Faculty of Graduate Studies

Inventory of the Potential Artificial Recharge Practice in the Eastern Aquifer basin: The Case of Al -Qilt catchment, Palestine.

By

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MSc Thesis

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Dedication

I Dedicate My Work

To Whom I Belong;

To My Parents,

To the spirit of my grandmother,

To My Brothers and Sisters,

To All My Friends,

For Their Help, Support and Encouragement.

Acknowledgments

I would like to express my deepest thanks to Dr. Marwan Ghanem for his support and continuous care, it was pleased that he a supervisor in this work. My thanks are extended to the members of thesis committee; Dr. Maher Abu Madi and Dr. Sameer Shadeed, for their important comments, and I would express special thanks to Drs. Ebel Smidt for his valuable comments. In addition, thanks are extended to Palestinian Water Authority (PWA), Palestinian energy Authority (PEA) and meteorological department, for provided data that supported this thesis.

Abstract

Al-Qilt catchment is classified as arid to a semi-arid area that suffering from water shortage and area without Sustainable management for water resources. Groundwater is the main source for freshwater in the area, but the area suffer that, the ability of wells and springs to cover the water demand is low. Therefore, it is important to find feasible solutions to increase aquifer storage. One of the identified feasible solutions might be the use of artificial recharge system by using winter flood and treated wastewater in the dry season as a source for artificial recharge.

The methodology of the work begins with collecting and analyzing the data that needed for estimate the water balance and to define the best areas for artificial recharge. Groundwater balance were estimated, and the best suitable areas for artificial recharge were identified.

To calculate water balance, Soil Moisture Demand (SMD) by using GIS model in semi-arid areas is used. Many parameters were used as inputs such as rainfall, temperature, monthly relative humidity and solar radiation. The result shows that The yearly recharge by this method is estimated about 99 mm/year in the upper parts of the catchment and estimated about 12 mm/year in the lower parts of the catchment.

In addition to (SMD), other methods are used to estimate the groundwater recharge, for example, chloride mass concentration, Guttman and Zukerman equations for the West Bank and Goldschmidt equation.

The annual recharge according to chloride mass concentration found to be 118 mm/year, the annual recharge that estimated by (SMD) about 84 % of chloride mass concentration. The annual recharge by Guttman and Zukerman equations for the West Bank estimated about 126 mm/year, annual (SMD) recharge represent 79 % of annual recharge by Guttman and Zukerman. While the annual recharge by used Goldschmidt 1959 is estimated to be 118 mm/ year.

GIS-based suitability was used to determine the best locations for artificial recharge project based on the slope of the area, runoff, infiltration capacity, land use, distribution of groundwater wells and the depth of groundwater table.

The results show that 159 km^2 of Al-Qilt catchment is moderately suitable to perform the artificial recharge project by using injection wells, represent 91 % of the total area. While the area of high suitable for artificial recharge by using injection wells estimated about 14 $km.^2$ The area that estimated to be suitable for artificial recharge by using treated wastewater estimated about 115 km^2, which represent 66% of the total area, while 59 km^2 is considered not suitable for artificial recharge by using treated wastewater as source for external water that infiltrate to groundwater.

الخلاصة

تعد منطقة القلط من المناطق الشبه الجافه حيث تعاني من الطلب العالي للمياه و تعتبر الوديان والابار هي المصدر الرئيسي للمياه في المنطقة، الا أنا قدرتها على تغطية الطلب المائي منخفضة، لذلك من كان من الضروري البحث عن مصادر جديدة لرفع منسوب المياه بالمنطقة.

من الطرق المتاحة لرفع منسوب المياه في المنطقة الضخ الصناعي للماء وذلك من خلال تجميع مياه الفيضان في الشتاء واستعمال المياه العادمة المعالجة في الصيف كمصدر لدعم موازنة المياه في المنطقة. وتم ذلك بالاعتماد على خصائص المنطقة المكونة من صخور الدلوميت والرواسب والصخور الجيرية المنتشرة.

وتتلخص الية العمل في الدراسة من خلال تحليل وتجميع المعلومات الازمة لعملية حساب الموازنة المائية واللازمة لتحديد المنطقة المناسبة لعملية الضخ الصناعي سواء باستخدام مياه الفيضان الناتجة في الشتاء أو المياه العادمة المعالجة. موازنة المياه في المنطقة تم حسابها وافضل الاماكن المناسبة للضخ الصناعي تم تحديده.

موديل مقياس رطوبة التربة في جي أي أس قد استعمل لحساب الموازنة المائية في وادي القلط وقد ادخلت مجموعة بيانات لحساب الموازنة وهي: كمية هطول الامطار، درجات الحرارة، نسبة الرطوبة وكمية الاشعاع الحراري. وقد وجد أن كمية المياه السنوية المخزنة في المنطقة العلوية من وادي القلط تساوي 99 ملم / سنة، بينما في الجزء الشرقي من وادي القلط فأن كمية المياه المخزنة تساوي 12 ملم / سنة.

وقد استعملت طرق اخرى لحساب الموازنة المائية في وادي القلط، من خلال استعمال طريقة تركيز الكلور في المياه الجوفية وجد ان كمية المياه المخزنة سنويا تساوي 118 ملم / سنة. وقد وجد أن كمية المياه المخزنة من خلال معادلات زجرمان وكوتمان تساوي 126 ملم/سنة

وفي معادلة غولدسمدت (1959) فأن المخزون المائي في القلط يساوي 118ملم/سنة.

لتحديد المناطق المناسبة للضخ الصناعي حيث استخدمت Weighted Overlay Method وتم استخدام عدة معايير لتحديد المنطقة المناسبة للضخ وهي الانحدار، الجريان السطحي، قدرة الصخور على الترشيح واستعمال الاراضي وكثافة الابار وعمق المياه الجوفية. اشارت النتائج أن 91 % من المنطقة مناسبة لعملية الضخ الصناعي من خلال تجميع مياه الفيضان وذلك بمساحة 159 كيلو متر مربع. وأن نسبة المناطق المناسبة لعملية الضخ الصناعي بواسطة المياه المعالجة من خلال قدرة الصخور على ترشيح المياه هي 66 % وذلك بمساحة 115 كيلومتر مربع.

Chapter one

1. Introduction

1.1 Background

Water very important substance, responsible for the presence of life in the earth, it's an important factor that serve human existence and influencing civilization processes. Palestine is known for suffering shortage of renewable water resources, leading to a low per capita water consumption of 72 l/c/d (PWA, 2011), 72% of the WHO minimum standard of 100 l/c/d (Abu Zahra, 2001). Palestine suffers from a huge demand for water use, which estimated to be by more than 50% until the year 2020 (Froukh, 2003). This huge demand needs to search for another additional source of water, the eastern basin can support the Palestinian with groundwater but it is expected to encounter severe drawdown which may lead to the depletion in water storage and a decline in water quality due to increase the salinity (Daghrah, 2005).

This study is focused on Al-Qilt catchment, as part of the eastern basin. Al-Qilt catchment is situated in the arid and semi-arid area, where the conservation of water resources is not significant (Abu Helo, 2008). There is an increase in population, thus the demand for water is increasing for both domestic and agricultural uses (PCBC, 2007). In addition, Water shortage is become more worse as result of Israeli control over most water resources in the West Bank, therefore, high intensive water resources management is needed to achieve high efficient for utilizing the limited available water resources.

The main source for water in the Al-Qilt catchment is the groundwater, it is favored over surface water for live saving and to use for other purposes, thus the augmentation of groundwater quantity and the quality is essential. The water level of groundwater depends basically on the natural recharge that occurs in the winter season (Ghanem, 2002). High continuous demand for water in the Al-Qilt area leads to a rapid degradation in the quantity and the quality of fresh groundwater resources (Abu Helo, 2008), so the sustainable management for groundwater is very important, that depend on the advanced technologies for efficient water use, and the produce new water sources that decrease the water shortage in the Al-Qilt catchment. Artificial groundwater recharge will be one of the proposed management options, which perform as a new source of water within the aquifer (Saleh, 2009).

Artificial recharge by treated wastewater considered an important source of increased water level (Pedrero, 2011), about 32% to 35% of the families in the West Bank are joined to a wastewater group system (PWA, 2011). Treated wastewater from treatment plants is stored in storage tanks and become contaminated again if not stored properly.

In the Al-Qilt catchment, the huge amount of treated wastewater flowing from Al-Birah treatment plant into wadis without benefits use. The majority of the treated wastewater evaporates and portion infiltrates to groundwater. An artificial recharge method will lead to effective use of treated wastewater after stored, the artificial recharge is an effective process to improve the quality of the existing wastewater through using soil filtering treatment (Goren, 2014). Using treated wastewater as a source of groundwater recharge also prevents wastewater from causing pollution during storage or infiltrating to groundwater in an uncontrolled way or causing Eutrophication if added to surface water (CH2MHILL, 1999).

In addition, steep slopes and biological properties for Al Qilt catchment make it among the most likely areas in the West Bank to experience floods (ARIJ, 1995). Floods flow from the western mountain toward the Dead Sea in the eastern part of the catchment and then mix with saline water in the Dead Sea, so large quantities of this mixed water lost without human benefit. Artificial recharge is a worldwide recognized method for the preservation of runoff and the replenishment of groundwater resources, by studying the hydrological, geomorphological properties and water balance of the catchment, will help in choosing the appropriate method for artificial recharge in the Al-Qilt catchment.

For successful implementation for the Artificial Recharge project, the hydrogeology parameters are the most important that must be determined (Mahadvi, 2013). The first step is collect all available data from there sources and authorities and convert to geological maps or get data as geological maps. The geological map indicates the geological strata, the rocks texture and structural expressions like Strike, Dip, Faults, Folds, Flexures, Intrusive bodies. These maps also bring out the correlation of topography and drainage to geological contacts (Sukumar, 2010).

All information such as groundwater lateral flow, chemical properties of water qualities and the hydrologic rock unit and the presence of groundwater would be derivative from hydrogeological maps (Mahdavi, 2013). Before implementation of an artificial recharge scheme, a detailed Hydrogeological Mapping study is required, the important for hydrogeological mapping is to create a new hydrogeological mapping that can analyze the groundwater regime and determine the best location for artificial recharge project (Raymond, 2009).

The water bearing capacities of important hydrogeological units help to determine the water table level. The form of the water table can be interpolated from wells depth in the study area. The minimum and maximum water table levels determine the amplitude of ground water level fluctuations, which is an important consideration for artificial recharge (Raymond, 2009).

The main aims of artificial recharge process of groundwater are simply to increase the quantity of water that enters the aquifer at a specific site. To determine the impact of increased water table by artificial recharge, two hydrological parameters must be adjusted, hydraulic conductivity and storability of the aquifer. These two parameters are important to study the success or failure of a groundwater artificial recharge (GAR) site (Bouwer, 2002). Water balance analyses have been calculated to identify the quantities of available water to recharge the aquifer in the Al-Qilt catchment. Groundwater and surface water quality were also assessed via analyses of water samples from different locations and sources and compared to international water quality (WHO) analyses standards (Abu Helo, 2008).

1.2 Objectives

The objectives of the study are:

1. To determine the appropriate locations and methods to be used for artificial groundwater recharge in Al-Qilt catchment by using treated wastewater as a source for external water to increase groundwater table.

2. To determine the appropriate locations and methods to be used for artificial groundwater recharge in Al-Qilt catchment by using winter flood as a source for external water.

3. To calculate the water balance of the groundwater in the Al-Qilt catchment by using Soil Moisture Demand (SMD) model and compare with other different analytical methods.

1.3 Research methodology

The Depiction of the overall research methodology is illustrated in Figure 1.1. Where the methodology consists of many stages include:

1. Collection of data: These data were obtained from field visits, reports and previous studies, and from the Palestinian water authority. The collected data include the followings:

- Geological map, topographical map.
- Geological cross-sections.
- Climatic data which include rainfall, temperature and relative humidity
- The distribution of wells and springs and discharge amounts.
- Water quality characteristics.
- Infiltration capacity values.

2. Field work, many field visits were done in order to study the physiogeographic characteristics of the catchment.

3. Preparing maps by using GIS to determine the proper locations for artificial recharge structures based on the following criteria: Slope, Infiltration capacities of the sediments, Runoff, Land use, Depth to groundwater, Wells distribution in the study area.

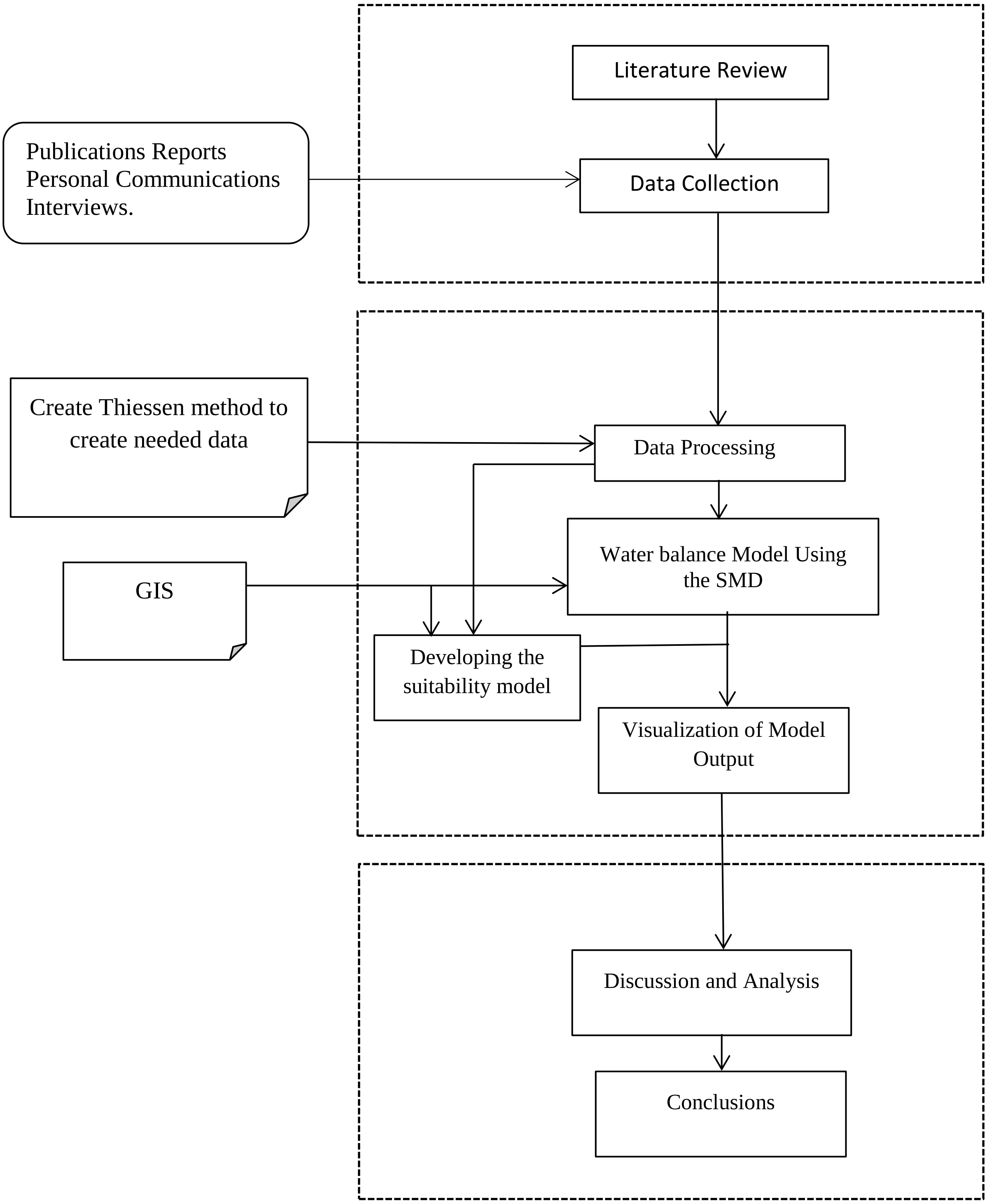

Figure 1.1: Depiction of the overall research methodology.

1.4 Literature Review

The groundwater artificial recharge (GAR) is a process by which excess water is purposely directed into the ground to rebuild or augment groundwater supplies (Mahdavi, 2013). It is accomplished by one of three methods: spreading on the surface, injecting water through recharge wells, or by altering natural conditions to increase infiltration (NRC, 1994).

Groundwater recharge methods are classified as one of three general types, indirect and direct subsurface and direct surface (Asano, 1985). Whether used independently or in combination, the approach chosen should be based on soil characteristics, type of aquifer and water-table properties, climate, environmental constraints to increase quantity of groundwater (Johnson and Finlayson, 1989).

According to Hamdan (2012) The use of harvested rooftop stormwater runoff in Gaza strip is an acceptable option for artificial recharge. The water quality is an important parameter that taken in consideration. That found The concentration of chloride and nitrate is law in the harvested water while the other metals such as iron, zinc, and copper were in the acceptable limits set by WHO and high concentration of the total organic carbon (TOC) is found.

Saleh (2009) studied the effect of artificial recharge by using floodwater on the groundwater system in the Faria catchment. The appropriate sites for artificial recharge were established. By using soil moisture demand, the water balance was determined. The results were that around 36 MCM is the natural recharge in the top parts of the catchment against a total catchment recharge of 60.3 MCM. The human-made artificial recharge in the top catchment can give about 3.2 MCM. The Weighted Index Overlay Method (WIOA) was applied to determine the most proper locations for artificial recharge structures based on infiltration capacity, slope, type of aquifer to be recharged and the existence of fractures. The results show that 14% of the total area is very suitable for artificial groundwater recharge.

Hammouri et .al (2013) Used Slugger-Dol model to determine the appropriate sites for artificial recharge in the Jordan valley, eight parameters were used as thematic layers prepared by GIS, slope, land use, geology, runoff, distribution of wells, water quality, the water level in summer and geomorphology. All parameters are collected and integrated by GIS model builder. According to (Al Saud, 2010) The use of geology and type of rocks are important parameters that effect on the water movement, in addition, the presence of land uses (covers) have high influence on the behavior of water flow on terrain surfaces and the recharge process to determine the appropriate location for artificial recharge.

Another example in Jordan Al Qaisi (2008) lists that the artificial recharge project at Wadi Madoneh (close to Amman city) has been completed. First examinations were done to estimate the available quantity of stormwater for infiltration, in order to estimate water balances and to define places for the artificial recharge support. In 2007, the real infrastructure consisting of four infiltration dams was created in the Madoneh area.

On another hand, EL-Arabi (2012) mentioned as the result of Lack of irrigation water sources in Egypt bring out the effect of applying non-conventional water supplies. Egypt started a plan to study the probability of artificial recharge for the increase of groundwater quantity in Abu Rawash farm as a case study, in addition, to studying the environmental impact assessment (EIA) of artificial recharge experiment to assess the feasibility guidelines for the future recharge projects. Results indicated that the artificial recharge for groundwater aquifer using treated wastewater is promising, whoever it requires additional comprehensive study to judge the aquifer story influences the mechanism of recharge with treated wastewater. The health hazard due to variations in the physical and chemical properties prevailing in the aquifer or due to limited adsorption capacities as well as the microorganisms survive and toxic pollutants degradation.

Mahdavi et. al (2013) indicate that because of groundwater depletion Shahrekord plain in Iran, groundwater artificial recharge (GAR) using surface water is the suggested solution since that improves the aquifer storage. Discovery of aquifer storage place is the first step in planning (GAR) schemes. Data affecting (GAR) including ground surface slope, soil infiltration rate, vadose zone thickness, the electrical conductivity of the surface water, land-use and stream network were collected. After provision of digital maps, they were classified, weighted and integrated through Boolean and Fuzzy operators.

Juaidi (2008) concentrates on the quantification of groundwater recharge for the whole West Bank and for each aquifer using the Soil Moisture Demand (SMD) method. The SMD method is the most appropriate method for recharge evaluation in arid and semi-arid situations. Model Builder of GIS was used to promote the recharge quantification and to efficiently account for the spatiality inherent in recharge. Results verify that the highest recharge happens in the North-West of the West Bank and the lowest in the South-East. The total annual recharge for the entire West Bank is 852 MCM for the year 2004. In addition, the Guttman and Zukerman (1995) equations were used to calculate the annual recharge and found that the weighted average of annual recharge for the entire West Bank is 126 mm/year.

Marei et. al (2010) indicate the evaluate of groundwater recharge using the chloride mass balance method in the West Bank. The chloride mass balance method was used to evaluate recharge at various localities serving the three groundwater basins of the Mountain Aquifer in the West Bank. The recharge rate for the Eastern Basin was estimated as within 130.8 and 269.7 mm/year, with a total average replenishment volume of $290.3 \times 10^6\ m^3$/year. For the Northeastern Basin, the estimated recharge rate varied within 95.2 and 269.7 mm/year, with a total average recharge volume of $138.5 \times 10^6\ m^3$/year. Lastly, the recharge rate for the Western Basin was within 122.6 and 323.6 mm/year, with a total average recharge volume of $324.9 \times 10^6\ m^3$/year. The data reveal a replenishment potential within the estimated replenishment quantities of early studies for the similar area. Also, the range was within 15 and 50% of whole rainfall, which is still within the range of earlier studies. The geological structure and the climate conditions of the western slope were obviously performed a major role in the increase of total volume. In some cases, such as the geological formations in the Northeastern Basin, the interaction between Eocene and Senonian chalk formations result in minimum recharge rates.

BGS (2005) has evaluated the groundwater recharge for the West Bank aquifers using the SMD method for two area, Wadi Natuf catchment and the main outcrops of the aquifers underlying the West Bank. To assist the recharge, a distributed recharge model was produced using object-oriented techniques. The work on the Wadi Natuf catchment was promoted by several field visit reports offered by the "Sustainable Management of the West Bank and Gaza Aquifers. This model was based on ArcGIS and the method was used soil moisture deficit and wilting point.

Hartono (2005) Evaluated the groundwater recharge for Chicot aquifer (State of Louisiana, USA) utilizing a GIS-based water balance method that combines rainfall, soil characteristics, runoff, storage, soil moisture and evapotranspiration to estimate recharge rates across the aquifer. Results reveal how annual and changes in the agricultural request and rainfall can immediately effect on the recharge.

Dashtpagerdi (2013) used artificial recharge to discuss the critical condition of groundwater reserves in Sefieddasht plain. This study was carried out to determine the suitable areas for artificial recharge in Sefieddasht plain. Four portions, namely alluvial nature, alluvial thickness, slope and infiltration rate parameters were examined and maps created and classified utilizing GIS. The fuzzy logic model was applied to preparing the suitable areas for artificial recharge. Finally, land use maps were used as a filter. Based on results 4.12% of the region was recognized as a suitable area for artificial recharge.

Rushton, et. al (2005) have evaluated the groundwater recharge utilizing the SMD method. Evaluation of recharge in a diversity of climatic situations is probably using a daily soil moisture balance based on an individual soil store. The potential evapotranspiration was introduced in the conceptual and computational models. The actual evapotranspiration is less than the potential value when the soil is under stress.

The stress factor is estimated in terms of the readily and total available water parameters which depend on soil properties and the effective depth of the roots. Runoff was estimated as a function of the daily rainfall intensity and the current soil moisture deficit. A new concept, soil storage was introduced to account for continuing evapotranspiration on days following heavy rainfall even though a large soil moisture deficit exists. Algorithms for the computational model were provided.

Dyer (2009) used soil balance GIS model builder in the USA to estimate the recharge by using simple daily soil water balance model. The potential evapotranspiration, actual evapotranspiration, the deficit, runoff and the change in storage map are created. The component of the model is monthly rainfall, monthly temperature and radiation. The potential evapotranspiration was estimated by using Turc equation. The Dyer water balance model can be used to estimate the recharge in the arid to semi-arid region.

Chapter Two: Description of the Study Area

2. Physiography

2.1 Location

AL-Qilt catchment is part of the West Bank which located in the eastern basin covering about 174 km^2 (Daghrah, 2005). The main recharge area for the catchment is the Jerusalem – Ramallah mountain in the west part of the catchment. The location of the catchment in West Bank is shown in Figure 2.1.

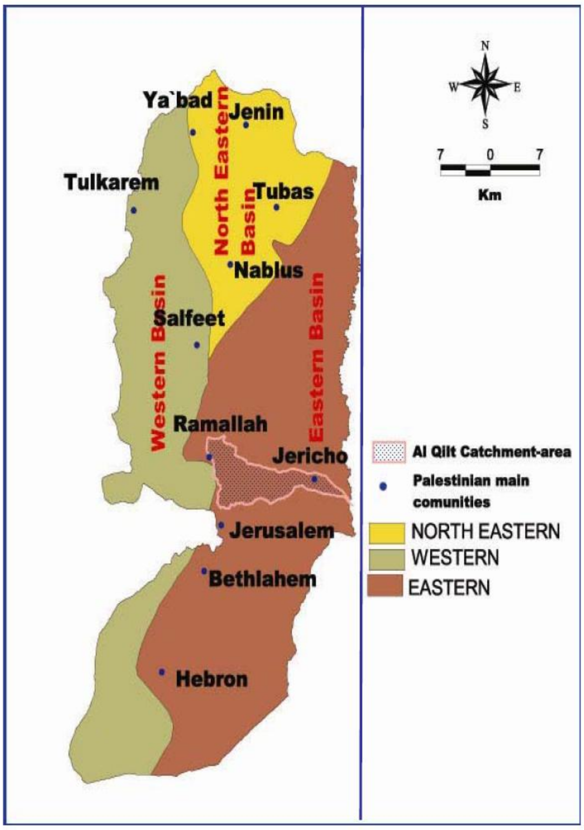

Figure 2.1: The location of Al-Qilt catchment in the West Bank.

The water drainage system in the Al-Qilt catchment start from Ramallah and Jerusalem mountains (Central Mountains) moving toward the Jordan river - Dead Sea sub-basin (Rofe and Raffety, 1963). Al-Qilt catchment is characterized as a steep area which varies in elevation from 900 m.a.s.l in the western part to - 400 m.b.s.l in the eastern part (Abed Rabbo et. al, 1999).

Al-Qilt catchment has a lot of tributes, such as Wadi AL-Ein (7.5km), Wadi Mukhmas (9km), Qalandiah (2km) and Stone cut (2km). All of these wadis are located in the left bank of Al-Qilt catchment (Samhan, 2013), the length of wadi Al-Qilt with its tributaries is in the range of 45-50 km (Samhan, 2013). Figure 2.2 shows the attributes of Al-Qilt catchment.

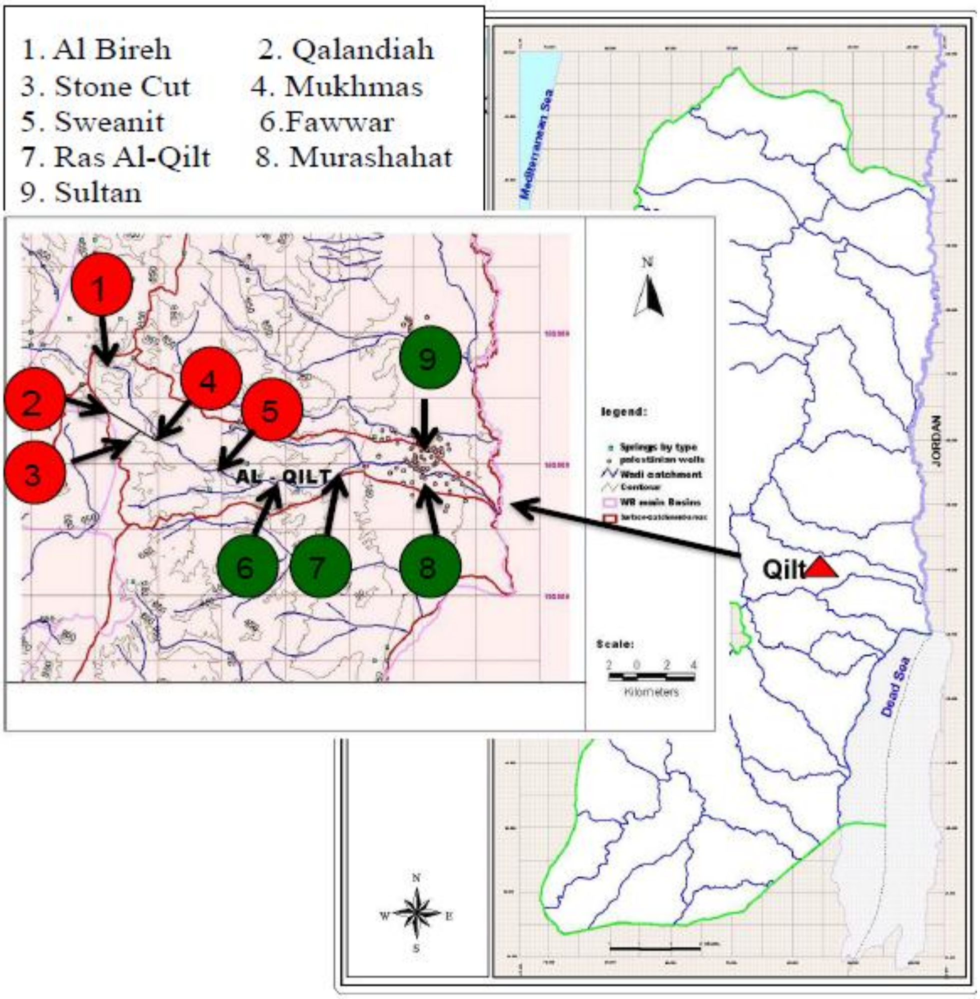

Figure 2.2: The attributes of Al-Qilt catchment.

Three main springs (Ein Al-fawwar, Ein fara, Ein Al-Qilt) are present in Al-Qilt catchment. Ein Al-fawwar situated at an elevation of 75 m.a.s.l and which located 4.5 km from Ein fara, Ein fara located at an elevation of 325 m.a.s.l (Abu Helo, 2008). The discharge of the Ein- fara depends on the type of season and the amount of discharge varies from summer to winter by a small amount. Ein Al-Qilt located downstream of 2.3 km away from Ein Al-fawwar at an elevation 10 m.a.s.l. Geological sketch section along the line of springs in Al-Qilt system shown in Figure 2.3.

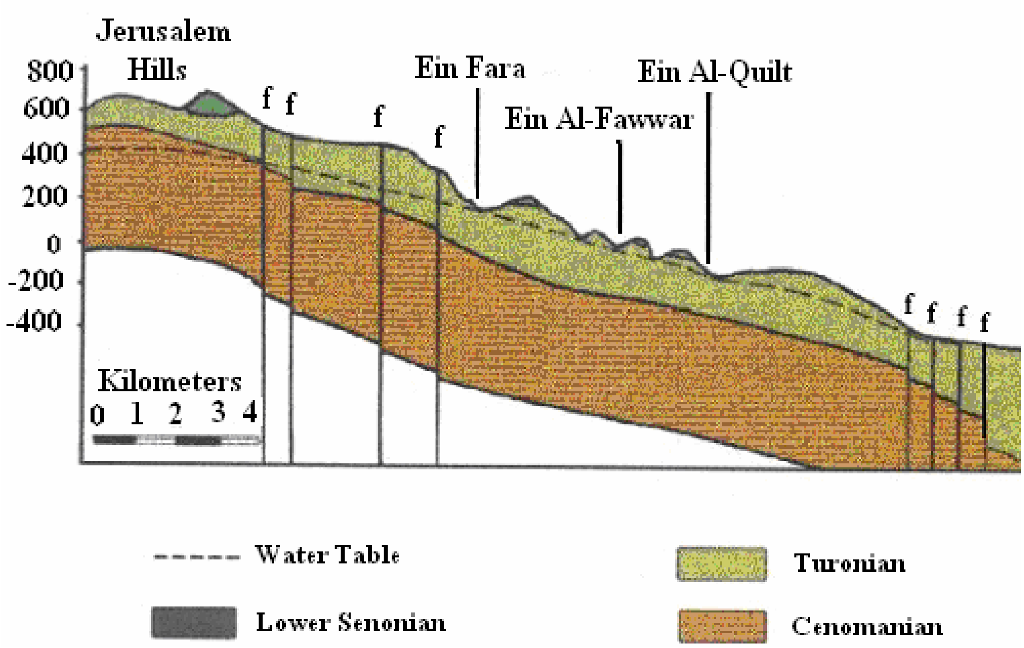

Figure 2.3: Geological sketch section along the line of springs in Al-Qilt catchment.

(Abed Rabbo et. al, 1999).

Al-Qilt catchment is described by relatively steep slopes which start from Ramallah city in the Western part of the catchment and descend to Jericho city in the eastern part of the catchment then becomes flat surface when passing to the Jericho city (khayat, 2005). In A-Qilt catchment, water moving from the upper part in the western region moving toward the Dead Sea (Daghrah, 2005).

2.2 Population

There is an increase in population in Al-Qilt catchment. The total Palestinian population in the Al-Qilt catchment is 128,049 inhabits (PCBS, 2007). There are six settlements existing in the catchment with total population 29,250 (PCBS, 2007). The total inhabits in the Palestinians cities in the catchment for (2007) is a list in Table 2.1, and the total inhabits in the Israel's settlement for (2007) is a list in Table 2.2

Table 2.1: Total inhabits of Palestinian Communities.

Number	Communities	Population
1	Beitin	2,014
2	Al-Bireh	35,910
3	Deir Dibwan	4,937
4	Burqa	1,964
5	Kofr Aqab	10,103
6	Qalandia camp	7,962
7	Mukhmas	1,305
8	Al-Ram	18,356
9	Jaba	2,870
10	Hizma	5,645
11	Beit Hanina	966
12	Anata	10,864
13	Ein dyouk	783
14	Jericho	17,515
15	Deir Al-Qilt	4
	Aqbat Jaber	6,851
Total		128,049

Table 2.2: Total inhabits in Israel's settlement.

Number	Settlements	population
1	Psagot	1,333
2	Kokhav Yakov	3,922
3	Malle Mukhmas	998
4	Almon	740
5	Adam	1,988
6	Neveh Yakov	20,269
Total		29,250

2.3 Climate

The West Bank is described as semi- arid area with two different seasons, hot seasons which start from June to October and cold wet seasons which starts from November to May (ARIJ, 1996). Al-Qilt catchment is affected by two wind directions throughout the whole day (ARIJ, 1996). In the morning hours, the wind comes from the Dead Sea with an average velocity of 3m/sec, then it reflects toward the North-West with the average velocity of 5m/s (khayat, 2005). Maximum wind velocity occurs in the spring season with an average velocity of 15m/sec (ARIJ, 1996).

2.4 Temperature

The temperature in the West Bank varies from season to other, the average temperature in hot season ranging from 20 to 23 °C, the maximum temperature reach 43°C in August. In the winter season, the temperature range varies from 10 to 11 °C and drops to 3 °C as a minimum in the January (Marie, 2001).

Many factors affect the variation in the temperature such as elevation and distance from the coast and the environment around the stations (Ghanem, 1999). In the western part of Al-Qilt catchment, January is the coldest month with an average temperature of 6 - 12 °C and August is the warmest month with an average temperature of 22 – 27 °C, while in the eastern part of Al-Qilt catchment (Jordan valley), the average temperature in January estimated about 7-19 °C and in August the average temperature about 22 - 39 °C (PDM, 2012).

2.5 Rainfall

The amount of rainfall in the West Bank varies from area to other and from upstream to downstream. Moist air masses from the Mediterranean bring most of the rain that falls on the western part of Al-Qilt catchment, where Ramallah and Jerusalem central mountains with an annual rainfall of 500 to 700 mm/year (Abed Rabbo et al, 1999). These annual rainfall values decrease as moving to the east (Jericho) to 150-200 mm/year (Ali et al, 1999). The average rainfall over the catchment being about 400 mm/year (PWA, 2009).

According to (Abed Rabbo et al, 1999), The maximum rainfall occurs in the west with an annual rainfall of 700 mm/year and the minimum rainfall occurs in the east (Jordan valley) with an annual rainfall of 150 mm/year. The amount of rainfall decreases as moving toward the Dead Sea with an average annual rainfall of 90 mm/year (Ali et al, 1999). The average annual rainfall in the main recharge area in the western part (Ramallah-Jerusalem mountain) that belong to upper Bethlehem with an area of 80 km^2 is 500 mm (Abed Rabbo et al, 1999).

2.6 Evaporation

Al-Qilt catchment in summer season affected by high temperature, so the relative humidity is low (PWA, 2009). The maximum evaporation occurs in July with a value of 298 mm (Samhan, 2013). In the winter season the evaporation decreases to 59 mm (PWA, 2011).

2.7 Relative humidity

The relative humidity (RH%) represents the atmospheric moisture content. It depends on three factors: temperature, elevation and distance from the coast (ARIJ, 1996). In the West Bank, temperature increases from west to east and RH % varies from north to south. The mean annual relative humidity is between 50 % in the eastern part of Al-Qilt catchment and 70 % in the western part (Samhan, 2013), the highest rate occurs in winter with value 75% due to lower temperatures (ARIJ, 1996).

2.8 Geology

2.8.1 Cretaceous Formation

There are two forms in the Al-Qilt catchment, Upper Cretaceous Formation and the Quaternary formation.

1. Upper Cretaceous Formation, The Upper Cretaceous Formation divided into three main type:

a. Cenomanian Age Formation, which consist of two formations, the first is Hebron formation and the second is Bethlehem formation. According to (khayat, 2006) Hebron formation is the most important groundwater system in the West Bank. The top part of this structure consists from dolomitic limestone, brittle karstified, gray dolomite and gray limestone, while the bottom of this structure consists from hard dolomite and dolomitic limestone with silicification (Samhan, 2013). The lithology is uniform as a result of attendance dolomite and dolomite limestone (Abu Helo, 2008). the porosity of this formation is not important as the rocks well joined and karstified.

b. Turonian – Jerusalem Formation, this formation is separated into three parts, Derorim formation, Shivta and Nezer formations. Derorim formation extended in the western part and the north western of the Al-Qilt catchment. The Derorim formation upper part consist of chalk rocks while the base part of the study area consist of karastified rocks and dolomite mixed with clay and marls (Daghrah, 2005).

c. Senonian age rocks (Abu Dis Formation), where Abu Dis formation consist primarily from chalks, marls and dark chalks that result from the presence of bituminous material (Saleh, 2009). The chalk rocks created fracture formation that making fracture flow for groundwater, the appearance of fracture does not prevent the aquifer to be aquiclude as a result of presence clay nature (khayat, 2005). The depth of the groundwater varies between 0 and 450 m and the thickness of this formation is ranging between 40 m to 150 m (Abu Helo, 2008).

2. The Quaternary formation, this formation consists from two types: Alluvial deposits and Lisan formation.

a. Alluvial deposits (Holocene or sub-recent Alluvial aquifer).

These sediments spread the region alongside the Jordan valley by 1 km in the north and 5 km in the south as pair parallel series (Abu Helo, 2008). Alluvial sediments are being adjacent the western side of Al-Qilt consists of unconsolidated lenticular bottoms of gravels, sands, clay and laminated marls, these are not defined either vertically or horizontally (Saleh, 2009). The thickness of these sediments is deeply variable and become relatively high beside the foothills in the west and little in the east (khayat, 2005). These deposits are interfingering with the lacustrine sediments of the lisan formation (CH2MHill, 1999). They are of the Pleistocene to recent in the age, bordered structurally by the Jordan rift regional fault in the east and another fault of 12 km length in the west (Abu Helo, 2008).

b. Lisan formation (Pleistocene Lisan Samara formation).

Lisan formation sediments are belong to Quaternary period and classified into three portions samara coarse clastic, samara silt, and Lisan. The Lisan formation covers a large portion of the Jordan Valley and Composed mainly of laminated marl, gypsum and clay with some sand bottoms and stones (Daghrah, 2005). The best exposures are found along the sides of the Jordan River flood plain (Abu Helo, 2008). The highest thickness of this formation is not well known and according to many previous studies, this formation is acting as an aquiclude and underlying the alluvial deposits (CH2Mhill, 1999).

The Geological map of Wadi Al- Qilt is illustrated in Figure 2.4. and Table 2.3 list the Generalized Geological columnar section indicating the aquifer characteristics of various formation in the study.

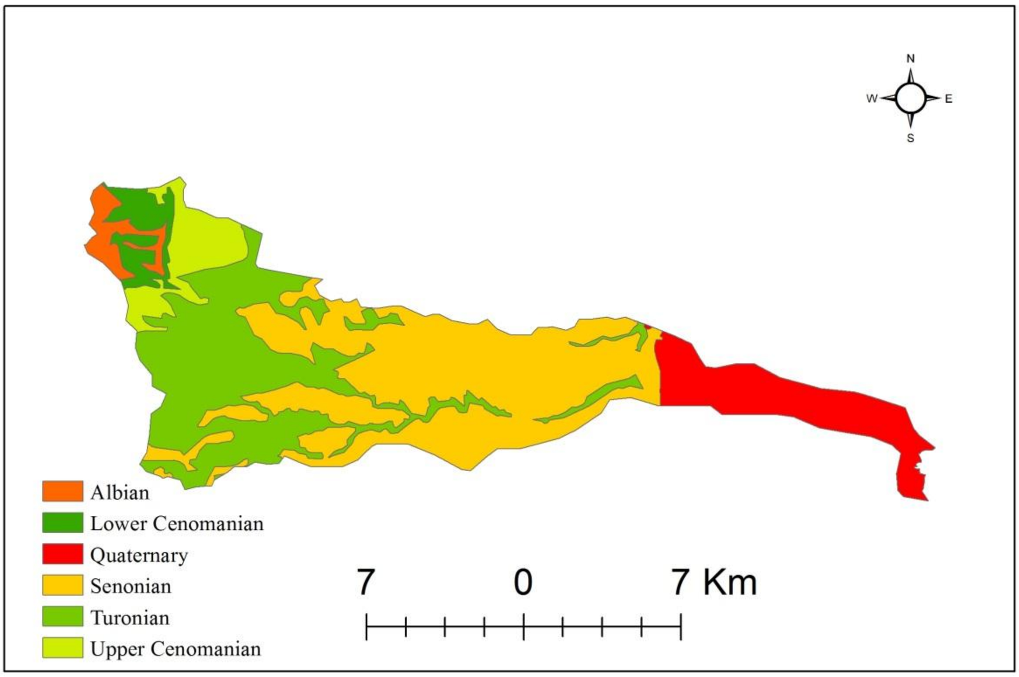

Figure 2.4: Geological map of Wadi Al-Qilt.

Table 2.3: Generalized Geological columnar section indicating the aquifer characteristics of various formation in the study (EQA, 2004).

Period	Age	Group	Formation name		Thickness (m)	Simplified lithology	Classification
Quaternary	Pliocene-Pliestocene	Dead Sea	Palestinian	Israel	200-300	Conglomeates	Aquifer/ Aquiclude
			Lisan	Lisan		Sandstone	
			Samra	Samra		and clay	
Upper Cretaceous	Senonian-Paleocene	Mt. Scopus	Abu Dis	Taqiye	100- 300	Chalk	Aquiclude
				Ghareb			
				Mishash			
				Menuha			
	Turonian	Judea	Jerusalem	Nezer	200- 300	Limestone	Aquifer
				Shivta		Limestone	
				Derorim		Marls	
				Weradim		Dolomite	
	Cenomanian	Upper	Bethlehem	KefarShaul		Limestone	
		Lower	Hebron	Amendav		Dolomite	
Lower Cretaceous	Aquifer		Yatta	Moza/Ein Yorqe'am, Beit Meir		Marl	Aquiqlude
			Upper Bietkahil	Kisalon	200- 270	Dolomite	Aquifer
				Soreq		Dolomite and marl	
			Lower Bietkahil	Givat Ye'arim		Dolomite	
				Kefira		Marly limestone	
			Qatana	Qatana		Marl	Aquiqlude- Aquitard
			EinQinya	EinQinya		Marly limestone	
			Tamun	Tamun		Marl	

2.9 Soil

The soil in the Al-Qilt catchment is composed mainly of five types. These types of soil are arranged from upper to lower, Terra Rossa, Mediterranean Brown Forest, Coarse Desert Alluvium, Brown Alluvium, Desert Alluvium (PWA, 2014). Figure 2.5 Shows the types of soil in the Al-Qilt catchment. While Table 2.4 lists Major Soil Types and Characteristics in Al-Qilt catchment.

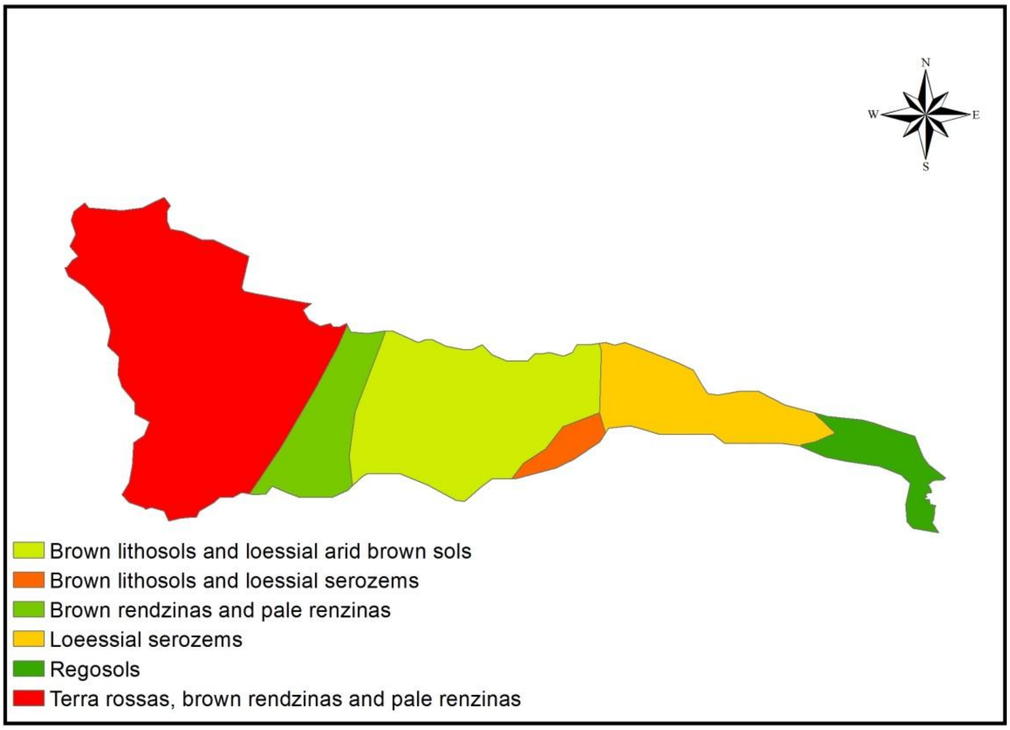

Figure 2.5: Major Soil Types and Characteristics in Al-Qilt catchment.

According to (ARIJ, 1995) the Jericho area covered by alluvial arid brown by an area of 6,470 hectares. Alluvial arid brown consists mainly from plains and alluvial fans, which result of erosion of clayey materials and calcareous silty.

Table 2.4: Major Soil Types and Characteristics in Al-Qilt catchment (PWA,2011).

Soil type	**General characteristics**	**Texture**	**Area (%)**
Brown lithosols and loessial arid brown sols	The parent rocks of this soil association are chalk, marl, limestone and conglomerates	Loamy	5.3
Loeessialserozems	Parent rocks are conglomerate and chalk	Sandy loam	12
Brown lithosols and loessial serozems	This soil is originally formed from limestone chalk, dolomite and flint.	Sandy loam	2.3
Regosols	The soil parent materials are sand, clay and loess.	Clay loam	26.4
Brown rendzinas and pale renzinas	It’s from out crop of lime stone or calcareous cust.	Clay loam	9
Terra rossas, brown rendzinas and pale renzinas	The parent materials for this type of soil are originated from mainly dolomite and hard limestone. Soil depth varies from shallow to deep (0.5 to 2 m)	Clay	45
Total			100

2.10 Land use classes

The term land use refers to man’s activities on land which are directly related to land. It depends on many factors including type of soil deposits, distribution of residential and vegetation cover. Figure 2.6 shows the spatial distribution of land Use (LU) for Al-Qilt catchment.

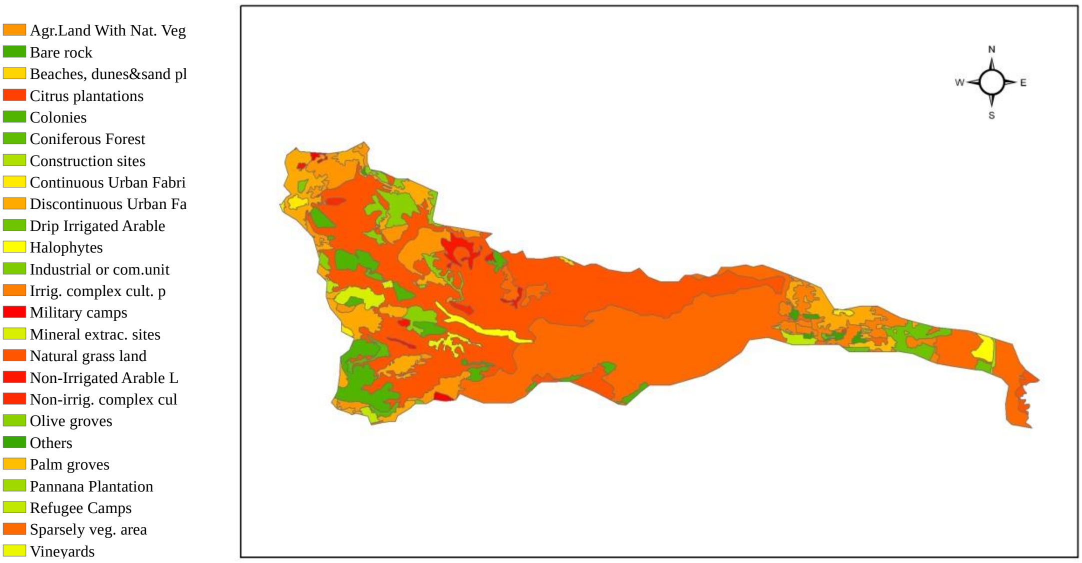

Figure 2.6: Land use map of Al-Qilt catchment.

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2.11 Digital elevation model for Al-Qilt catchment (DEM)

A digital elevation model (DEM) for the Al-Qilt catchment was created by using the GIS (v.10.2) model by clip process using the polygon of the catchment. Figure 2.7 shows the digital elevation model of Al-Qilt catchment. The source for the polygon of Al-Qilt catchment is Palestinian water authority (PWA, 2014).

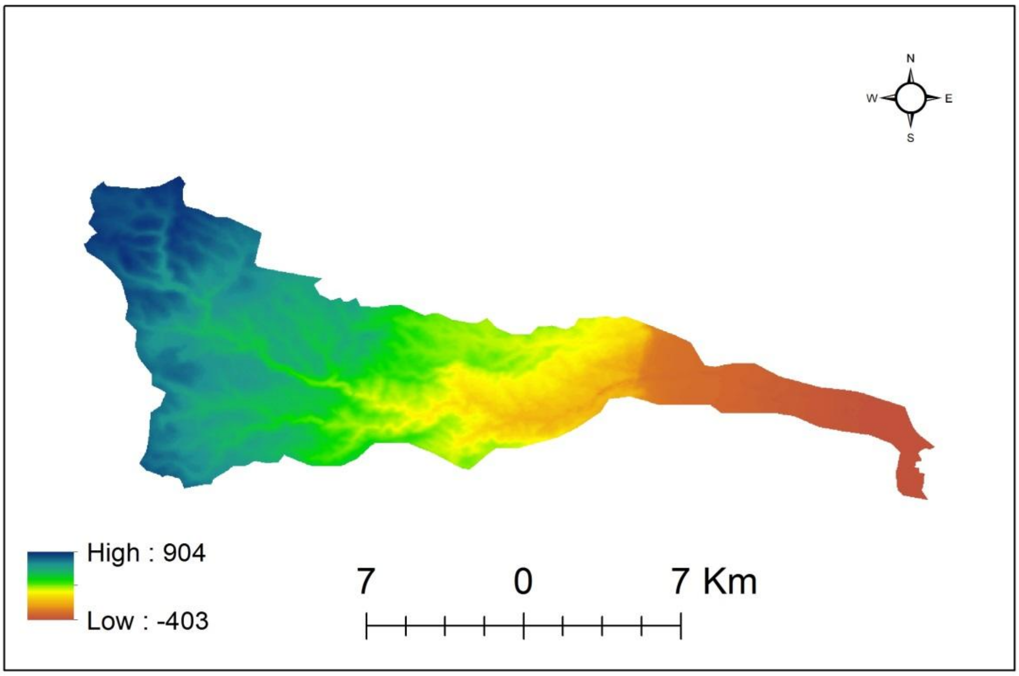

Figure 2.7: The Digital elevation model of Al-Qilt catchment.

2.12 Hydrogeology

2.12.1 Discharge Variation And Springs

The area of the catchment is estimated to be 174 km^2, the main recharge for Al-Qilt catchment is located in the west (Jerusalem and Ramallah mountains) with area of 80 km^2 and average annual rainfall 500 mm to 540 mm (Marie, 2001; Daghrah, 2005). The presence of Nari rocks in Al-Qilt catchment effect on the effective recharge and the potentiality for recharge, recharge area reduce to be about 42.5 $km^2$and the potentiality for recharge of the aquifer equal 21.5 x10^6 m^3 (Rofe and Raffety, 1963).

The Al-Qilt catchment spring emerge from the western central mountain which considers as the main recharge for the area, where the precipitation on this recharge area is about 540 mm (Marie, 2001; Abu Helo, 2008**),** this aquifer feeds from two aquifer, the upper aquifer and the lower aquifer. The upper aquifer belongs to Albian to Turonian age, where the type of rocks are dolomite and limestone dolomite (khayat, 2006). The lower aquifer falls within the upper and lower Cenomanian. Figure 2.8 illustrates the hydrological system of the study area.

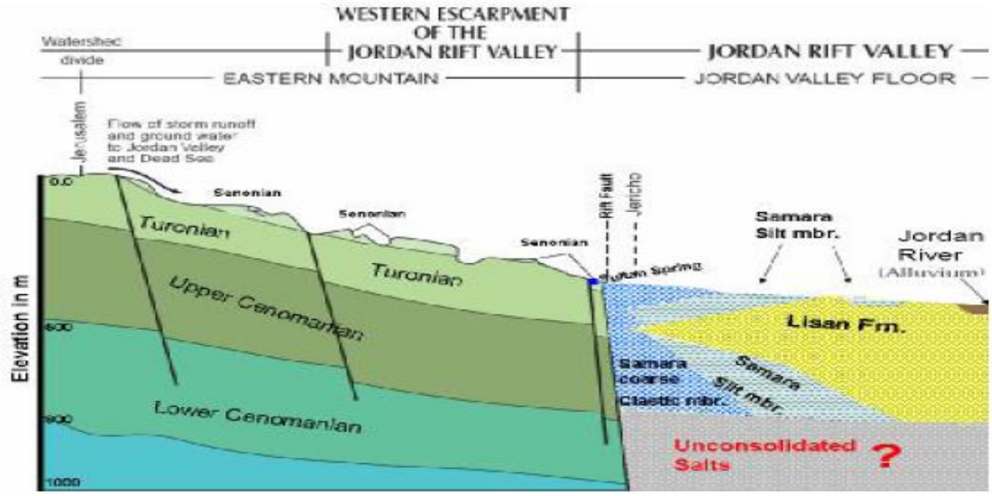

Figure 2.8: Schematic hydrogeological system in the AL-Qilt catchment. (Abu Helo, 2008).

The main source for springs discharge (Ein Fara, Ein Al Qilt, Ein Al Fawwar) in Al-Qilt catchment is considered as massive reservoir under pressure that pumps with annual discharge 9 x $10^6\ m^3$(Abu Helo, 2008). The average velocity flows from spring to other varies, for Ein Fara its equal 15 L/sec while for both of Al-Qilt and Fawwar spring together the discharge rate is 100 L/sec (khayat, 2006). The variation in discharge in springs through the year is little. The amount of discharge for the springs from year to another depending on the amount of rainfall. The highest spring discharge occur in heavy rainfall seasons is Ein Al Fawwar (Blake and Goldschmidt, 1948).

The channel of Al-Qilt is filled from the reservoir that filled from of Ein Al Fawwar. The over flow discharges of Al-Qilt is fluxing toward the channel of wadi Al-Qilt and then combines with the water flux which its source from Wadi Sweanit and Wadi Fara (Abu Helo, 2008) . The discharge of the spring is pulses, each pulse consume 20 minute to perfume one cycles. The main reason for this pulses is the karasric fracture nature in the aquifer (spring) area. A v- shape cavern is filled before siphonic discharge expels the water in these regular pulses (Abed Rabbo, 1999). The largest flood occurred in 1991/1992 when water levels reached record heights on adjacent lands (Abed Rabbo, 1999).

The main aquifer that ground water for Al-Qilt catchment is belong to (cenomanian – Turonian age) . The Cenomanian –Turonian age is divided into two group ,The upper Cretaceous carbonate aquifer and Dead Sea group (The Jordan Valley deposits).

1. The upper Cretaceous carbonate aquifer : The main rocks consist of karastified rocks ,the thickness of this formation varies from west of Jericho to be 170 m and it is increasing toward the upper part of Jerusalem at thickness 200 m (Samhan, 2013). This formation is divided into lower confined sub aquifer and the upper confined sub aquifer. The lower confined sub aquifer consists of Lower BeitKahil Formation , while the upper sub confined aquifer consists of Hebron, Bethlehem and Jerusalem formation (Daghrah, 2005).

2. The Jordan Valley deposits [Dead Sea Group]: Two Dead Sea group aquifers are located in the Jericho area. These are:

a. The Holocene (sub-recent Alluvial aquifer) which cover Jordan valley and the surrounding areas. The major wadis consist of terrigenous deposits, that formed through accumulation of alluvial fans after large floods , and it consists from all lithologies deposited that move in alternating channel according to their transport energy, so the permeable zone covered by impermeable lithologies that formed. The thickness of this formation varies from the high thickness in the rift margins and thin thickness in the center of fault basin. The Pleistocene gravel aquifer usually perform bottom bed for the alluvial aquifer, so there is hydraulically interconnected for this aquifers (EQA, 2004). The water move from Ramallah to Jericho city with high decline in the anticlinal axis. The distance between the discharge area and between recharge area is long , so the axis decline is large (Abed Rabbo, 1999). The Anticlinal axis is about +450 from Ramallah and declines eastward toward Jericho city to level – 300 and – 350 in the upper and lower aquifer .The discharge wells also responses to the change in replenishment (khayat, 2005).

As water transfers from western part (Ramallah) toward the eastern and south part of Al-Qilt catchment makes a variation in the piesometric level that ranging from 300 to -337 , so Water levels in the area decreases as move toward the east. There is decline for water level occur in the aquifer as a result of high ground water abstract rate (Saleh,2009), which change the hydraulic properties of the aquifer (khayat,2005). Figure 2.9 illustrated the Ground water level of the Plio-Pleistocene Aquifer (Abu Helo, 2008)).

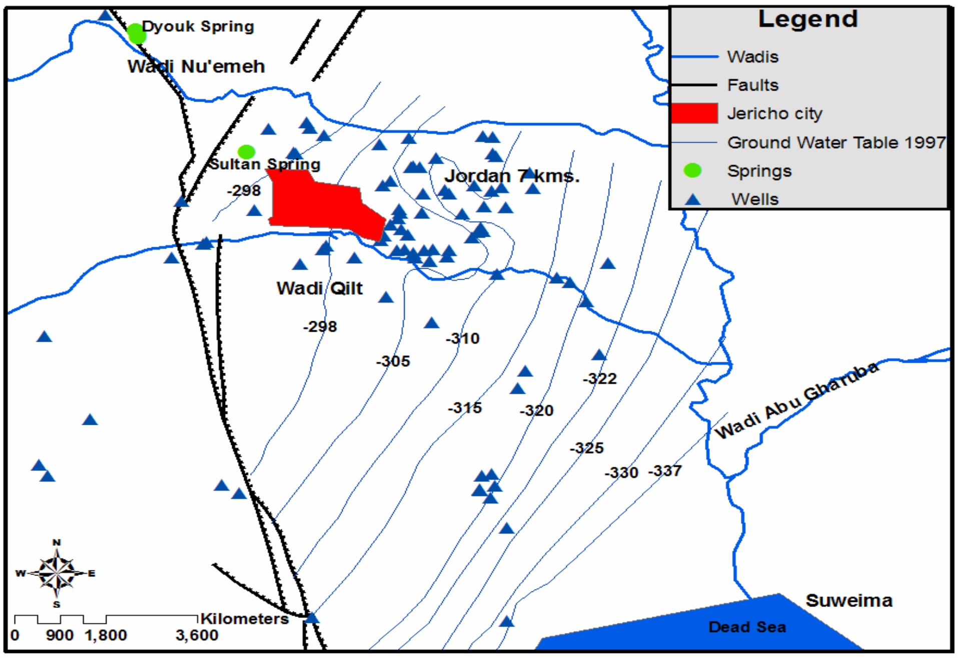

Figure 2.9: Groundwater level of the Plio-Pleistocene Aquifer (khayat, 2005).

2.13 Groundwater and Wells

The number of groundwater wells in the Al-Qilt catchment is very high and it mostly at two locations. The first is located on the top of the mountains and along the foothills, which belong to Regional upper Cretaceous Aquifers (PWA, 2011). The discharge of the upper Cretaceous aquifer range between [100 and 300 m^3/h] which consider low to moderate discharge with saline water (Guttman, 2006). The wells located in this aquifer close to the Ramallah and Jerusalem mountain which perform as the recharge area, are facing large water level fluctuation problem which sometimes influence on the wells discharge (Ali, 1999). The other wells located in Jordan valley area that belong to Jordan valley deposits. These wells are shallower than the first group with an average depth around 100 meters. The discharge of this wells are lower than the other group and reaches tens of m^3/hr (ARIJ, 1995). The source for water that recharge Jordan valley aquifer results from water lateral flows from the surrounding mountainous aquifers, in winter season the water reach the Jordan valley aquifer by infiltration process, the amount of exceeded irrigation water back again to aquifer and mixed with saline water from deep aquifer. The water level dropped and these saline waters flowed towards the pumped wells raising the salinity of the water (Guttman, 2006).

2.14 Water quality

There are two sources of pollution in the study area:

1. Natural sources which include atmospheric deposition of pollutants after rainfall precipitation, and the pollutants that result from the interaction between water and the rocks that it infiltrates through (Abu Helo, 2008).

2.The other source is from industry such as wastewater sewage where, heavy metals, organic and inorganic pollutants that infiltrate to ground water (Daghrah, 2005). Results indicate that there were high concentrations of Lead and Cadmium compared to Palestinian guidelines; These high concentrations were at Fawwar and Ras Al-Qilt and were found in waters used for domestic purposes. The main problem with ground water in the study area is the increase of nitrate and salinity (Abu Helo, 2008). The Lisan formation is the main source salinity, since the Lisan formation has low permeability it acts as an aquiclude.

Hydro-chemical parameters of water remain constant within the study area. The Jordan valley is characterized by an increase in Mg due to changes in the aquifer rocks from lime stone to dolomite (Daghrah, 2005). There is also an increase in TDS and Cl concentrations. Hydrochemistry of water shows that the area is affected by high salinity in east. The high concentrations in the eastern part of the Jordan valley are due to:a. Anthropogenic effects of sewage flow b. The presence of karatic fracture increase the pollution and the lisan formation dissolution to produce salts (Abu Helo, 2008) c. Deep brine water.

The shallow Pleistocene aquifer is subjected to anthropogenic pollutants such as raw sewage and industrial activities as well as toxic chemical escapes from pipes. Infiltration from wastewater is an addition source of pollution. Al-Qilt catchment suffers from anthropogenic pollutants, this pollutant considers dangerous on the water supplies in the urban area. Anthropogenic pollutants infiltrate to ground water and increase the concentration of nitrate and chloride (salinity increase) that transfer to ground water and the water quality will net met the (WHO) standards. There are many sources of pollution in Al-Qilt catchment since it has a unique lithological structure (karstic) the salinity will increase. Both inorganic and organic pollutant exist in Al-Qilt springs. The source of organics is raw domestic wastewater while industrial activates contribute both organic and inorganic pollutants . In recent years pollution of the Al-Qilt catchment has increased as chloride and nitrate increase. The type of pollution depends on the type of the aquifer and the activities surrounding the well. The quality of water in the west of the catchment is better than the water quality in the east. Springs experienced fluctuations in the concentrations of pollutants (PWA, 2014). There are a variation in concentration of water pollutants which depend on many factors, such as total precipitation and total pumping rate and finally the human activity in the surrounding pumping area .It was found that the concentration of chloride in springs has been increasing over time. For example, figure 2.10 shows time series from Dyouk spring and Sultan spring. Dyouk spring is located in an area where Bedouins live with their animals and agricultural activities. Sultan spring is located between populated areas, tourism destinations, and agricultural activities.

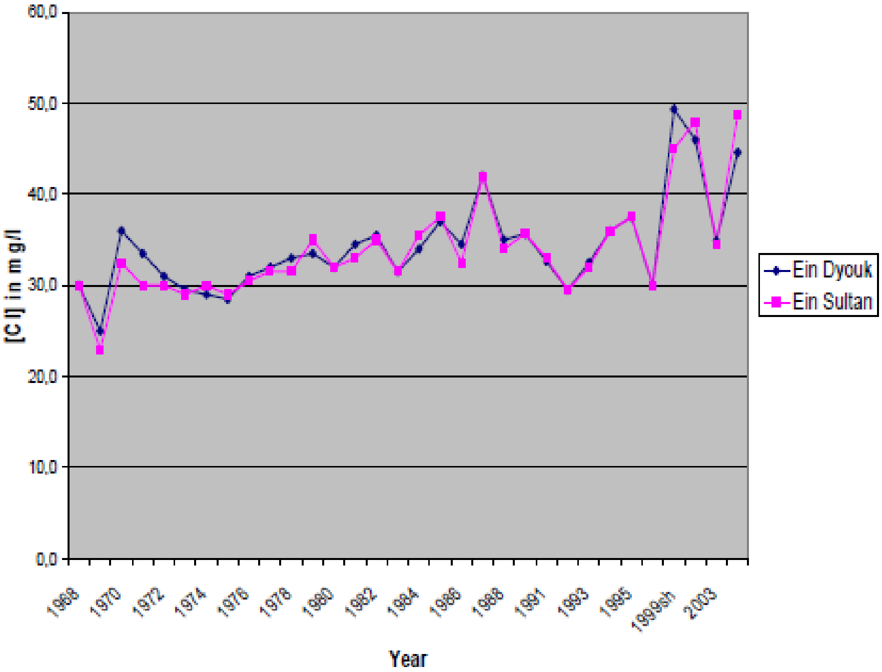

Figure 2.10: Chloride concentration for the Dyouk and Sultan springs during the period 1968 to 2004 (Abu Helo, 2008; khayat, 2005).

Chapter Three: Water Balance

3. Soil Moisture Demand (SMD)

3.1 Introduction

The potential recharge is defined to be equal the amount of water that infiltrate from the top soil zone to the groundwater (Saleh, 2009). Any methodology selected for the evaluation of potential recharge must be appropriate for a wide variation of climatic and hydrological conditions (Junaidi, 2008). The major physical processes must be described sufficiently and useless complexities should be replaced with parameter values established on readily available field data (Rushton, 2005). The estimation of the net groundwater recharge is a big challenge for the hydrologist because there is no special technique to obtain out the net recharge (Rushton, 1979). There are many methods for quantification of groundwater recharge from rainfall (Ghanem, 2002). Each method has its shortcomings in terms of applicability, precision and complexity (Baalousha, 2005). Although many empirical formulas were developed to find out the net groundwater recharge, none of them have proved to be efficient and accurate (Baalousha, 2005).

The soil moisture demand (SMD) is a method used to estimate the recharge (Saleh, 2009). According to (Rushton, 2006) when the soil moisture content reaches a limited and constant value of water capacity which called field capacity, the soil become to have the ability to free drainage. To determine when the soil reaches this critical condition, it is necessary to simulate soil moisture conditions throughout the year (Dyer, 2009), this involves the representation of the relevant properties of the soil and the capacity of crops to collect moisture from the soil and transpire water to the atmosphere (Saleh, 2009).

If no crops are growing or there is only partial crop cover, bare soil evaporation must be considered. Bare soil evaporation is important both in semi-arid locations to represent soil moisture conditions at the end of the dry season and in temperate climates where recharge occurs in winter when evaporation is usually the major loss from the soil (Rushton, 2006). Transpiration and evaporation often occur at less than their potential rate due to crop stress arising from limited soil moisture availability (Rushton, 2006). Crop stress (Deficit) is included using the concepts of total available water and readily available water and thus reduced evaporation depends on this concept. The input to the soil moisture balance is infiltration which equals the daily precipitation less than any interception or runoff. Runoff can be represented as a function of daily rainfall intensity and the current soil moisture deficit. Recharge estimation of Al-Qilt catchment is important in order to have good insights of the water budget and to make a balance between the total pumping and the aquifer recharge. There are many methods that are used to estimate groundwater balance in the Al-Qilt area including soil moisture demand (SMD). The Soil Moisture Demand (SMD) is the best method that used to estimate the recharge in the arid and semi-arid area (Juaidi, 2008). Soil Moisture Demand used by calculating the remaining of all the other fluxes such as precipitation, runoff, evapotranspiration, and change in storage (Rushton, 2006). The components of the (SMD) are finite parameters, consist of potential evapotranspiration, soil available water content, and rainfall. Figure 3.1 illustrates the conceptual depiction of the components of the SMD method.

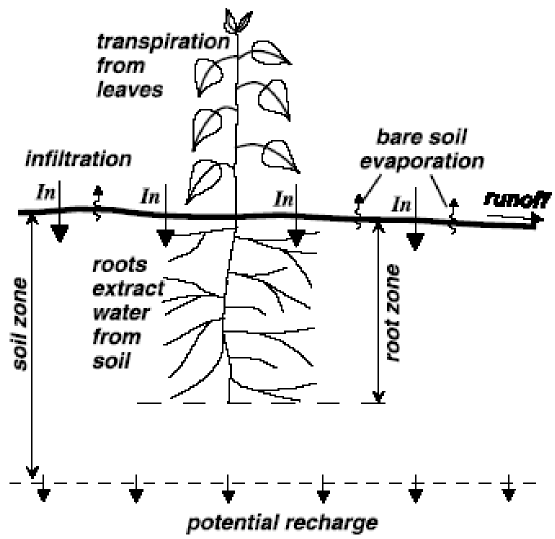

Figure 3.1: Conceptual depiction of the components of the SMD method. (Rushton et. al, 2005).

The important of using Soil Moisture Demand (SMD), its ability to estimate the recharge for the specific area by using the recharge model, through using simple and limited data such as rainfall, relative humidity, solar radiation and temperature, these data consider with high confidence. In addition, the (SMD) not expensive method where the properties of the soil does not need to measure under the root zone. The soil water balance model is used in the thesis (Dyer, 2009).

3.2 Methodology

To estimate the water balance model in (Dyer, 2009) the following parameters were prepared:

- Digital Elevation Model for the study area (DEM).
- The monthly precipitation for entire catchment.
- The monthly temperature for entire catchment.
- Soil moisture content.
- Solar radiation.

The output of running soil moisture water balance model is potential evapotranspiration for entire DEM, actual evapotranspiration (AET), soil moisture storage, runoff (surplus) and soil moisture deficit. All of this parameters are calculated for every grid cell in the digital elevation model of the study area. Figure 3.2 shows The flow chart of soil moisture demand.

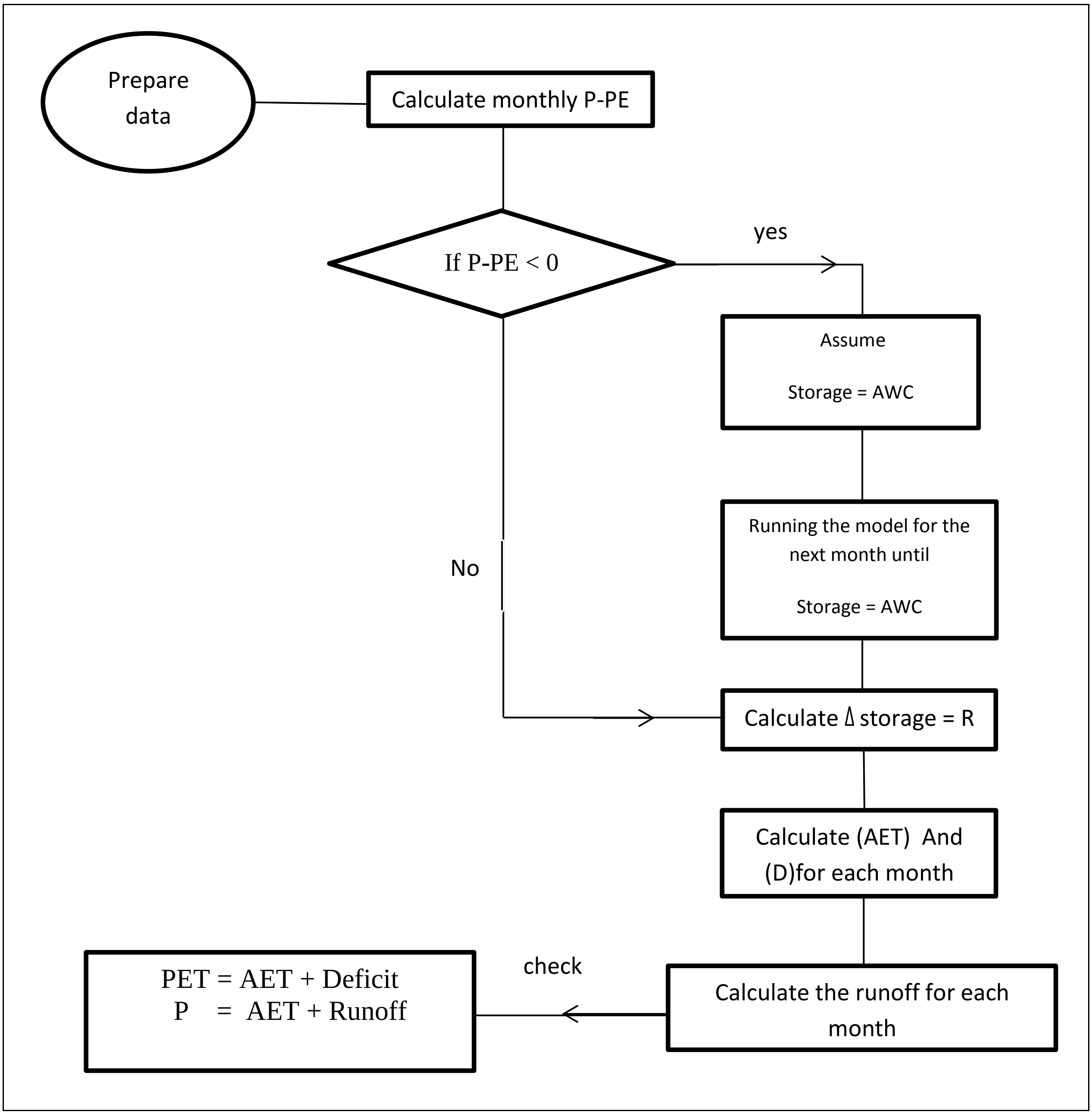

Figure 3.2: Flow chart recharge by soil moisture demand

3.2.1 The Monthly Rainfall (Precipitation (P))

The monthly rainfall grids for the catchment are created by first multiplying the DEM by zero to get the study area shape. The Thiessen polygon method is then used, taking into consideration three points Ramallah, Jerusalem and Jericho to produce Thiessen polygon (Appendix 1.3). The weight for each city in the catchment is determined, then multiplied the weight by monthly rainfall for each city. Twelve monthly rainfall grids are created. In addition, the annual rainfall grid is created for the entire catchment. The maximum monthly rainfall (150 mm) occurs in January while annual rainfall for the entire area is 414 mm. Table 3.1 Presents the Thiessen weight for each city in the Al-Qilt catchment.

Table 3.1: The Thiessen weight for each city in the Al-Qilt catchment.

City	**Weight (%)**
Jericho	44
Ramallah	12
Jerusalem	44
Total	100

3.2.2 The Monthly Temperature (T)

The monthly temperature grids are created using the Thiessen polygon, multiplying each weight by monthly temperature for each city (Appendix 1.2). Twelve monthly temperatures are created for entire catchment. The maximum temperature is in August with a value of 28 C°, while the minimum temperature 13 C° occurs in February. Relative humidity must also be taken into consideration. Twelve monthly relative humidity grids are created using the Thiessen polygon. The maximum relative humidity in the catchment is 60 % in January.

3.2.3 The Soil Moisture Content

Soil Available Water Capacity (AWC) grids are also prepared. The amount of water that can storage at any particular time is called soil moisture content (Juaidi, 2008). The amount of water that can be storage depends on many properties of soil like soil formation (texture) and amount of organic compound in the soil (Saleh, 2009). Small soil such as fine grains considers high field capacity than sandy soil (Saleh, 2009). The maximum amount of soil moisture is called field capacity, while the lowest value will reach close to zero. Six types of soil texture are found in the study area (PWA, 2014). The Terra Rossa, Brown Rendzinas and Pale Rendzina soil depth is generally shallow < 2m, Brown Lithosols and Loessial Arid Brown Soils mostly contain grazing plants and in Sand Regosols and Alluvial Soils the common grown are subtropical fruits and winter vegetables. The Available Water Content equals root depth in the area multiplied by water content. The highest water capacity in the study area, 100 mm, is found in clay (Saleh, 2009) and the lowest value is 12 mm, is found in sandy soil textures (Building Center, 2011). Figure 3.3 illustrates the Soil Available Water capacity for Al-Qilt catchment created by GIS.

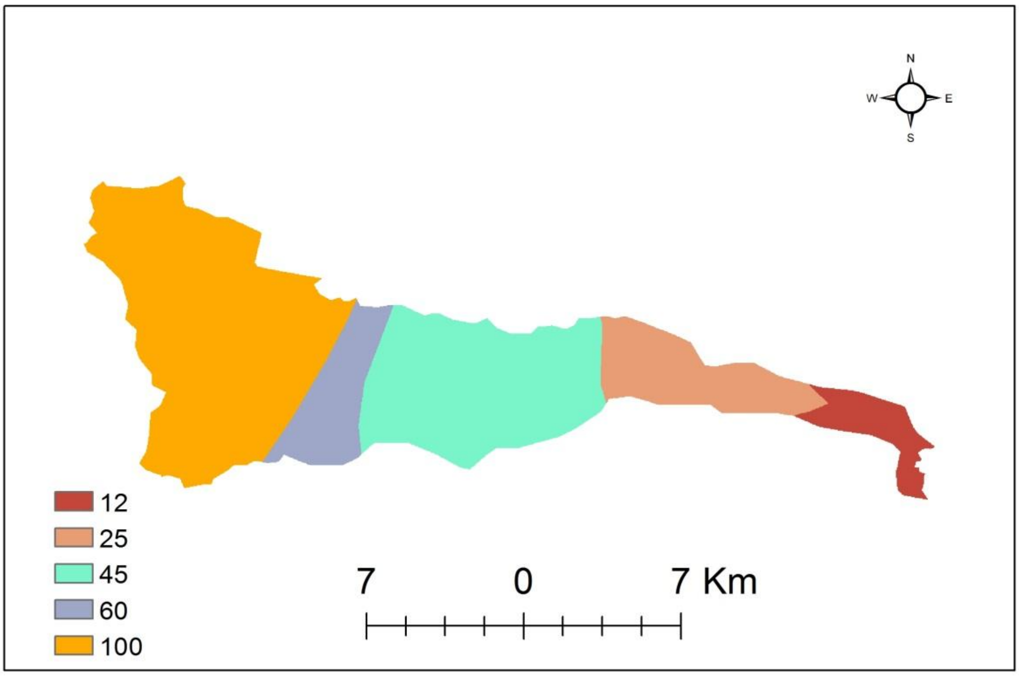

Figure 3.3: The Soil Available Water Capacity for Al-Qilt catchment .

3.2.4 Evapotranspiration

The climate of Al-Qilt catchment is classified as humid in the western parts, while it is arid in the eastern parts. The evapotranspiration is a combination of evaporation and transpiration (ASCE, 1990). High potential evapotranspiration (PET) rate occurs in the hot dry season and low potential evapotranspiration (PET) occurs in wet seasons (Juaidi, 2008). The actual evapotranspiration (AET) depend on the a viability of water (Dyer, 2009). The (PET) and (AET) are similar in the presence of sufficient amount of water moisture (ASCE, 1990). In this study, ArcGIS (v.10.2) is used to estimate the potential evapotranspiration as a function of temperature and global radiation and relative humidity in each month for a single point or for the entire DEM by using Turc equation, The use of Turc equation to find (PET) best than Penman-

Monteith which use more parameter (wind speed, humidity, radiation and temperature) (ASCE, 1990).

The potential evapotranspiration is measured by using Turc equation:

$$PET = 0.013 \times [T/(T+15)] \times (R+50) \times [1+((50-RH)/70)] \quad \ldots\ldots\ldots\ldots(1)$$

Where

RH: The average monthly relative humidity (%).

T: The temperature factor in (℃).

R: The Global Solar Radiation for the whole area in (cal/cm^2).

The estimation of (PET) in the united states by using the Turc method is considered the best method (Federer et al,1996). To calculate the recharge by (SMD) the potential evapotranspiration (PET) for every grid cell with the digital elevation model is computed by using monthly relative humidity, monthly temperature factor and the monthly radiation.

The Global Solar Radiation (R) determined by Diffusion (D) and transmitivity (T) (the proportion of solar radiation outside the atmosphere and that reaches the surface) for the catchment which calculated by taking a single point in a flat surface, since solar collectors are horizontal (NREL, 2008), Jericho city is taken as a single point in the catchment that used to calculate the global solar radiation.

By using the annual global radiation the best monthly of (D) and (T) are determined, solar radiation parameter run in the whole catchment by using the digital elevation model for the area to find the total monthly radiation (from January to December) (Dyer, 2009). To perform Turc equation method water balance method by (SMD) model is run, the three parameters (T, RH, R) for each month is introduced to TURC equation by GIS model builder (ASCE, 1990). Twelve monthly PET is created, all of the monthly PET are collected to produce the annual PET. The annual PET is shown in Figure 3.4.

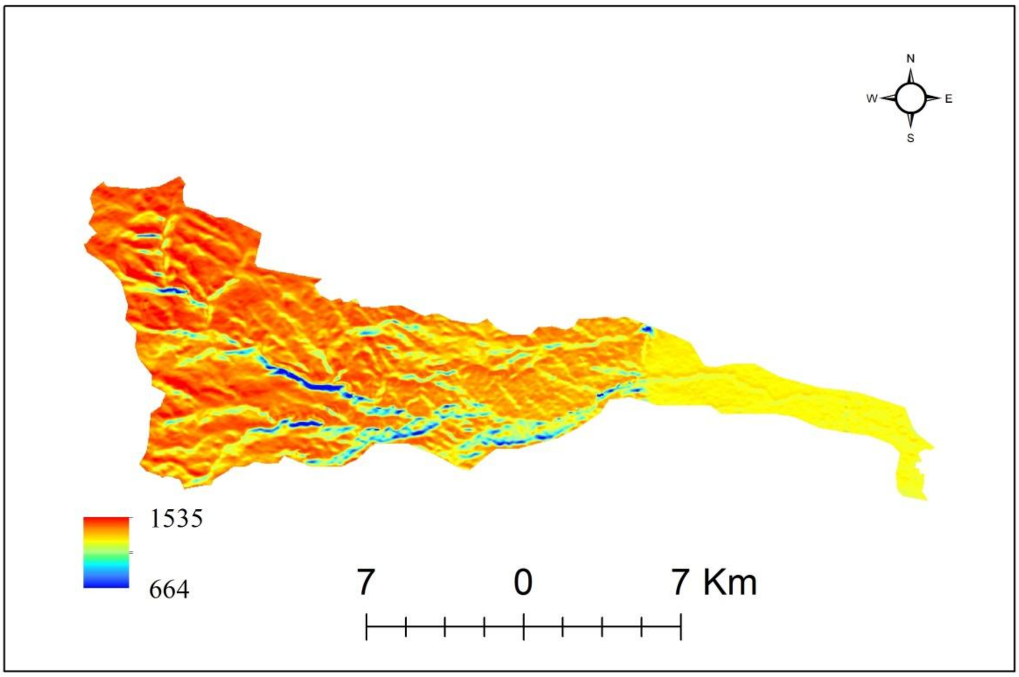

Figure 3.4: The annual potential evapotranspiration for the study area.

The value of the Actual Evapotranspiration (AET) must be determined, Actual Evapotranspiration (AET) depends on the rainfall and the initial soil moisture (Saleh, 2009). If the total of these two quantities is more than the PET then the AET will equal the PET (Juaidi, 2008). This is the case for the rainy months (Nov-march). Otherwise, the total of rainfall and initial soil storage will be the (AET), which is the case for the months (April to October). Based on above, the monthly (AET) is produced, integrating together to produce the annual (AET). Figure 3. 5 illustrates the amount of actual evapotranspiration in the area (mm).

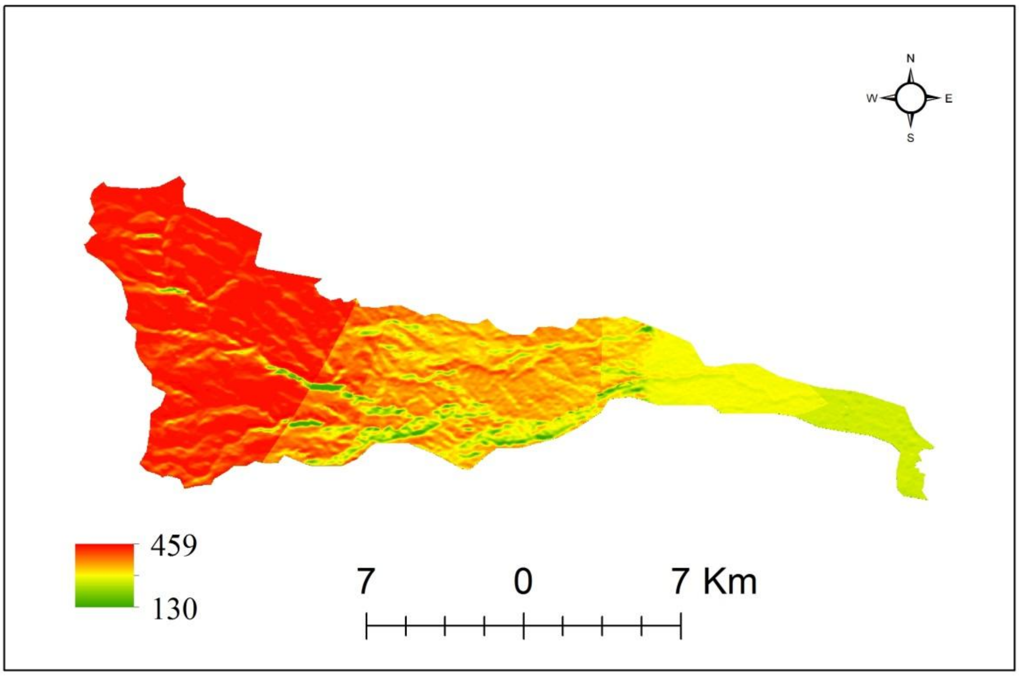

Figure 3.5: The amount of actual evapotranspiration in the area (mm).

3.2.5 Recharge (Delta Storage)

The total soil storage is calculated in the daily time step. The total monthly storage is equal to the last day storage for that month (Dyer, 2009). With time, the soil moisture decreases linearly as the soil in drainage state. According to (Mather, 1974), 50 % of soil moisture available when the field capacity reaches 50 %. By using water balance model, the presence of rainfall and soil moisture storage is the limited factors to estimate and to allow recharge of the aquifer to occur. The area with higher slope considers an important factor that effect on water balance estimation (SAS, 2004). The output of monthly recharge shows that the recharge occurs from November to march while from April to October the groundwater recharge is Zero. The groundwater recharge for raining months is illustrated in Figure 3.6 to Figure 3.10.

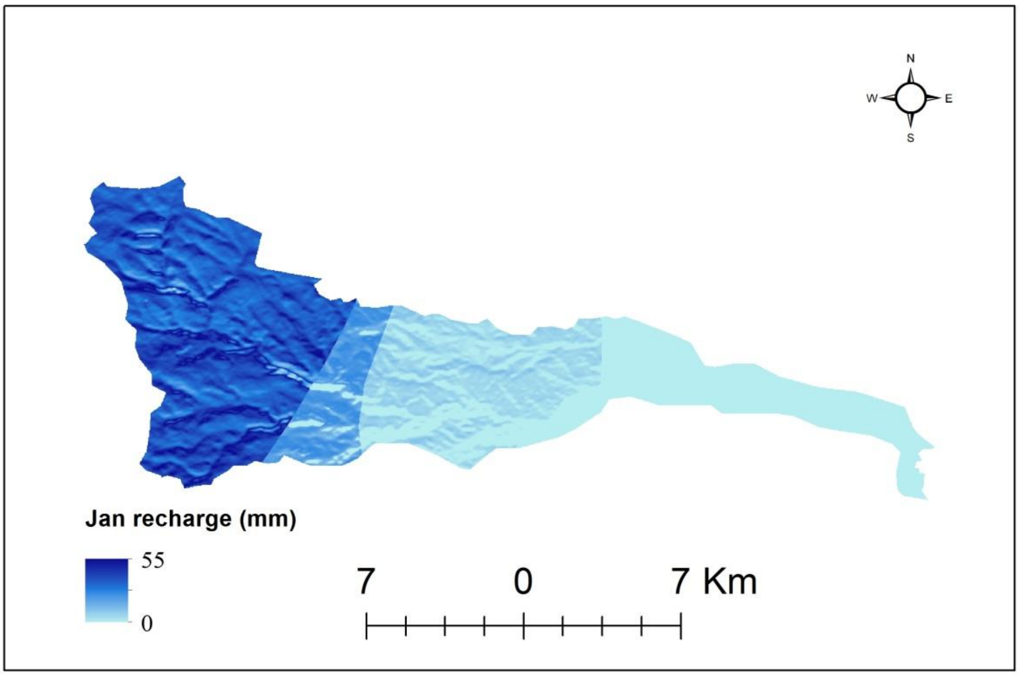

Figure 3.6: Depiction of the recharge for the month of January.

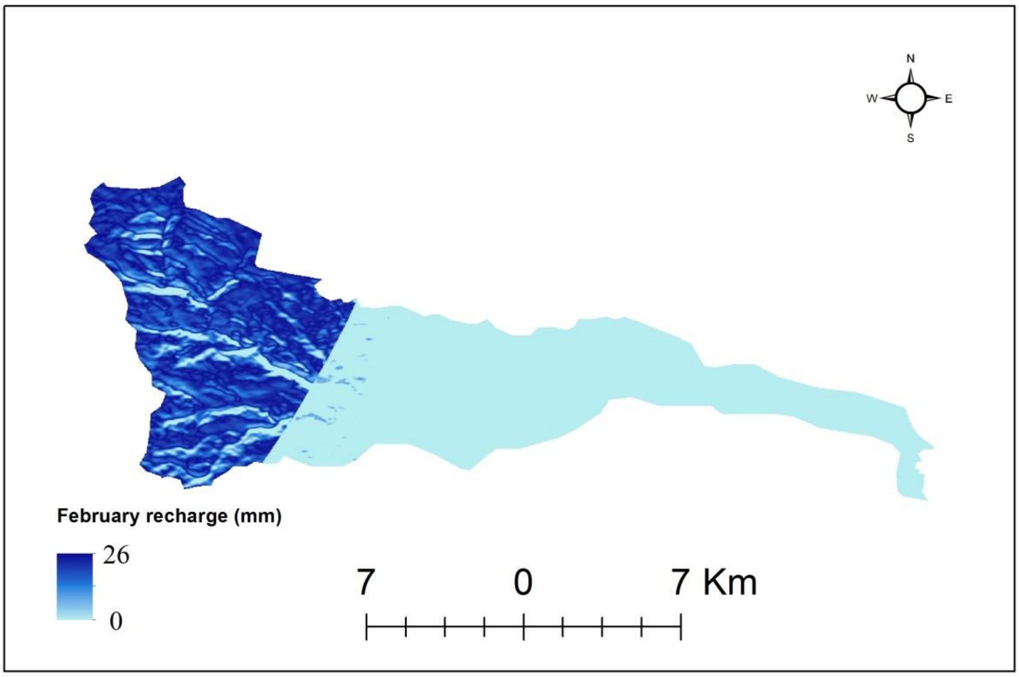

Figure 3.7: Depiction of the recharge for the month of February.

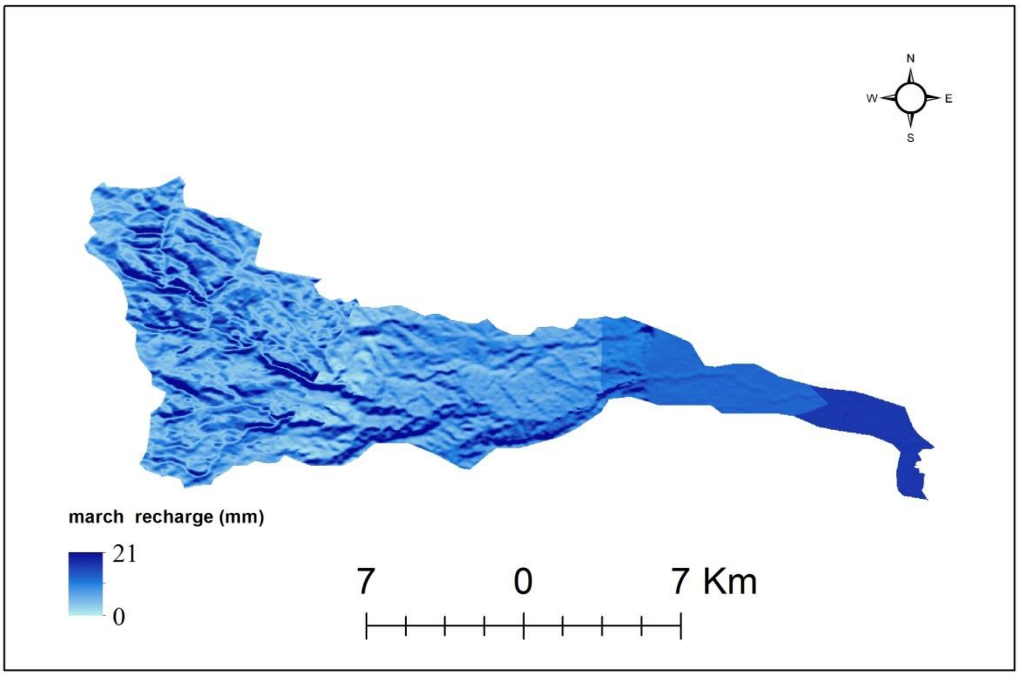

Figure 3.8: Depiction of the recharge for the month of march.

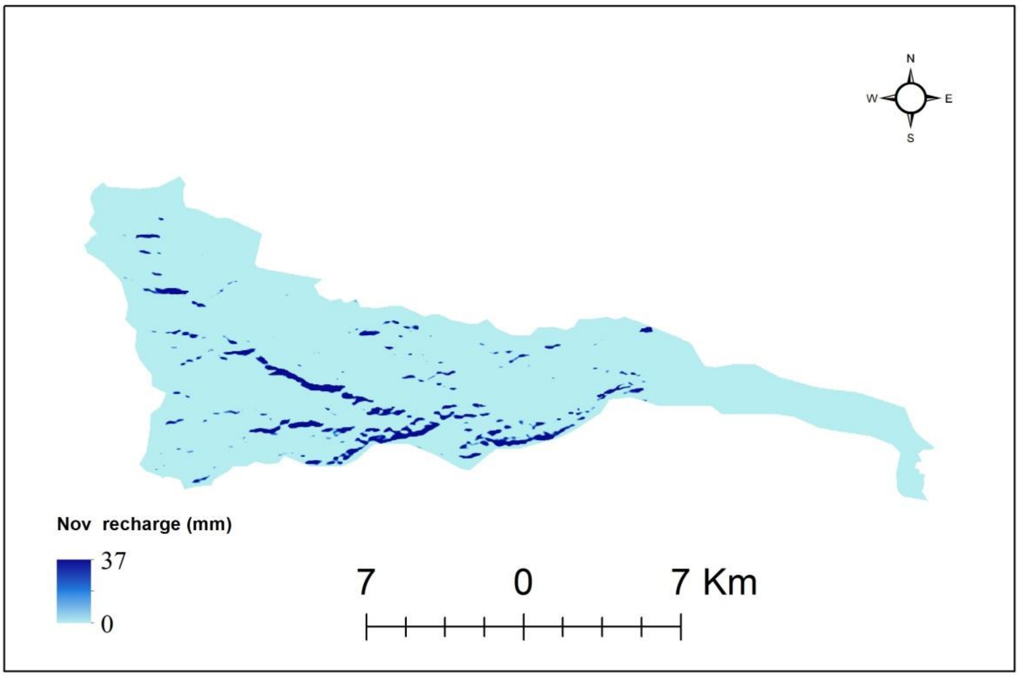

Figure 3.9: Depiction of the recharge for the month of November.

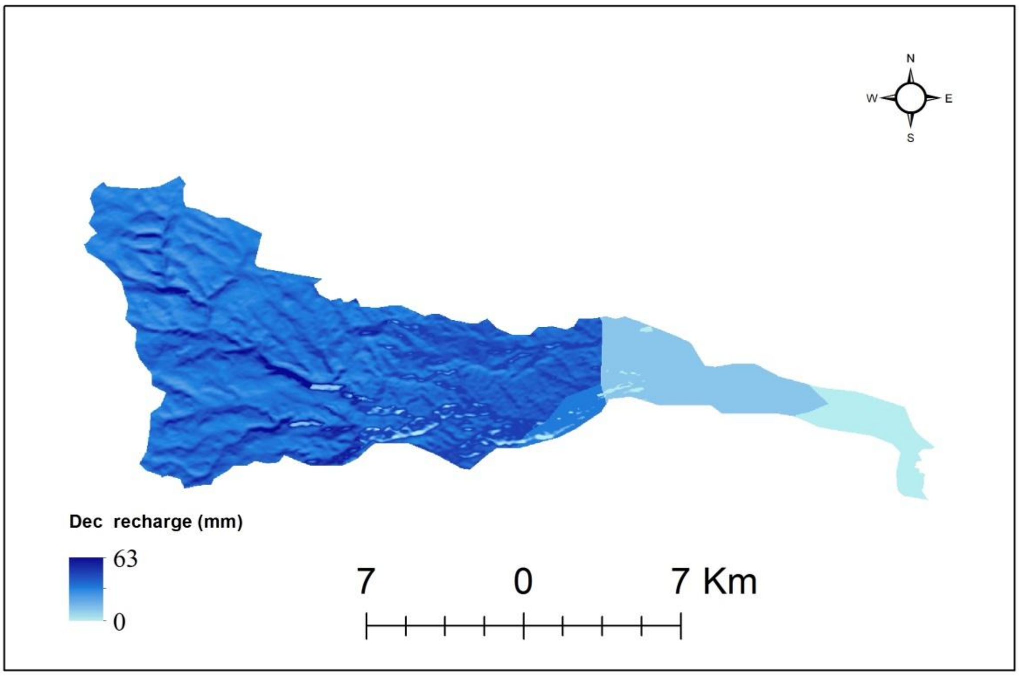

Figure 3.10: Depiction of the recharge for the month of December.

The amount of annual recharge in Al-Qilt catchment based in SMD model is calculated as list in Figure 3.11.

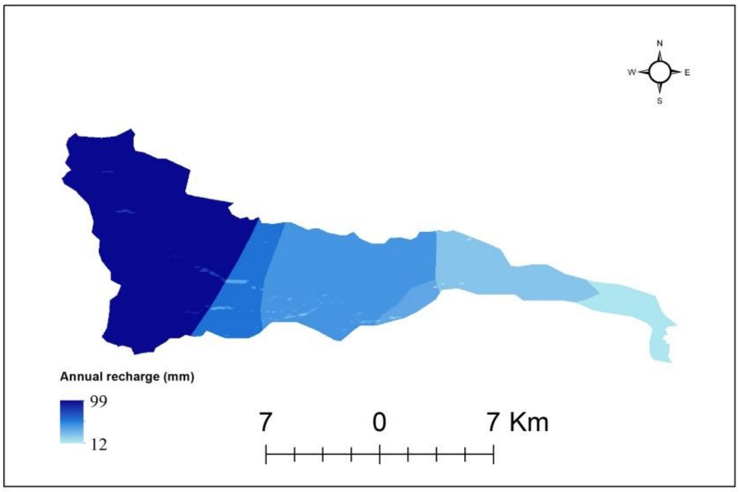

Figure 3.11: The amount of annual recharge in Al-Qilt catchment based on (SMD).

3.2.6 Rainfall Runoff

The runoff for the catchment area on monthly time is determined as a residual term of the catchment water balance equation by taking into consideration monthly actual evapotranspiration obtained in sector 3.2.4 and monthly rainfall (Rushton, 2006).
The runoff season occurs when rainfall exceeds potential evapotranspiration and the soil has reached its field capacity (Saleh, 2009). Any extra water applied to the soil runs off, if this water runs off into close streams and rivers it could produce flooding. In the soil moisture balance method, the following equation (Dyer, 2009) must take in consideration to calculate the monthly runoff.

$$\text{Rainfall} = \text{AET} + \text{runoff} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(2)}$$

By using the monthly rainfall that was established and the monthly (AET), the above equation is running in the GIS model, twelve monthly runoff is produced. There is no rainfall runoff from (April to October) and the runoff from (January to December) is shown in Figure 3.12. And the annual runoff for the Al-Qilt catchment is calculated and listed in Figure 3.13.

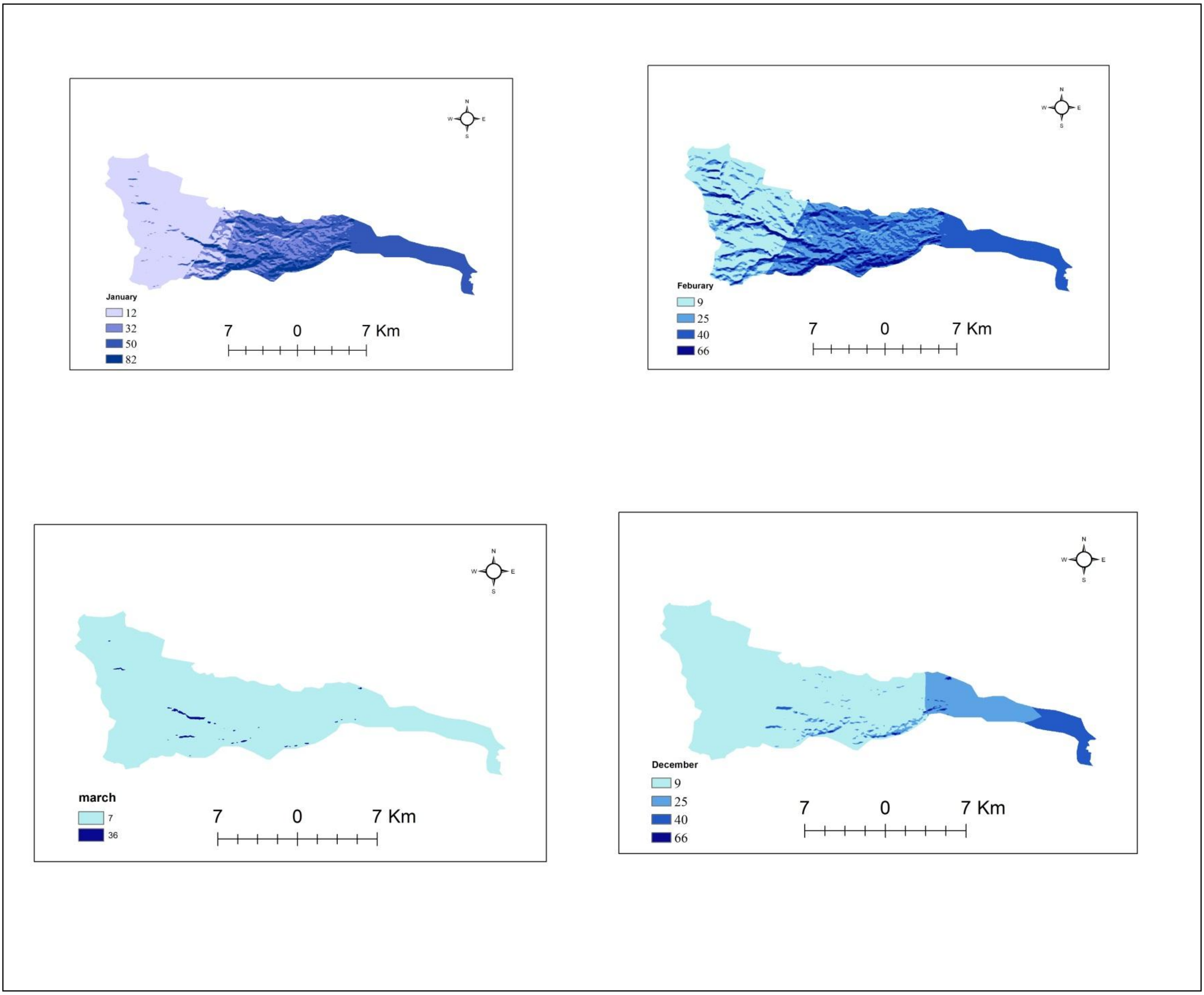

Figure 3.12: The monthly runoff (mm) in the Al-Qilt catchment.

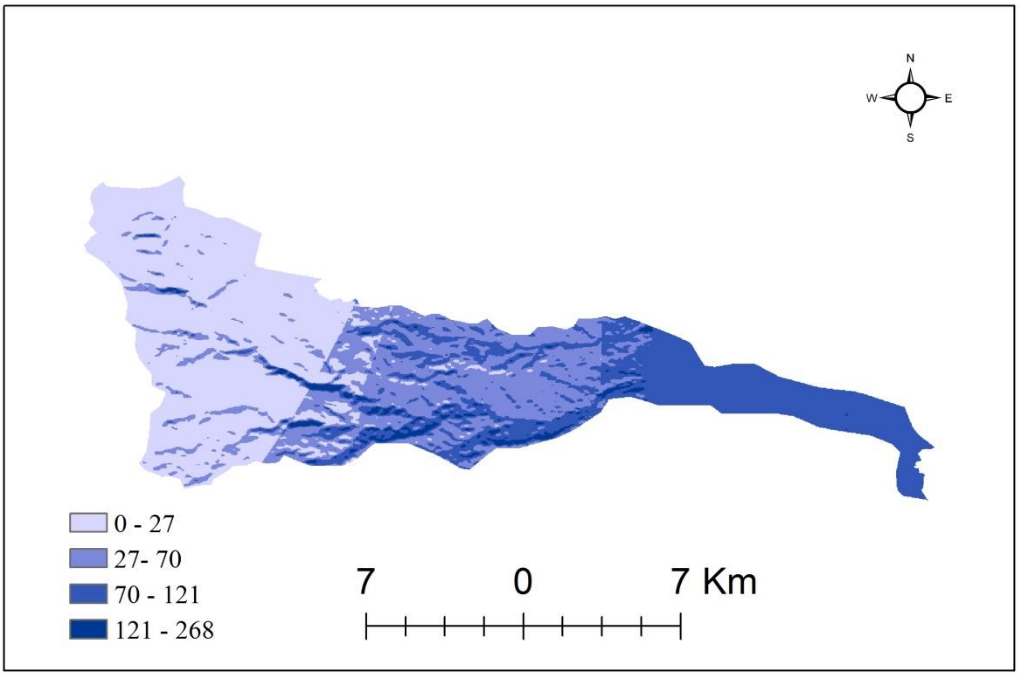

Figure 3.13: The annual runoff (mm) in the Al-Qilt catchment.

3.2.7 The Annual Deficit

Deficit refers to evaporative demand not met by available water, or it's defined as the difference between potential and actual evapotranspiration (Dyer, 2009). The deficit period happens when potential evapotranspiration exceeds rainfall and soil storage has reached the minimum value which zero mm. This is a season when there is basically no water for plants (Juaidi, 2008). Farmers then tap groundwater supplies or water in nearby rivers and ponds to irrigate their crops. Thus, the magnitude and duration (length of season) of the deficit can be used to predict the need for irrigation water (Rushton, 2006). Whether a place experiences all four seasons depends on the climate and soil properties. Wet climate and those places with soils having high field capacities are less likely to experience a deficit period. Furthermore, the duration and rainfall intensity of any season will be determined by the climate and soil properties.

Given equal amounts of rainfall, coarse textured soils will generate runoff faster than fine-textured soils and may experience more huge runoff (ASCE, 1990).

The monthly deficit is calculated by using the actual evapotranspiration and the potential evapotranspiration, that created in the above section according to the following equation(Dyer, 2009):

$$PET = AET + Deficit \quad \ldots\ldots\ldots\ldots\ldots \quad (3)$$

The monthly deficit is joining together, the annual deficit is created as list in Figure 3.14.

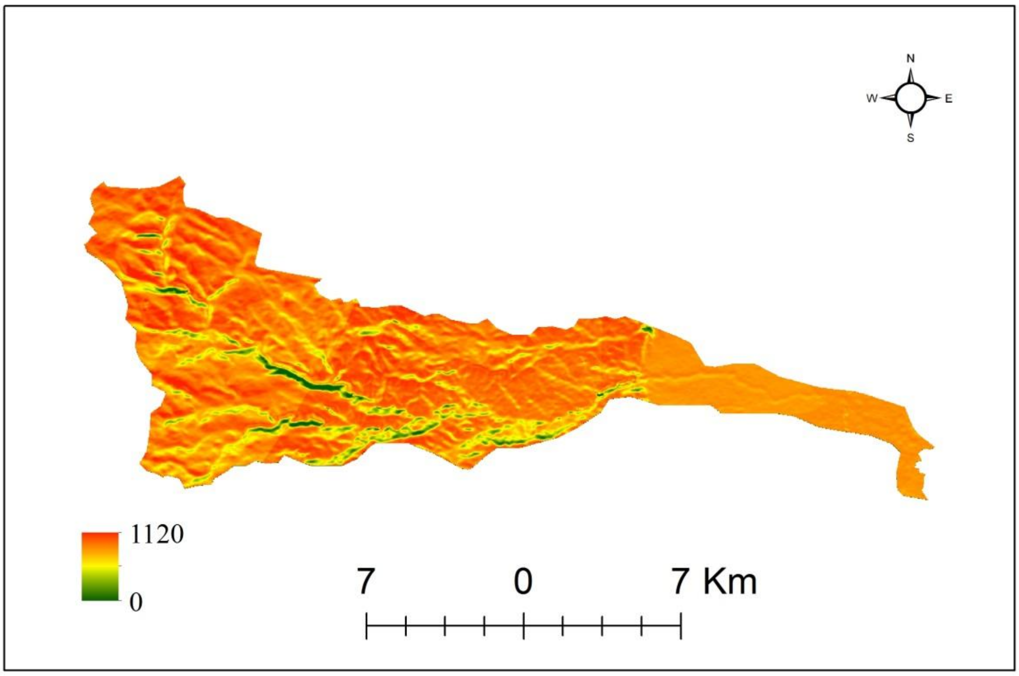

Figure 3.14: The annual deficit in the Al-Qilt catchment.

3.3 Recharge calculations based on analytical equations

3.3.1 Chloride mass concentration

According to (Ghanem, 2002) Groundwater recharge in arid and semiarid areas could be calculated from the ratio of chloride or bromide concentration in rainwater and ground water according to the equation:

$$R = \left(\frac{P - D_s}{CL_{gw}}\right) \times CL_P \qquad \ldots\ldots\ldots\ldots(4)$$

Where

R: The average annual recharge (mm/year).
P: The average annual precipitation (mm/year).
Ds: The average runoff in mm/year in the area of study.
CL_{gw}: The average annual chloride of groundwater (mg/L)
CL_P: The average annual chloride of rainwater (mg/L).

The annual average concentration of chloride in rainwater in the Jordan Rift valley is 10 mg/L (Schwartz, 1980; Meteorological Service, 1997). The average chloride concentration in the rainfall in the eastern mountain is 9.06 mg/L (Herut et al,1994). While the concentration of chloride in the Hizma precipitation is equal to 6.62 mg/l while in Ramallah rainfall is equal to 9.30 mg/l (Marei, 2001).

The average chloride concentration in Faraa and Al-Qilt springs by taking eight samples for each spring is 44 mg/l (Abu Helo, 2008). The runoff in the in the western area of the catchment is found to be ranging from 0 to 6 % of the rainfall, the value estimated in section 3.2.6. The average precipitation taken for the whole area by the Thiessen method is 414 mm/year. The rainfall in the upper part of the catchment 615 mm, so the annual recharge according to chloride mass concentration is found to be 118 mm/year. Appendix (1.1) lists the concentrations of chloride in Al-Qilt springs.

3.3.2 Guttman and Zukerman equations

The yearly average of potential evapotranspiration in the upper part of Al- Qilt catchment is 1536 mm and The average of actual evapotranspiration is calculated to be 459 mm per year for the. In the upper part of the study area, the monthly average maximum temperature in winter months is between 16 °C and 18°C and between 20 and 28°C in summer. In the catchment, the average maximum relative humidity in the upper part of the area was 76 % in winter and 44 % in summer. For the same period in the eastern parts, the annual maximum was about 58% and the yearly minimum 36% during hot days. The annual recharge for ground water in the Al-Qilt catchment can be estimated by using Guttman & Zukerman (1995) that created for Palestine.
:

$$R = 0.8 \times (P - 360) \qquad P > 650\,mm \qquad .5$$

$$R = 0.534 \times (P - 216) \qquad 300 < P < 650\,mm \qquad .6$$

$$R = 0.15 \times P \qquad < 300\,mm \qquad .7$$

Where

R: Estimation Recharge from precipitation (mm/year).
P: Average Annual precipitation for the whole area(mm/year).

By Applying the Thiessen Polygons method, Al-Qilt catchment was subdivided into three categories, Jerusalem, Jericho and Ramallah, the total annual rain is 414 mm/ year. Using the Thiessen method, the total annual recharge in the catchment is 126 mm/year. The recharge rate for the Al-Qilt catchment based on the Guttman and Zukerman list in Table 3.2.

Table 3.2: The recharge rate for the Al-Qilt catchment based on the Guttman and Zukerman equations

Committees	Recharge/ city (mm)	Recharge for the catchment (mm)
Ramallah	213	26
Jerusalem	205	90
Jericho	24	10
Total		126 (mm)

3.3.3 Goldschmidt (1959) equation

The recharge for groundwater can be estimated by using Goldschmidt and Jacobs (1959) equation. Its depend on the relationship between precipitation and flow data.

The Goldschmidt & Jacobs (1959) equation

$$R = 0.86 (P - 360)$$

Where R is the water crop (runoff + recharge) and P is annual precipitation. For Mediterranean areas, the annual precipitation is between 300 and 650 mm. The water crop for the Upper Qilt catchment was calculated to be 118 mm/year from Goldschmidt.

3.3.4 Recharge estimation comparison

The total recharge that estimated by SMD is 99 mm/year, while the total annual recharge by the Guttman and Zukerman equation is 126 mm/year. The annual recharge estimation by Chloride mass concentration equal 118 mm/year while the annual recharge by Goldschmidt (1959) method is 118 mm/year. Table 3.3 list the annual recharge percentage comparison to (SMD).

Table 3.3: The annual recharge percentage according to (SMD).

Guttman Zukerman equation	126 mm/year
Chloride mass concentration	118 mm/year
Goldschmidt (1959)	118 mm/year
By (SMD)	99 mm/year in upper part

Chapter Four: Suitability of Artificial Recharge

4. Artificial Recharge

4.1 Introduction

Artificial groundwater recharge methods are engineering methods, where water is introduced to the groundwater to augment groundwater resources (Saleh, 2009). The goals of artificial recharge are to decrease land subsidence, reserve water, enhance the quality of the water by soil-aquifer treatment or geo-purification and to utilize the aquifer as water transportation systems (Bouwer, 2002). In general, there are two techniques of artificial recharge, Direct (surface recharge) and Indirect methods. The Combination of two methods in the same project is also possible (Saleh, 2009).

The direct method includes surface recharge and injection wells. In the surface recharge, water flows from the ground surface to the aquifer by means of infiltration process through the soil zone (El-Arabi, 2012). The ground surface is normally excavated and water is added to spreading basins, ditches, pits, and shafts and thus is allowed to infiltrate. Surface infiltration consists of In-channel and off-channel facilities (Bouwer, 2002). The advantage of the use surface recharge is considered Low construction and maintenance cost but it facing Clogging of the surface material by suspended sediment. This method is more appropriate for area abundant land availability, high permeability of the soil and shallow unconfined aquifer (Hamdan, 2012).

Injection methods are used as an option to surface spreading operations when a zone with low permeability within the unsaturated zone (Saleh, 2009). This method is suitable for an area where a thick impervious layer exists between the surface of the soil and the aquifer. The injection wells are relatively inexpensive but facing Clogging up at the infiltrating surface (Al Qaisi, 2008).

In the other part, Indirect methods involve introducing groundwater pumping tools near combined surface water bodies to increase groundwater levels and cause infiltration elsewhere in the drainage basin. Indirect methods include improving aquifers to improve groundwater resources (Al Saud, 2010). Within the framework of the artificial recharge study in the Al-Qilt catchment, the two sources that taken in consideration for artificial recharge treated wastewater and winter flood. As a result of huge flood in winter, water move toward the eastern part of Al-Qilt catchment, reach the Dead Sea and mixed with saline water, this water lost without sufficient use for agricultural or domestic use.

4.2 Methodology

4.2.1 Weighted Overlay Method for Artificial Recharge

The current research has been focused on the artificial recharge site selection process, weighted overlay method has been used to identify the potential zones for groundwater recharge which can also be used as sites for artificial recharge. The overlay weighted process method is used to determine the suitable location for the implementation of artificial recharge. It defined as an easy and straightforward method for a mixed analysis of multi-class maps (Saleh, 2009). The benefit of this method is that human judgment can be taken into consideration.

Various thematic maps were developed, reclassified based on different parameters weights that are assigned in Table (4.1) and integrated using the "Raster Calculator" function in the spatial analysis module within GIS environment.

Table 4. 1: The weight for each parameter to use flood as source for external water.

No	Criteria	Class	Weighted Rating	Weighting (%)
1	Slope	0 – 6	4	10%
		6– 12	3	
		12 – 22	2	
		22 – 50	1	
2	Land use	Agricultural	5	15%
		Urban	2	
		Industry	1	
		Open cover	4	
		Extract site	3	
3	Groundwater depth	Low	1	15%
		Medium	2	
		High	3	
4	Density of wells	1	1	15%
		2	2	
		6	3	
		36	4	
5	Run off	0-27	1	25%
		27-70	2	
		70 -121	3	
		121-268	4	
6	Infiltration Ability	Law	3	20%
		Medium	2	
		High	1	

The recharge potential index is achieved by summing the pixel values for every area that produced from multiplying the scores with its weight, according to the following equation:

The potential index equal

$$S_W \times S_s + L_W \times L_s + D_W \times D_s + I_W \times I_s + R_W \times R_s + WD_W \times WD_s \ldots\ldots 1$$

Where

S: Slope of area.

L: Land use.

D: Depth of ground water.

I: Infiltration capacity.

WD: Wells density.

R: Runoff.

The subscript W indicates the weight of parameter and R indicate to its scores. Thus, many thematic layers of influencing parameters like Geology, Depth of groundwater, slope, Drainage density, Runoff and Land use were developed and assigned weights. Dataset types and thematic maps including spatial and non-spatial data in digital form were developed, collected and integrated through GIS techniques. The six parameters criteria for the analysis are defined and each parameter is assigned weighted based on its importance. Methodology flowchart for the artificial recharge of ground water in Al-Qilt catchment is shown in Figure 4.1.

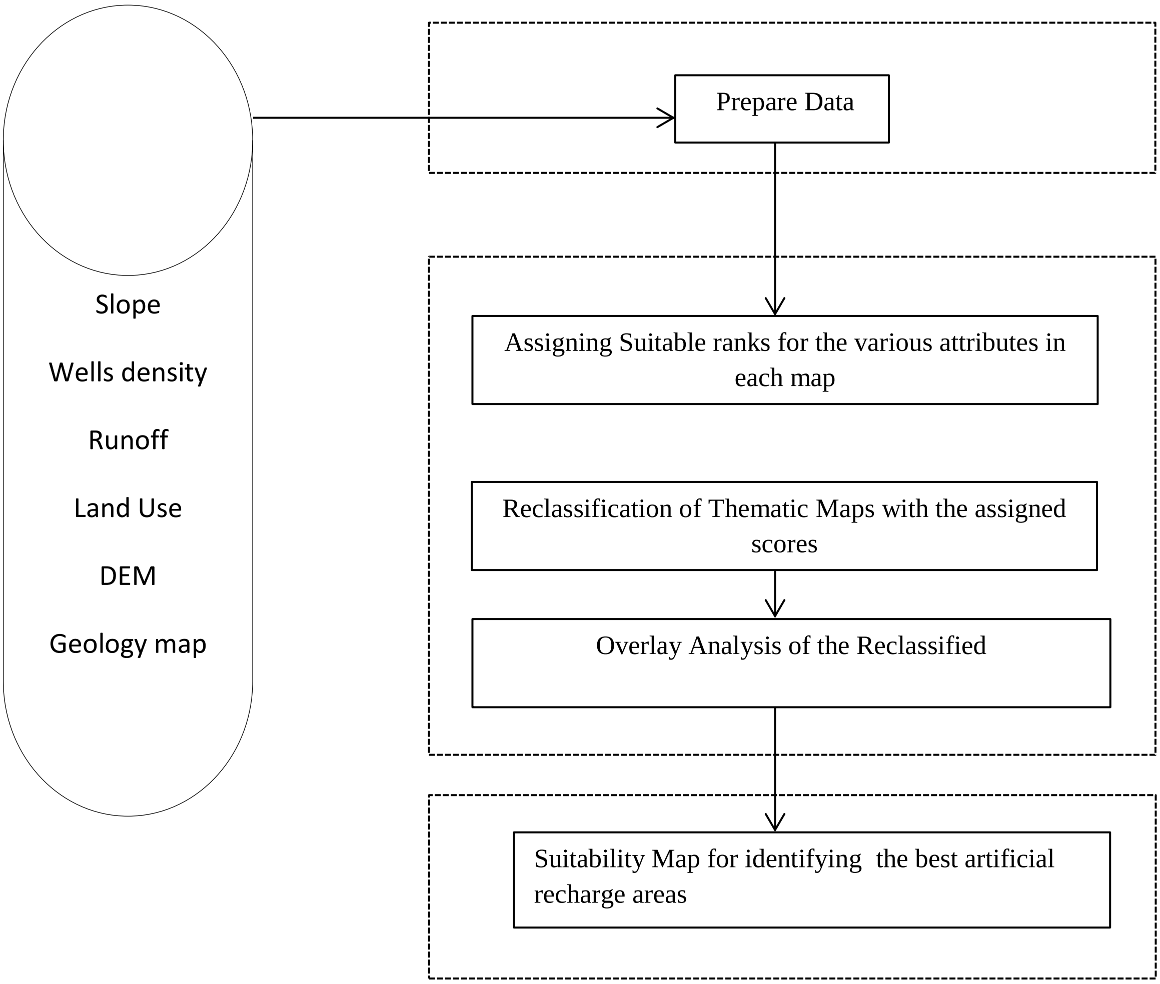

Figure 4.1: Methodology flowchart for the artificial recharge of groundwater.

4.2.2 Preparation of thematic maps

4.2.2.1 Slope

The slope is the most important parameter that affect the determination of the artificial recharge sites in the infiltration process (Raymond, 2009). The water speed and direction depends basically on the slope of the area. Al-Qilt catchment is described by a steep slope that drainage from the upper part (central mountains) toward the Jordan valley. The slope was derived from Digital Elevation Model (DEM) by using GIS techniques. The slope of Al- Qilt catchment is divided into four classes ranged from 0 to 50 degree. Gentle slope considers more appropriate zone for artificial recharge than the steep slope in the infiltration process (Asano, 1985). The slope in the area is divided into four classes where the area with high slope give scores equal 1 and the area with low slope give score equal 4. Figure 4.2 Shows the slope in degree for Al-Qilt catchment.

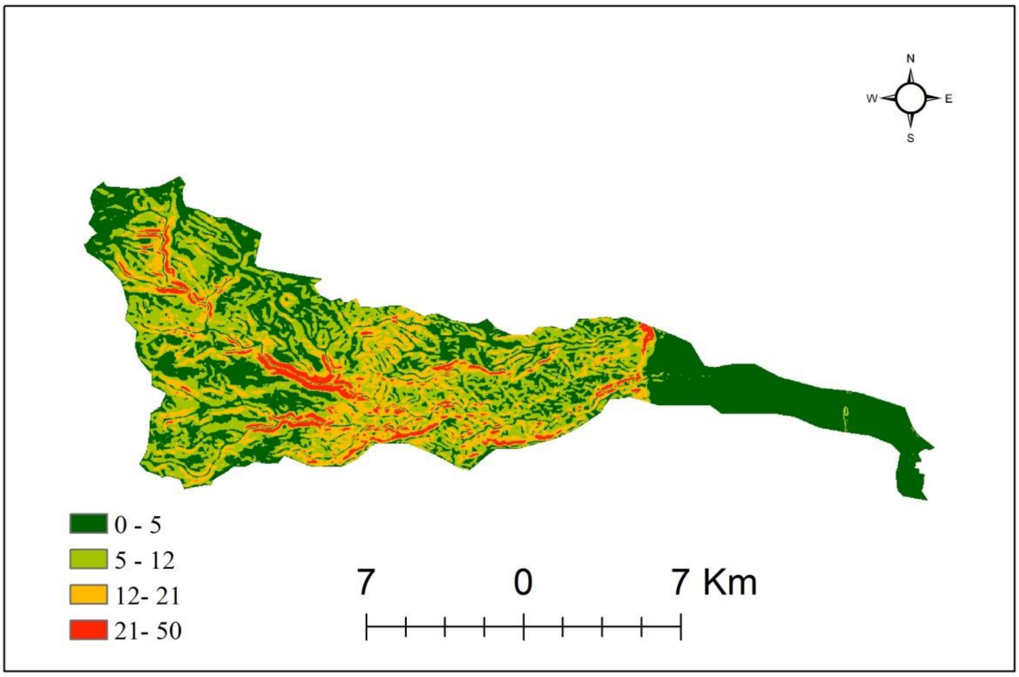

Figure 4.2**:** The slope in degree for Al- Qilt catchment.

4.2.2.2 Infiltration Capacity

For effective recharge, the following conditions should be met (Jafar et al, 2004): 1. The Substance in the deposits must have a large vertical permeability 2. The aquifer must adequately be transmissive for transport of water away from the spreading area and the relationship between type of formation and infiltration rate are considered.

Rocky out the crop in Al-Qilt catchment range in age from Cretaceous to Quaternary age. For estimating the infiltration rate, The raster map of infiltration capacity was prepared based on the geological properties. Each cell for the raster is classify according to its infiltration capacity that determined by the type of rocks. In the Al-Qilt catchment five formations are found:

1. Upper part of Cenomanian: Belong to Bethlehem formation, basically consists limestone and dolomite, marly and karastic limestone while the lower part consists of limestone, marly, chalky limestone and dolomitic limestone (Abu Helo, 2008), this type of rocks consider medium infiltration capacity (Saleh, 2009). And it's known as the good aquifer.

2. Jerusalem Formation: The rock of this formation consists mainly of massive limestone, dolomite and chalk in places (Daghrah, 2005). So this formation is considered medium infiltration capacity (Saleh, 2009), the Turonian period part of this formation and the lithology consists of karstified limestone and dolomite with thickness 40 to 120 m (PWA, 2010); Khayat, 2005).

3. Albian Age: This formation covers the upper part of Al-Qilt catchment and mainly consists of limestone and dolomitic limestone with low infiltration capacity (Saleh, 2009).

4. Quaternary (Holocene and Pleistocene age): Consists of Alluvium and Lisan formation respectively (Daghrah, 2005). The lisan formation characterized by low permeability and lower transmissivity (Abu Helo, 2008).

5. Senonian age rocks (Abu Dis formation): It is composed from chalks and marls, the chalk usually white but in some areas dark colored due to the presence of bituminous materials (Khayat, 2005), the thickness of this formation range between 40 to 150 m. And it has medium infiltration capacity (Saleh, 2009). The geological formation for the study area is shown in Figure 4.3.

Based on type of rocks, infiltration capacity are determined and classified to low infiltration, high infiltration and moderate infiltration capacity. Figure 4.4 Shows the infiltration capacity for each formation in the Al-Qilt catchment.

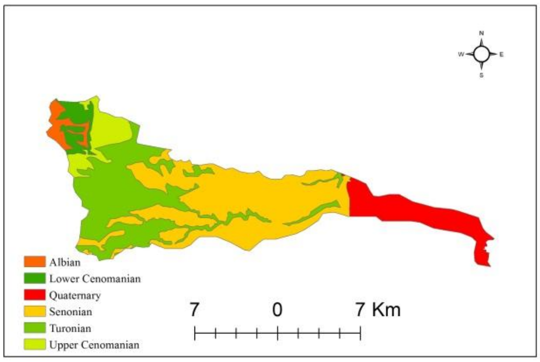

Figure 4.3: The geological formation for Al-Qilt catchment.

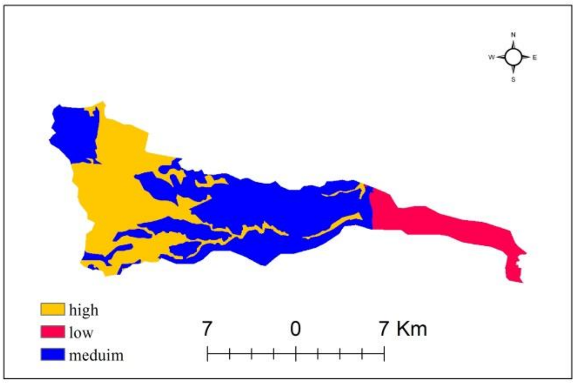

Figure 4.4: The infiltration capacity classification in Al-Qilt catchment.

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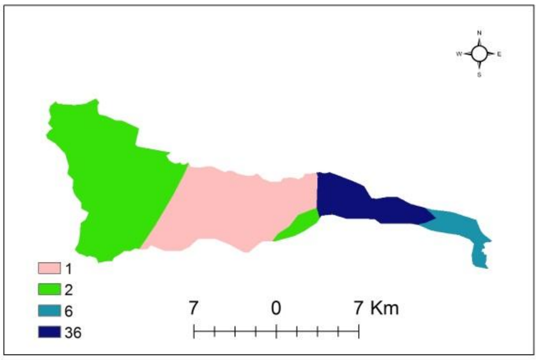
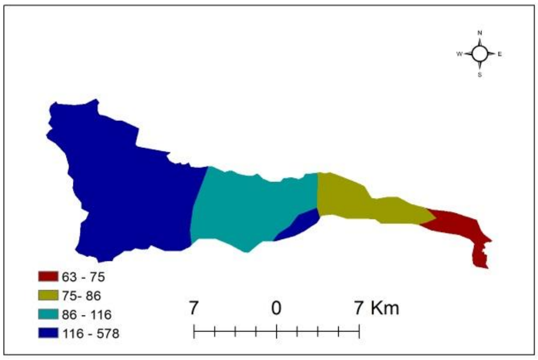
4.2.2.3 Wells Distribution And Wells Depth

The whole number of the Palestinian wells in the West Bank is 383 of which 119 wells are not pumping or dropped. The total yearly abstraction from the pumping wells is about 65.5 MCM in the year 2011 among of which 33.5 MCM for domestic use and 32 MCM for agricultural (PWA, 2011). A number of Israeli wells within West Bank are 39, and the average seasonal abstraction of those wells is appraised at about 54 MCM (PWA, 2011). The geological distribution of springs shows that 90% of springs are found in the north and center of West Bank. More ever, lots of rich springs of fresh water are located in the north, lower quantities of weak springs are located in the middle and precious springs with saline water are found in the south (PWA, 2011). Jericho, Ramallah and Jerusalem are the three cities that form Al-Qilt catchment with the total amount of water abstraction of 50 MCM for both domestic and agricultural use (PWA, 2011).

The wells distribution map and average depth of water table are created by GIS tools and is shown in Figure 4.5. Most wells are located in the eastern part of the catchment. As the number of wells increase, it is the effect on the water table and lowering the groundwater level. The area with a high number of wells is more appropriate for artificial recharge. The value of 4 is given to high density while 1 given to lower density.



wells distribution



Average depth of ground water (m)

Figure 4.5: The wells distribution and the depth of ground water in Al-Qilt catchment.

4.2.2.4 Land Use

The land use of the Al-Qilt catchment is classified into five main classes, urban, cover land, industry land, open land and extract land. The land use map for this classification is created and the area for each land use type is calculated. The area for each land use class in the catchment is shown in Table 4.2.

Table 4. 2: The area for each land use class.

No	Land use class	Area (km^2)	(%) of the total area
1	Urban	28	16 %
2	Cover land	144	83 %
3	Industry	0.24	0.1%
4	Open cover	0.19	0.1%
5	Extract land	1.49	0.8%
Total		174	100%

The map suitability for artificial recharge is created according to weights for each parameter in table 4.1 by using GIS builder model. Figure 4.6 show the suitability for the using flood as source for artificial recharge. Table 4.3 shows the area for each zone that calculated using flood as source for artificial recharge.

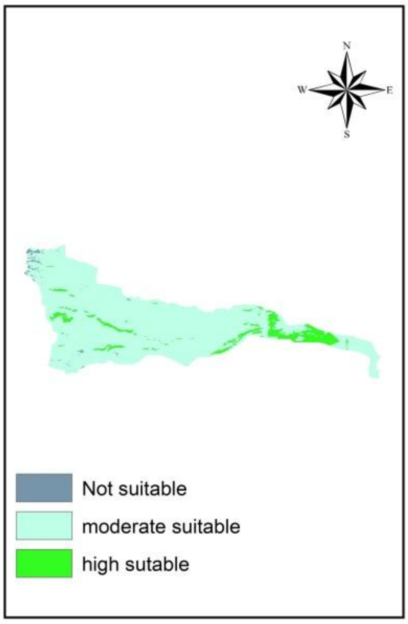


Figure 4.6: Site Selection for artificial recharge map.

Table 4.3: The area for each zone that calculate by flood method .

No	Classification	area(km^2)
1	Not Suitable	1.4
2	Moderate Suitable	159
3	High Suitable	14
	Total	174

4.2.2.5 The Artificial Recharge By Treated Wastewater

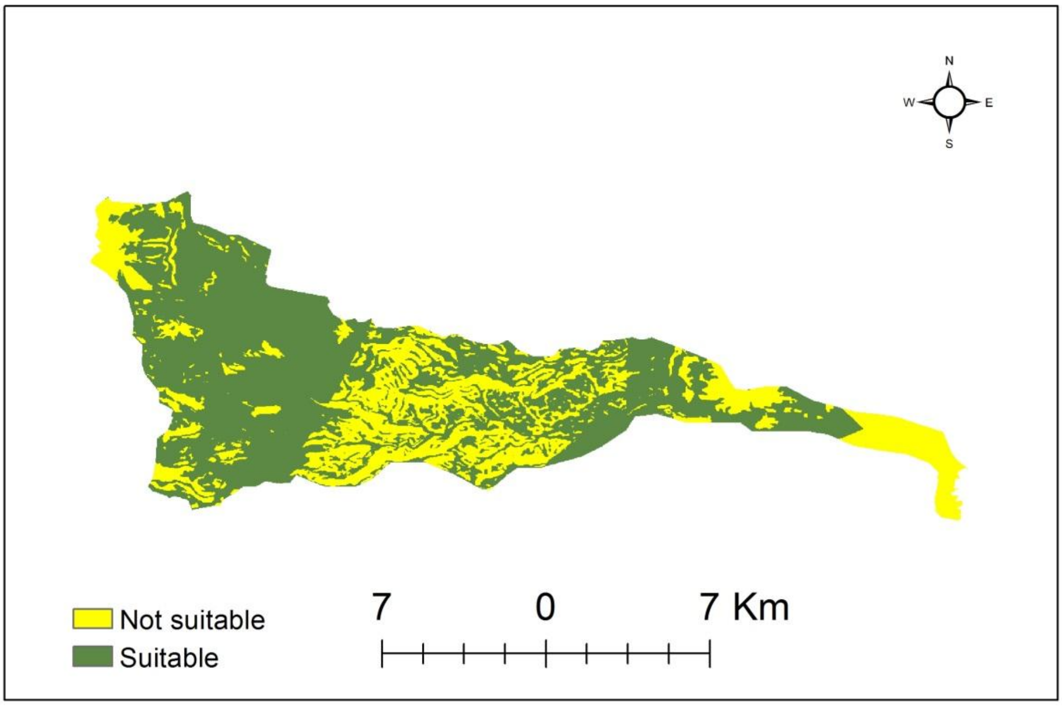
Infiltration methods involve basins, vaults, drains, dry wells, porous pavement. Infiltration methods need proper site soils and geological conditions, favorable hydrogeological conditions and land availability (Saleh, 2009). For direct aquifer recharge, infiltration methods should be established near of existing wells in order to be reused and should be established away from civil cities to reduce the risk of polluting the underground aquifers. The types of formations are essential for recharge because recharge from one place to another depends on the type of rocks and ability to join.

Many parameters are taken into consideration to determine the best location for the artificial recharge in the Al-Qilt catchment by using treated wastewater. The parameters are the slope, rocks infiltration, distribution of wells and the depth of ground water (Rasheed, 2010). The most important parameter in determining the artificial recharge by in the infiltration process (Asano, 1985). As the infiltration process used treated wastewater the runoff parameter is excluded. Table 4.4 shows the weight for each zone that calculated by infiltration system. The area that considers with gentle slope, open cover, high infiltration capacity, high depth and number of wells given high scores. And by using overlay weighted method, the suitability map of artificial recharge is created.

Table 4.4: The weight for each zone that calculate by infiltration system.

Parameter	Weights (%)
Slope	25
Land use	15
Infiltration capacity	30
Distribution of wells	15
Depth of ground water	15
Total	100

The suitability map by using treated wastewater as source for artificial recharge by infiltration process is shown in Figure 4.7.



.Figure 4.7: The suitability map of artificial recharge by using treated wastewater.

The ability of artificial recharge classified into two groups, suitable and not suitable area. The areas artificial recharge by using treated wastewater is list in table 4.5.

Table 4. 5 The area for each zone for artificial recharge by using treated wastewater.

NO		Area (km^2)
1	Suitable	115
2	Not suitable	59
Total		174

4.3 Artificial recharge methods

4.3.1 Injection wells

The conventional methods that used in artificial recharge are the infiltration process and the injection wells, the choice which of this methods are appropriate depends on the properties of the rocks. The choice of injection wells depends on rocks profile that are consists of impermeable strata between the ground surface and the groundwater while the use of infiltration process appropriates for an area that consider of high infiltration capacity.

4.3.2 Rainwater Harvesting

The rainwater harvesting process is one option that used as source for groundwater artificial recharge. The excess water in the surface roof are collected and from area that have gentle slope . the study of the properties of harvested water are very important that make the water able for direct use , or ability to augment the ground water aquifer. The harvested process can be done through built small barriers across small streams.

In the West Bank the rainwater harvesting is implemented in the Faria catchment, according to (Rasheed, 2010) the main aims of this project is to manage runoff resulting from excess rainwater during the winter season in the Faria catchment, especially in the northern part of the upper catchment by using the basis of hydrological data and the rainfall quantities and measurements of runoff. The harvested water collected by the dam which hold the rain flood during the winter season, the dam built in the area that consider with high infiltrating capacity

Chapter Five: Conclusion and Recommendation

5.1 Conclusion

The basis of the SMD method for estimating recharge when the soil moisture content reaches a limited and constant value of water capacity which called field capacity, the soil become to have the ability to free drainage. By SMD, the maximum recharge in the upper part of Al-Qilt catchment with a value of 99 mm and the lowest value of 12 mm in the eastern part. The recharge in the western part is 24% of the annual rainfall and 3% in the eastern part of the catchment. The potential evapotranspiration in the upper part of the catchment is 1535 mm/year and in the lower part is 664 mm/year (eastern part), higher in the upper part related to the high elevation which has higher potential evapotranspiration. By using Thession method, the maximum rainfall for the entire catchment is (150 mm) occurs in January while annual rainfall for the entire area is 414 mm. The natural recharge in Al-Qilt catchment is estimated. It is found that, the main area for recharge is the central mountains and the low water recharge is found in the Jordan valley because of the presence of the Lisan formation, which has low permeability and transmisitvity. The runoff in the study area is estimated, to be 121 mm in the lower part and ranging between 0 to 27 mm in the upper part. The total Annual runoff in the study area found to be 6 % of total precipitation in the upper part, and 29 % in the lower part of the catchment. By using SMD the annual deficit is 1120 mm/year for the entire catchment. The Annual of PET is 1535 mm / year. The soil moisture deficit represents 73 % of PET. Mass balance equations are used as another method to estimate the water balance budget, the average chloride concentration in Faraa and Al-Qilt springs sample for each spring is 44mg/l, the runoff in the area is found to be 6% of the rainfall, the annual recharge according to chloride mass concentration is found to be 118 mm/year. The annual recharge by using the Goldschmidt and Jacobs (1959) was calculated to be 118 mm/year. Using flood as the source for artificial recharge in Al-Qilt catchment can be achieved in the eastern part of catchment by small area while moderate suitability for flood method is shown with an area 159 km^2 . Using treated wastewater source for artificial recharge in Al-Qilt catchment can be achieved in the eastern part of catchment with moderate suitability with an area of 115 km^2.

5.2 Recommendation

The following recommendations are suggested:

1. It is recommended, to improve the accurate of the artificial recharge sites other parameters such as distance to the treatment plant, the water quality of the treated wastewater compared to WHO standards and distance from urban roads to prevent water pollution can be introduced.

2. It is recommended to study the effect of the surfaces on the quality of flood.

3. It is recommended to build the appropriate designs for injection wells for artificial recharge based on the type of sites and to study appropriate project budget.

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Appendix

Appendix 1.1: The concentration of Chloride in Al-Qilt springs (Abu Helo, 2008).

Spring	Sample_Date	Ph	Temp (c)	Cl (mg/l)
En Fara	29.08.2006	7.3	21	48.3
En Fara	30.10.2006	7.14	22.2	46.1
En Fara	25.12.2006	7.5	22	44.3
En Fara	14.01.2007	7.3	21	50.1
En Fara	12.02.2007	7.05	21	52.3
En Fara	09.03.2007	7.6	20.7	47.5
En Fara	23.03.2007	7.3	21.3	33.8
En Qilt	29.08.2006	7.05	21.7	47.3
En Qilt	30.10.2006	7.1	21.7	44.3
En Qilt	25.12.2006	6.89	21.4	41.5
En Qilt	14.01.2007	6.8	21.2	47.4
En Qilt	12.02.2007	7.35	21.2	42.7
En Qilt	12.02.2007	7.55	21.1	39.0
En Qilt	02.03.2007	7.55	20.1	44.6
En Qilt	23.03.2007	7.27	21.3	28.4
Average				44.4

Appendix 1. 2: Mean Average Temperatures (°C).

City	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Ramallah	8.7	9.9	12.3	15.6	20	22.5	23.5	23.8	22.8	20.4	15.5	10.6
Jericho	13.2	14.6	17.4	21.7	25.6	28.5	29.9	30	28.6	25.1	19.6	14.7
Jerusalem	9	12	10	18	21	23	24	25	24	22	14	10

Appendix 1.3: Mean Monthly Rainfall (mm).

City	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Ramallah	129.6	138.9	98	17	3.3	0	0	0	0	24.8	79.5	123.3	615.2
Jericho	35.8	31.2	24.7	1.9	0	0	0	0	0	7.1	21.6	33.4	166
Jerusalem	130	135	95	13	2	0	0	0	0	20	78	129	602