



## Thesis Approval

### Estimation of Runoff and Infiltration Using the Curve Number for Wadi Ta'amira / Bethlehem

Prepared By : Reem Yacoub Malki Zeitoun


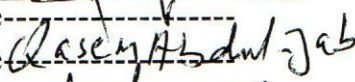

Registration No.: 20411228

Supervisor: Dr. Ziad Qannam

Master thesis submitted and accepted, Date: 24/01/2007

The names and signature of the examining committee members are as follows:

- 1 Head of Committe Dr. Ziad Qannam
- 2 Internal Examiner Dr. Qasem Abdul-Jaber
- 3 External Examiner Dr. Alfred Abed Rabbo

Signature   
Signature   
Signature 

Jerusalem – Palestine

## Abstract

The study concentrated on the estimation of runoff and infiltration by the Soil Conservation Service method (SCS) for Wadi Ta'amira in Bethlehem - Palestine. The study was performed between (2005-2006). The catchment is of 46.39 Km<sup>2</sup> which lies within 117,000 -130,000 N and 168,000-179,000 E referenced from the Palestinian Grid. The catchment lies on the Eastern Basin of the Mountain Aquifer where its drainage system is towards the Dead Sea. The significance of the study area is due to its historic and hydrologic importance. The study aimed to present water balance of the study area through calculating the runoff and infiltration by the SCS method which will be useful for future water resources management. This study will provide useful new information for hydrological parameters which are significant for the Eastern Basin with its local wells that support water for the southern part of the West Bank mainly Jerusalem, Bethlehem and Hebron districts.

The geology of the area belongs to the age from Albian to Senonian. The geological age ranges from the formation of Abu Deis, Jerusalem, Bethlehem, Hebron, Yatta, Upper Beit Kahil and Lower Beit Kahil. The lithology is mainly limestone, dolomite and dolomitic limestone. The soil of the study area includes Brown Rendzinas and Pale Rendzinas and Brown Lithosols and Loessial Arid Brown soils. It is mainly of limestone, chalk, dolomite and conglomerate with slow infiltration. It is of ( C ) soil type group, for the choice of the CN which is low in organic content and high in clay.

The GIS software package TNT-mips and Surfer 7 were used to draw maps. A Digital Elevation Model (DEM) was compiled to delineate the border of the catchment. An areal photo of resolution 1:50,000 pixels for Bethlehem governorate was used to draw a landuse map showing the main activities in the study area. The landuse map activities were used to identify the Curve Number (CN). An isohyetal map was drawn for the study area in which the areal rainfall was calculated to be 419.83 within the period of 1970-2000.

Daily rainfall data was collected from Cremisan monastery in addition to monthly and yearly records for the last century. The average rainfall over the study area was 574.7 mm/yr for the period 1900-2006. The daily missing data was correlated with Al Arroub meteorological station which showed good correlation. Monthly and yearly rainfall data was collected from local raingages within and near the study area in order to draw the isohyetal map of the study area and to calculate the areal rainfall.

The Soil Conservation Service method (SCS) is an appropriate method for estimating hydrological parameters of the water balance. It is mainly used for small unguaged watershed which depends on local information on soil type, vegetation cover types, landuse categories and antecedent moisture condition. Calculation of the CN depends on the daily rainfall records over the watershed for nearly three decades and a half from 1970-2000. From the accumulative five days records, calculation was done for CN1, CNII and CNIII with its initial abstraction and potential retention for the dormancy and vegetation period. Calculation of surface runoff and infiltration by the CN method showed to be 70.36 mm/yr and 101.22 mm/yr respectively which is considered to be of 16.76% for runoff and 24.11% for infiltration.

In Goldschmidt formulas runoff was 39.77 mm/yr with 9.47% of the annual average rainfall while infiltration was 51.43 mm/yr of 12.25% of the annual average rainfall.

According to the accuracy and reliability of (SCS) method, the results by empirical formulas are neglected. The actual evapotranspiration is 203.9 mm/yr and the area is classified as semi humid area.

The results of estimating runoff and infiltration in the study area showed high percentages which are valuable for future planning. High runoff percentage enhances the directors of water resources management for harvesting such water in the form of dams which will be later used for irrigating purposes. High infiltration percentage also encourages the local government to prevent groundwater contamination from waste water or other contaminants by planning future infra structure for sewage treatment plant in the area.

# تقدير المياه الجارية و الترشح باستخدام طريقة المحافظة على التربة لوادي التعامرة

## / بيت لحم

### ملخص

تشمل الدراسة على تقدير الجريان المائي و الترشح بطريقة مؤسسة المحافظة على التربة (Soil Conservation Service) لحوض وادي التعامرة في منطقة بيت لحم فلسطين ما بين الفترة الزمنية 2005-2006. تبلغ مساحة الحوض 46.39 كم<sup>2</sup> و يقع الحوض بين خطي 117000 إلى 130000 شمالا و بين 168000 إلى 179000 شرقا حسب الرسم البياني الفلسطيني. تظهر أهمية الوادي حيث يقع على الحوض الشرقي للخزان الجبلي المائي الذي يصب مجرى الوادي باتجاه البحر الميت و تعتبر منطقة الدراسة ذات أهمية تاريخية و هيدرولوجية . أجريت الدراسة لعمل موازنة مائية عن طريق حساب نسبة الجريان و الترشح في المنطقة و ذلك لتزويد أصحاب القرار و ذوي السلطة بقراءات علمية تفيد لإدارة مستقبلية جيدة لمصادر المياه في المنطقة كذلك إضافة معلومات هيدرولوجية هامة و جديدة للحوض المائي الشرقي. ستضيف هذه الدراسة معلومات هيدرولوجية جديدة ذات أهمية للحوض الشرقي الذي يحتوي على الآبار الرئيسية التي تزود منطقة جنوب الضفة الغربية خاصة مناطق القدس, بيت لحم و الخليل. تنتمي جيولوجية المنطقة من العصر الألبى إلى السنوميني حيث تنتمي ما بين تكوين أبو ديس و عمان, القدس, بيت لحم, الخليل, بيت كاحل العلوي و بيت كاحل السفلي. تمتاز المنطقة بالأحجار الكلسية, دولومايت و دولومايت كلسي من نوع تربة رندزينا و رندزينا فاتحة اللون و نوع تربة طميية صحراوية و غرينية . تعتبر تربة المنطقة ذات تسرب بطيء و قليلة المواد العضوية و عالية في الترب الطينية وهي من نوع ( ج ) في حساب قيم ( CN ).

استخدم برنامج الخرائط المركبة (GIS software package TNT-mips) لرسم كافة الخرائط و تم رسم حدود المنطقة بالاستعانة بطريقة النموذج الرقمي للارتفاعات للتثبيت من حدود منطقة الحوض و كذلك رسم الوديان الفرعية المغذية للوادي الرئيسي. رسمت خريطة استخدام الأراضي بالاستعانة بصورة جوية للمنطقة ذات رسم بياني عالي ذات نسبة 1:50,000 بكسل وتم استخدام نسبة توزيع الأنشطة في المنطقة لحساب قيمة ( CN ) . حددت المنطقة المطرية بطريقة ايزوهايتل باستخدام برنامجي (Surfer 7) ثم (GIS software package TNT-mips) و تم حساب المنطقة المطرية بقيمة 419.83 ملم/سنة ما بين الفترة الزمنية 1970-2000 .

جمعت القيم المطرية اليومية من دير الكريمان للفترة الزمنية 1969-2006 بالإضافة إلى قيم شهرية و سنوية للعقود السابقة وتم تقدير القيم المفقودة بعلاقة رياضية مع محطة العروب. من كافة المصادر المتوفرة يوميا و شهريا و سنويا من مصادر تجميع مياه الأمطار و المحطات الجوية القريبة من المنطقة و تم تقدير القيم المفقودة بمعادلة رياضية لمحطة العروب. تم تجميع القيم المطرية الشهرية و السنوية م كافة المصادر المتوفرة من حيث مصادر تجميع مياه الأمطار و المحطات الجوية القربة من المنطقة و ذلك لرسم و حساب المنطقة المطرية لمنطقة الدراسة. بلغ معدل المطر السنوي لمنطقة بيت لحم استنادا إلى دير الكريمان 574.7 ملم / سنة للفترة ما بين 1900-2006.

تم عمل موازنة مائية للمنطقة و تم تقدير المياه الجارية و الترشح باستخدام طريقة المحافظة على التربة حيث أثبتت نجاح هذه الطريقة للأحواض الصغيرة غير المغلقة. تعتمد هذه الطريقة على عوامل خاصة بالمنطقة كنوع التربة و الغطاء النباتي و استخدامات الأراضي و رطوبة التربة مما يجعل هذه الطريقة أكثر دقة لأنها تستخدم مدلولات خاصة بالمنطقة. تعتمد هذه الطريقة على كمية الأمطار اليومية المتراكمة لفترة خمس أيام متتالية. يعتمد حساب قيمة ( CN ) على الأمطار اليومية للفترة الزمنية 1970-2000 و تم حساب كل من ( CNI ) و ( CNIII ) لكل من فترة السبات و فترة الإزهار و النمو. أظهرت نتائج حساب الجريان السطحي بطريقة المحافظة على التربة على 70.36 ملم / سنة ذو نسبة 16.76% و الترشح بقيمة 101.22 ملم / سنة ذو نسبة 24.11%. تم حساب الجريان و الترشح بطريقة ( Goldschmidt formulas ) و كانت النتيجة 39.77 ملم / سنة ذو نسبة 9.47% للجريان السطحي و للترشح 51.43 ملم / سنة ذو نسبة 12.25% . نظرا لدقة حساب الجريان و الترشح للمنطقة بطريقة المحافظة على التربة فتم إلغاء القيم المحسوبة بالمعادلات التجريبية. تم حساب التبخر - نتح حقيقي للمنطقة 203.9 ملم / سنة حسب المعلومات المتوفرة و تم اعتبار المنطقة شبه رطبة حسب تصنيف معاملات الجفاف المختلفة.

أظهرت النتائج قيم عالية لنسبة الجريان و الترشح مما تحفز ذوي القرار وذوي سلطة المياه على الاستفادة من هذه النسبة الضائعة عن طريق إدارة مائية جيدة لمصادر المياه و العمل على تجميع هذه المياه الجارية بعمل سد مائي للاستفادة لأغراض الري . المياه الجارية السطحية قد تهدد المياه الجوفية بالتلوث فلذلك يستحسن تجميع هذه المياه للإغراض الزراعية و عمل محطة معالجة مياه المجاري في المستقبل القريب.

## Table of contents

Number	Content	Page
	<b>Declaration.....</b>	<b>i</b>
	<b>Acknowledgments.....</b>	<b>ii</b>
	<b>Abstract (English).....</b>	<b>iii</b>
	<b>Abstract (Arabic).....</b>	<b>v</b>
	<b>Table of Contents.....</b>	<b>vii</b>
	<b>List of Tables.....</b>	<b>xi</b>
	<b>List of Figures.....</b>	<b>xii</b>
	<b>List of Appendices.....</b>	<b>xiv</b>
	<b>List of Symbols.....</b>	<b>xv</b>
	<b>Definitions.....</b>	<b>xvii</b>
	<b>Chapter one: Introduction.....</b>	<b>1</b>
1.1.	Introduction .....	1
1.2.	Justification.....	1
1.3.	Study problem.....	2
1.4.	Objectives.....	2
1.5.	Goals.....	3
1.6.	General review in thesis chapters.....	3
1.7.	Previous studies.....	3
	<b>Chapter two: Theoretical Background.....</b>	<b>6</b>
2.1	Introduction.....	6
2.2	Types of Runoff.....	6
2.2.1	Methods of calculation.....	8
2.2.1.1	Goldschmidt formula.....	8
2.2.1.2	Soil Conservation Service (SCS) method.....	9
2.2.1.2.1.	Retention parameters.....	12
2.2.1.2.1.1.	Landuse and treatment.....	13
2.2.1.2.1.2.	Hydrologic soil group.....	14
2.2.1.2.1.3.	Hydrologic surface condition.....	15
2.2.1.2.1.4.	Antecedent moisture condition.....	16
2.2.1.2.2.	Curve Number for urban landuses.....	17
2.3	Infiltration.....	19
2.3.1	Factors affecting infiltration.....	20
2.3.1.1	Surface entry.....	20
2.3.1.2	Percolation.....	20
2.3.1.3	Antecedent moisture condition.....	21
2.3.1.4	Climate conditions.....	21
2.3.1.5	Rainfall intensity and duration.....	21
2.3.1.6	Human activities.....	21
2.3.1.7	Depletion of ground water table.....	22

2.3.1.8	Quality of water.....	22
2.3.1.9	Vegetation.....	22
2.3.1.10	Grain size of soil particles.....	22
2.3.1.11	Catchments parameters.....	22
2.3.2.	Methods of calculation infiltration capacity.....	22
2.3.3.	Methods of calculation infiltration.....	23
2.3.3.1.	Soil Conservation Service method.....	23
2.3.2.2.	Goldschmidt and Jacobs formula.....	23
2.4.	Mean Areal rainfall.....	23
2.4.1.	Arithmetic Average.....	24
2.4.2.	Thiessen Polygon method.....	24
2.4.3.	Isohyetal method.....	24
2.4.4.	Grid Point.....	25
2.4.4.5.	Orographic method.....	25

**Chapter three: Methodology..... 26**

3.1.	Introduction.....	26
3.1.	Literature review.....	26
3.2.	Personal communications and interviews.....	26
3.3.	Field work.....	26
3.4.	GIS and mapping.....	26
3.4.1.	Digital Elevation Model.....	27
3.4.2.	Soil map.....	27
3.4.3.	Landuse map.....	27
3.4.4.	Areal rainfall map.....	27
3.5.	Climate and rainfall data.....	27
3.5.1	Rainfall data.....	27
3.5.2.	Temperature and Humidity.....	28
3.5.3.	Aridity .....	28
3.5.3.1.	Aridity index of Murai and Hunda.....	28
3.5.3.2.	Thornthwaite classification.....	29
3.6.	Water balance.....	30
3.6.1	Mean annual rainfall.....	30
3.6.1.1	Ishohyetal map.....	30
3.6.2.	Estimation of the surface runoff.....	30
3.6.2.1.	Goldschmidt formula.....	30
3.6.2.2.	Soil Conservation Service (SCS) method.....	30
3.6.3.	Estimation of infiltration and recharge.....	31
3.6.3.1.	Soil Conservation Service (SCS) method.....	31
3.6.3.2	Goldschmidt and Jacobs formula.....	31
3.6.4.	Estimation of the actual evapotranspiration.....	32
3.6.4.1.	Hydrometeorological method.....	32
3.6.4.2.	Empirical formulas.....	32
3.6.4.2.1.	Wundt.....	32

**Chapter Four: Study area..... 34**

4.1.	Introduction.....	34
------	-------------------	----

4.2.	Location.....	35
4.3.	Landuse.....	36
4.4.	Topography.....	37
4.4.1.	Watershed slope.....	37
4.4.2.	Watershed shape.....	38
4.5.	Geology.....	39
4.5.1.	Lithology.....	41
4.5.1.1.	Lower Beit Kahil Formation.....	41
4.5.1.2.	Upper Beit Kahil Formation.....	41
4.5.1.3.	Yatta Formation.....	41
4.5.1.4.	Hebron Formation.....	41
4.5.1.5.	Bethlehem Formation.....	41
4.5.1.6.	Jerusalem Formation.....	42
4.5.1.7.	Abu Deis Formation.....	42
4.6.	Soil.....	42
4.6.1.	Soil Types of Bethlehem Governorate.....	44
4.6.1.1.	Bare Rocks and Desert Lithosols.....	44
4.6.1.2.	Brown Lithosols and Loessial arid Brown Soils.....	44
4.6.1.3.	Brown Rendzinas and Pale Rendzinas.....	44
4.6.1.4.	Terra Rossas, Brown Rendzinas and Pale Rendzinas.....	44
4.6.1.5.	Brown Lithosols and Loessial Serozems.....	45
4.7.	Hydrogeology.....	45
4.7.1.	Groundwater Basins.....	47
4.7.1.1.	The North Eastern Basin.....	48
4.7.1.2.	The Western Basin.....	48
4.7.1.3.	The Eastern Basin.....	48
4.8.	Climate.....	50
4.8.1.	Temperature.....	50
4.8.2.	Relative Humidity.....	51
4.8.3.	Solar Radiation.....	52
4.8.4.	Wind.....	52
4.8.5.	Rainfall.....	53
4.8.5.1.	Distribution and density.....	54
4.8.6.	Aridity and Drought.....	58
4.8.6.1.	Aridity index of Murai and Hunda (1991).....	58
4.8.6.2.	Thornthwaite classification (1931).....	58
4.8.6.3.	UNESCO aridity index.....	58
4.9.	Vegetation.....	59
4.8.6.1.	Aridity index of Murai and Hunda (1991).....	53
4.8.6.2.	Thornthwaite classification (1931).....	53
4.8.6.3.	UNESCO aridity index.....	54
4.9.	Vegetation.....	55
<b>Chapter five: Results and Discussion.....</b>		<b>61</b>
5.1.	Water Balance.....	61
5.1.1.	Mean Areal Rainfall.....	61
5.1.2.	Surface Runoff.....	65

5.1.2.1.	Goldeshmidt Formula.....	65
5.1.2.2.	Soil Conservation Service (SCS) method.....	66
5.1.2.2.1.	Soil Group classification.....	67
5.1.2.2.2.	Cover Complex.....	67
5.1.2.2.2.1.	Vegetation and dormancy.....	67
5.1.2.2.2.2.	Landuse.....	67
5.1.2.2.2.3.	Antecedent moisture conditions (AMC).....	68
5.1.3.	Infiltration and Recharge.....	69
5.1.3.1.	Goldschmidt and Jacobs method.....	70
5.1.3.2.	SCS method.....	70
5.1.4.	Soil Moisture.....	70
5.1.5.	Interception.....	71
5.1.6.	Depression Storage.....	72
5.1.7.	Actual Evapotranspiration.....	72
5.1.7.1	Hydro meteorological method.....	73
5.1.7.2	Wundt.....	74
5.1.8	Effective rainfall.....	74
5.1.9.	Initial abstraction.....	74
<b>Chapter six: Conclusions and Recommendations.....</b>		<b>76</b>
6.1.	Conclusion.....	76
6.2	Recommendations.....	77
6.2.1.	Local government and communities.....	77
6.2.2.	Future studies.....	78
<b>References.....</b>		<b>79</b>
<b>Appendices.....</b>		<b>83</b>

## Chapter One

---

### Introduction

#### 1.1. Introduction

The West Bank faces a semi-arid climate with an increasing demand on the limited water resources. There are problems of poor aquifer management, including over exploitation of the groundwater reservoirs in addition to the continuity of the Israeli occupation of the West Bank control over the water resources. Water issues were significant in the bilateral interim Accords (1995) as well as will be in any future final Status negotiations between Israelis and Palestinians. From Oslo two, additional extraction of 70-80 Mill.m<sup>3</sup>/yr would achieve the Palestinians needs. Bethlehem city and its neighborhood which is proposed for the study lives even special scarcity of water as it is a touristy city where its major economy depends on tourism due to its historical and religious importance where Jesus was borne. Personnel communication with the Minister of Tourism declared that Bethlehem usually host one million pilgrimages annually. At the beginning of the third millennium, Bethlehem was supposed to host one million and seven hundred and fifty thousands pilgrimages thus increasing the demand on water supply (Minister of tourism, December 2006, Personal communication). According to this large hosting number of pilgrimages the area should have sufficient supply of water which will directly increase output of waste water. Bethlehem is located above the Eastern Basin of the Mountain Aquifer to the western edge of the Jerusalem desert.

#### 1.2 Justification

This study is important for many factors:

- Water is an important natural resource which affects the economy and the development of Palestine. The limited water resources for Palestinians include ground water supply from the local wells which are partly under the control of the Israelis and from rainwater collection in cisterns. The principal resource of high quality domestic water for the Palestinians in the West Bank is the Eastern Basin of the Mountain aquifer. WHO's recommendation for human consumption of water is 150 L/cap/day whereas the Palestinians receive 58 L/cap/day which is insufficient for increasing population of 3.0% in the West Bank (Abed Rabbo and Scarpa, 2006), (Passia, 2006).
- Estimation of runoff and infiltration from the water balance over the study area. The decrease consumptive rate of water for Palestinians encouraged the researcher to search on water balance analysis in the area which will be helpful for

sustainability future planning. Among the major parameters of the water balance are infiltration and surface runoff over the area. According to the available data for the researcher the choice for calculating the water balance over the area is done by the Curve Number Method –SCS.

- Curve Number method is an appropriate procedure since it is very difficult for gauging the surface runoff due to lack of sufficient equipment and gauging problems.
- Due to the lack of climatological instruments for measuring evapotranspiration and infiltration by empirical methods, the SCS method is used as an alternative accurate way for estimate runoff and infiltration. The SCS method is one of the successful estimation for runoff for the study area since it depends on actual parameters of the study area rather than empirical formulas.
- Bethlehem, as part of the West Bank, depends on the annual rainfall to recharge the eastern part of the Mountain Aquifer. Water management depends on empirical data of rainfall, runoff, evaporation and aridity that will help to identify the actual recharge for each region of the Mountain Aquifer. In addition, adequate water management in the area will sustain good water quality for future generations in which most of the local water networks are old and leaks which will lead to sufficient water loss.
- There are already five present wells which were dug in the 1970s in Bethlehem region and other new fourteenth production wells in the Eastern basin in the late 1990s under the control of the Palestinian Water Authority (PWA). Wadi Ta'amira basin is in Bethlehem where it is close to the five Herodion wells thus having a geographic importance.
- Bethlehem has religious importance where it usually hosts a large number of pilgrimages annually which increase the demand on sufficient water supply. On the other hand, tourism will be encouraged in the region if the area is supplied with sufficient water quantity. Water balance analysis is an indication for future local planning.

### 3. The Study Problem

Water is critical and scarce issue in Bethlehem as other parts of the West Bank since the water resources are limited. Lack of surface runoff and infiltration estimates for the study area encouraged the researcher for computing water balance. The possibility of estimating water balance from inputs parameters of the study area by means of estimating surface runoff and infiltration by the SCS method.

This study aims to answer the following question; "How much and what percent out of the rainfall in Wadi Ta'amira goes for runoff and infiltration annually".

### 4. Objectives

The main objective of the study is to provide the local communities with scientific data on runoff and infiltration over the study area. There are already available rainfall data without

availability of runoff records, especially for medium and small catchments. The result will be helpful for the directors of water resources including the directors of Palestinian Water Authority (PWA), Water Supply and Sewage Authorities (WSSA) and Local Governorate of Bethlehem which will be useful for future water planning. The result of the study will give the local authority a view on the annual loss of water through runoff which will encourage them to look for alternative solutions. Implementation of qualitative and quantitative water sustainability is through future planning for water balance management at the level of housing, farms and city. The previous declaration in addition to the data on runoff and infiltration will be helpful for future water management. The study will provide data on infiltration, runoff, rainfall, landuse activities which will be significant for future hydrological studies for Bethlehem precisely and Palestine in general.

## 1.5 Goals

This study many goals, the major of which are:

- Estimation of the percentage of rainfall that goes for runoff annually.
- Estimation of annual infiltration rate.
- Establishing a rainfall database for the area through collecting the available data from the different neighboring stations and estimating any missing records.
- Calculation the areal rainfall.
- Collect available meteorological data from rainfall, temperature and humidity for analyzing the water balance.
- Preparation of basic maps for the area such as landuse and wadis.

## 1.6. General review in thesis chapters

The thesis will discuss estimating of runoff and infiltration in the study area by the Curve Number method through six chapters. The first chapter is an introduction for the study showing previous implemented studies that were done in the area. This chapter covers the goals that will be implemented at the end of the study. The second chapter is a theoretical background shows the importance of water balance with its parameters. This chapter will cover the knowledge of the Soil Conservation Service method which will be used to estimate the surface runoff and infiltration. The third chapter is a methodology chapter showing the main methods used for achieving the goals. A fourth chapter discusses a review on the study area in terms of geology, hydrology, climatological data, soil type and vegetative cover in the study area. A fifth chapter is on results and discussion on the inputs and outputs of the water balance analysis. Finally, a sixth chapter is on conclusions and recommendations for future studies and general demands for decision makers.

## 1.7. Previous studies

There are several previous studies implemented on the Mountain Aquifer concentrated on several hydrological parameters. Most of these studies were introduced by PWA, local NGO's, academic institutes and others. The studies included publications in terms of scientific papers, reports, scientific survey and several unpublished academic studies. The main objective of these studies is to support hydrological data of the basins over the Mountain Aquifer. The hydrological data indicate the future water sustainability in the West Bank.

## Chapter six

---

### Conclusions and recommendations

#### 6.1. Conclusion

The conclusion of the study will determine the extent to which the aim of the study has been achieved. From the input parameters of the water balance over the study area, showed that the area receives sufficient precipitation to recharge the local aquifer. The study area, as part of the West Bank, depends on precipitation for replenishing the aquifer. Bethlehem contributes to arid and semi-arid climate with an increase in aridity towards the Eastern Slopes in the Jerusalem desert. However, the range of rainfall decreases from west to east due to drop in elevation. For instance, the average annual rainfall for Bethlehem during 1900 to 2006 from Cremisan Monastery of coordinates 166400E to 126000N and 820 m elevation is 574.7 mm/yr. During the previous century, the area faced several draft years; for example, in 1999 the least annual rainfall was only 219.8mm whereas a rainy year was in 1991-1992 with annual rainfall of 1118.6mm which was nearly double the average. From the comparison analysis of rainfall over the last ten decades showed that the area was faced with dry and wet years. This variation will affect on the water table of the aquifer which will need future efficient management.

Overexploitation of the aquifer by means of over pumping will lead the region towards a water stress. Although the control of water resources is within the Israeli's side, Palestinians should have enough water for drinking and for other domestic uses. The hydrology of Bethlehem area is affected from the presence of fissures, fractures, joints and karstification in addition to the rock porosity and permeability. In Bethlehem, karstification is well seen by caves in the area; for instance, Khureitoun cave near the village of Tequ'a in the Jerusalem desert, it is located nearly two kilometers south-east of Herodion Fortress. The estimated infiltration over the study area with the geological background is useful to predict future recharge for the aquifer and its future fate. Further studies on infiltration rate near the study area and along the West Bank will be a very useful estimation for future recharge for the aquifer basin. High infiltration percentage is an indication for good replenishment to the aquifer, thus the area should be environmentally protected to prevent contamination's entry. Thus the local government should take into consideration to prepare infra structure for sewage networks to prevent leakage of contaminants into the aquifer. In addition, they should also plan for sewage treatment plant to compensate water for irrigation uses.

The Curve Number Method is a versatile, an accurate and widely used procedure for runoff and infiltration estimation. This method includes several important properties in a surface drainage basin, soil's permeability, landuse and antecedent soil water conditions. It is an

adequate procedure to be implemented in other parts of the West Bank in order to give sufficient data for water balance analysis.

High percentage data on infiltration and runoff for the area will provide useful information for determining the quantity of water available for agriculture uses and future economical plans. The local government should take advantage of these results to harvest surface runoff in the form of dams or concrete dams which will be useful for irrigation purposes. The results of the study enhance the directors of local government for better future water management by rehabilitating the old water network pipes in order to prevent water loss. High infiltration rate will increase the recharge of the local aquifer which is considered the main and adequate water quality. It is also accompanied by high vegetative cover thus the local government should encourage the agriculture sector in order to decrease the terraced lands. The local municipalities should also limit the uncontrolled urbanization which will increase water loss through runoff.

## **6.2. Recommendations**

I recommend several useful future studies and implementations in the future for the local communities and future studies.

### **6.2.1. Local government and communities**

- The local municipalities of the area build up collecting sewers for surface runoff in order to be reused for irrigation purposes.
- The meteorological ministry and local NGO's build meteorological station in the area for correlating other meteorological parameters such as temperature, humidity, solarity and wind speed with precipitation analysis.
- Build up artificial collecting pools for surface runoff in the form of harvesting wells, dams or artificial wetlands which will maintain the diversity of the area for future generations.
- Awareness of the local inhabitants on the sacristry of water in the area since the local aquifer is of great hydrological importance.
- Collecting surface runoff towards an area of high infiltration rate in order to have artificial recharge which will replenish the aquifer.
- Limiting urbanization on the task of agricultural land in order to limit surface runoff and decrease the imperviousness of land cover.
- Encourage farmers to harvest surface runoff near their lands in the form of artificial pools to be used later for irrigation.
- Prevent soil erosion by planting trees and bushes.
- Build up sewage treatment plant in the area to prevent groundwater contamination because of high infiltration rate.

- Protect the local basin from overexploitation through preventing over pumping in the local wells by achieving good water management.
- Upgrade the meteorological stations in the country in order to have adequate data for future analysis especially for hourly records of rainfall which are useful for engineering purposes and hydrological analysis.
- Prepare GIS database on Hydrogeological and Hydrochemical digital database.
- Perform future studies by the local government on runoff, infiltration rate of different soil type for major significant wadis along the West Bank.
- It is recommended to build up a small dam in this watershed for collecting water runoff which will be useful for irrigation and solve the water stress.

### 6.2.2. Future studies

- Field estimation on soil moisture for the study area precisely and for other parts of the West Bank.
- A study on actual evapotranspiration and potential evaporation.
- Computation by the Curve Number method on other parts of the West Bank which has great importance on the aquifers in order to have good sustainable water quality for future generations.
- Actual records of runoff by gauging the surface runoff at Wadi Ta'amira and other important wadis along the West Bank.
- Prepare Digital elevation model for other parts of Bethlehem governorate and other regions in the West Bank.
- A study on the rate of infiltration through a study on the soil type of Bethlehem and other parts of the West Bank.
- Set up water gauges in the watershed will help in comparing the results between the measured values and the data obtained from SCS curve number method, and apply the same method on other watersheds.