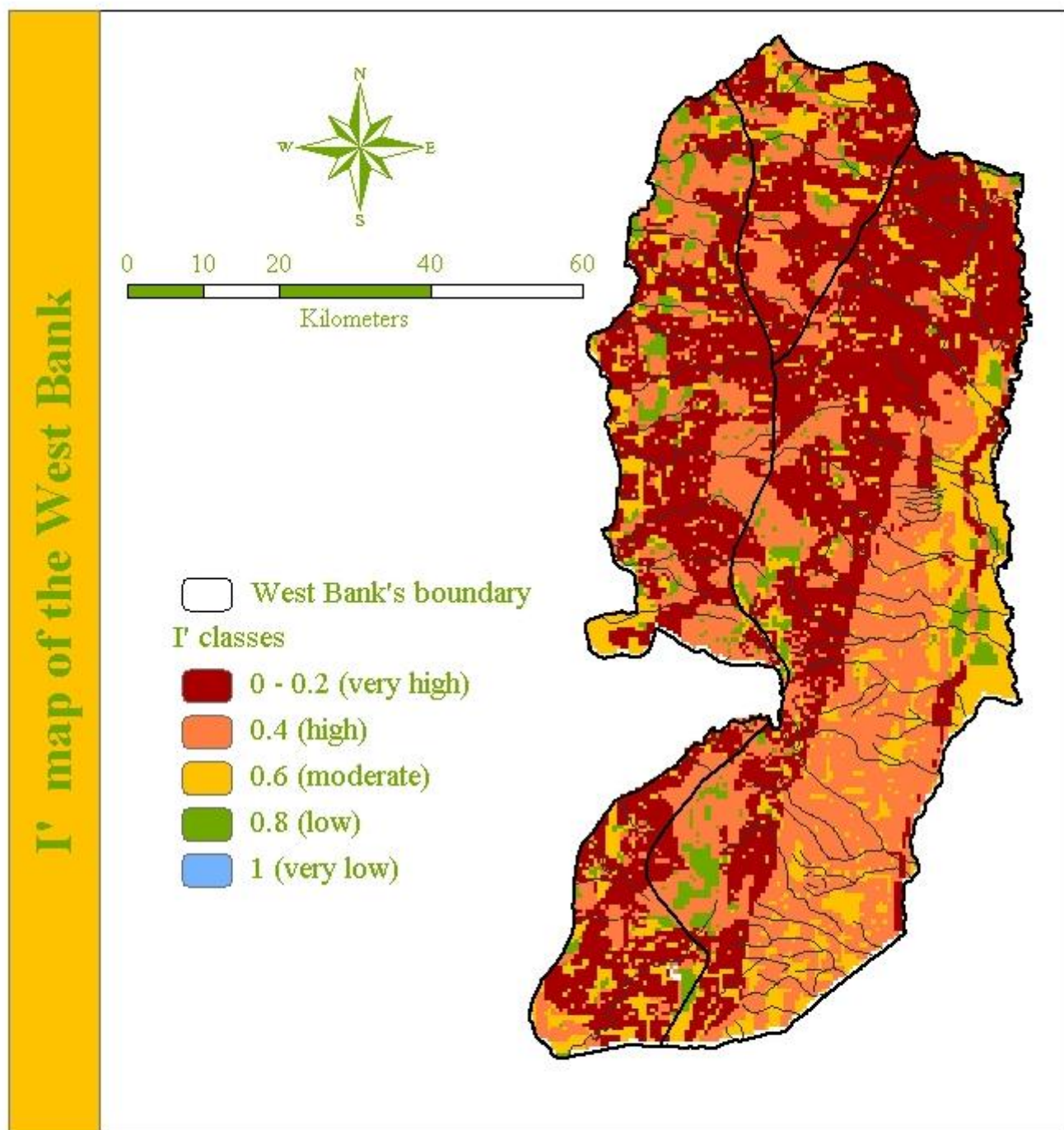


**Figure 5-16** I' Factor

In order to draw I-map; the I'-map shown in Figure 5.16 is intersected with the surface catchment map (Figure 5.17) which is obtained from drainage map using special analysis in the Arc-GIS.

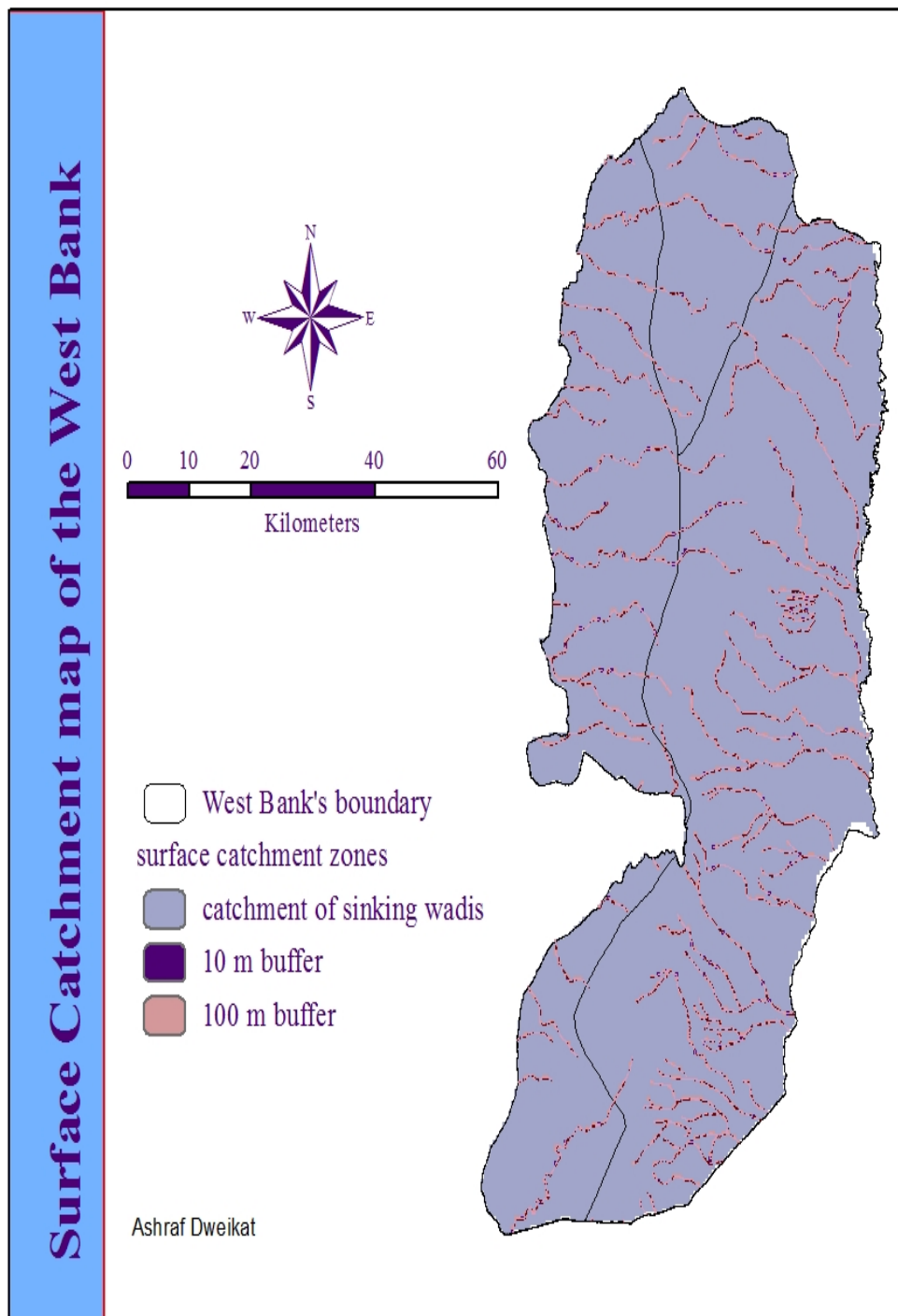


**Figure 5-17** Surface catchment map in West Bank

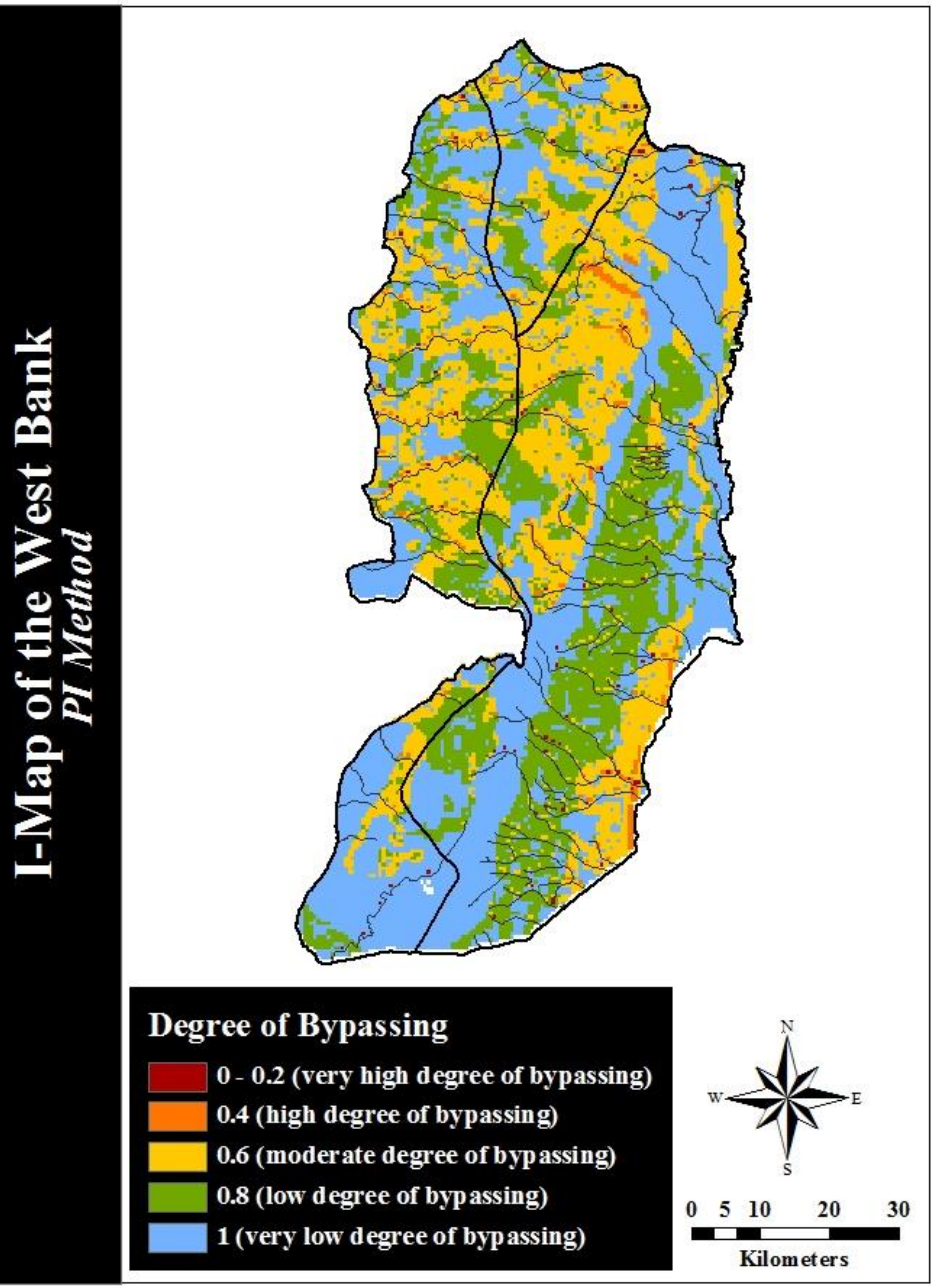


Figure 5-18 Infiltration Factor

## Vulnerability map:

A summary of what was done to produce the PI map is listed below:

- The first steps were toward the production of P-map using different types of data; starting with the soil maps that include both top soil and subsoil to get the first two maps (T-factor, S-factor).
- Geology map was used to construct the bedrock factor map (B-map) using the data of lithology and fracture for different rocks.
- Then geology map was also used in addition with rainfall map to produce the R-factor map.
- A union to join all the previously mentioned maps was done to produce the protective cover map (P-Map) which is the first half of Vulnerability Map.
- Soil map was used to determine the dominant flow process.
- Land use map was adjusted according to COST 620 action.
- Contour map was used to produce three zoned slope map.
- A union of dominant flow map, landuse map, and slope map produce I` map.
- Drainage map produces surface catchment map.
- Merging the I`prime map with the surface catchment map; the I map is obtained.
- A union between the two parts of the project (P&I) gives the PI map (Vulnerability map) which is shown in Figure 5-19.

# Vulnerability Map of the West Bank

*PI Method*

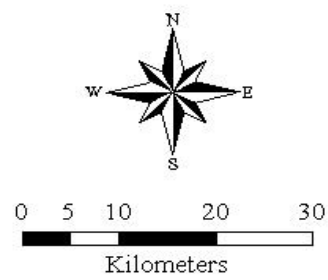
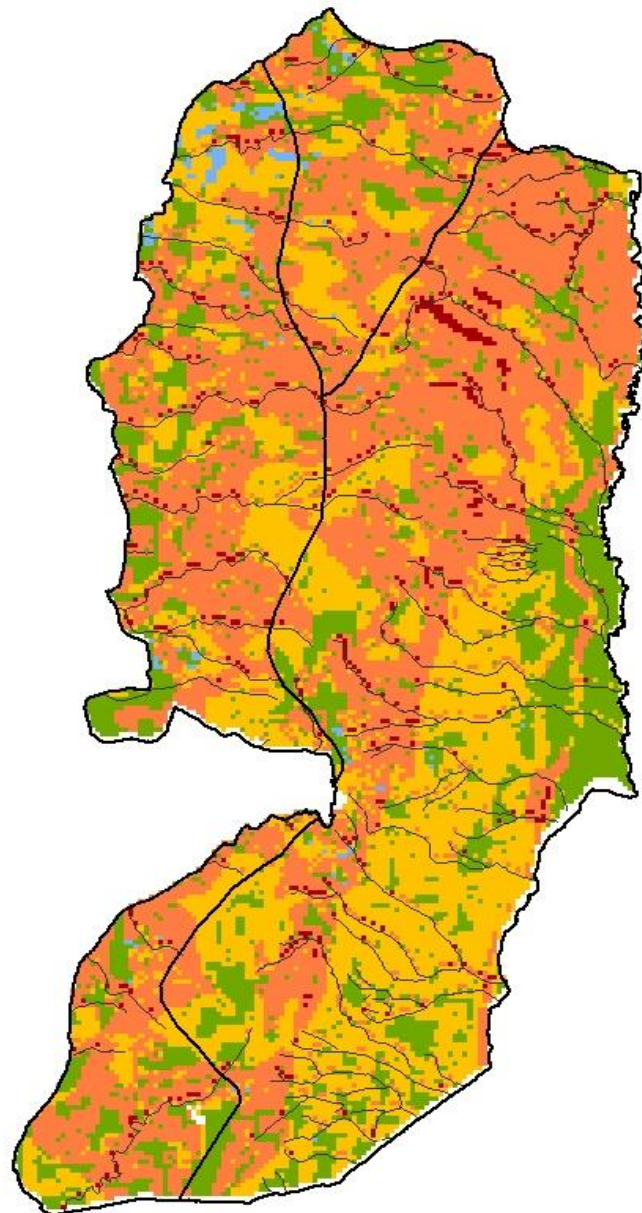


Figure 5-19 Vulnerability map for West Bank

## Results and Recommendations

### *Results & Conclusions*

Palestinian authority suffers from water scarcity due to illegal actions of the Israeli occupation; groundwater is the only source for drinking water for the Palestinians. This project aimed to produce a simple method to protect what is left in those water mines.

Vulnerability map as mentioned before is the first step to find the Risk map, Hazard map on the other hand is the other step. Those two maps work together to provide a comprehensive tool to show the full picture regarding groundwater protection.

Groundwater is subjected to various types of hazards produced by man kind or any other source of nature, prevention and reduction of contaminants is the first step in protecting groundwater aquifers.

The resulted essential Vulnerability map and using the ArcMap 10 program; shows that

West Bank is a high vulnerable area; where about 5% is classified as extremely high vulnerable zones with red color, 43% is classified as high, 34% is classified as moderate, 13% is classified as low, and only 5% is considered very low vulnerable zones. Those results can not be neglected and should be studied carefully.

If the resource vulnerability map is intersected with a map showing the flow route in the aquifer towards a spring or well, it can also be used for source vulnerability mapping.

Clearly in the protective cover map most of the west bank areas have highly protective covers, the infiltration map on the other hand shows that most of the area have considered low to moderate bypassed covers.

## Recommendations:

Vulnerability map of the west bank can be used as a construction manual that prevents the building of any contaminant resource in the low and moderate vulnerable zones. Those resources include industries like stone cutting and olive mills, also public and private facilities like landfills and septic tanks, also waste water treatment plants, gas stations, and any hazardous source in general.

Improving the waste disposal techniques and a better public awareness in order to reduce the hazards to the minimum, for example oil, gas, and fuels are washed down by rainfall or by human; this can be prevented unless the wash water is collected and disposed properly.

As for the government, the following must be taken into consideration:

- Amending the law articles regarding the water law; to take into consideration the vulnerable zones and the proper way to manage them using the vulnerability map constructed by this project.
- Training a team of specialists and technicians to work in this field to prevent any assault to groundwater resources.
- Discussing this subject in the Palestinian-Israeli negotiations that adjust Palestinian rights in this field.
- Creating a comprehensive data base all over the West bank and Gaza about the vulnerable zones supported by maps and specific details to be used by the trained team.
- Forming a national committee of the decision makers that sets plans and assure their implementation regarding the vulnerable zone in the area.
- Raising public awareness through heard and read media that shows the importance saving the vulnerable zones from contaminants and its direct effect on the on man's life to reduce their assaults and increase their support.

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