Faculty of Graduate Studies

Master Program of Water and Environmental Engineering

Master Thesis

Runoff estimation in Yatta area watershed

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by:

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Abstract

Similar to many Palestinian communities, Yatta area located in the southern part of the West Bank receives a limited quantity of water. The area has more than 70,000 inhabitants, more than 37,000 dunums of agricultural land planted with different types of crops in addition to different commercial and industrial activities (Yatta municipality, 2015).

The general objective of this research is to estimate the potential amount of total direct runoff from Yatta watersheds to be used in the agricultural lands and to evaluate its impact on the socio-economic situation in the study area.

In this research, rainfall received on Yatta area including the amount and variation was analyzed using statistical methods. When the standard deviation values of annual rainfall data were examined, their values were found to be far away from the mean. This reflects the variability of annual rainfall data during the long analysis period.

This research focused on estimating the potential amount of rainfall which could be collected from watersheds within the boundary of the area to be used for enhancing the agricultural lands in the area. The water would help improve crop yields, family income, create jobs and stop the deterioration of the green cover of the city. For this reason, a watershed model was developed using the WMS and the HEC-HMS applications. Accordingly, the rainfall distribution, evapo-transpiration, and physical characteristics of the watersheds were defined.

The watershed in Yatta area and the characteristics of this watershed was defined. WMS model was used to define and delineate this watershed and divide it to five sub basins using the Digital Elevation Model (DEM), land use, and soil type for Yatta area. Land use and soil type were created using the Geographical Information System (GIS). The boundary of Yatta watershed and its sub subbasins in addition to their physical properties are saved and exported HEC-HMS. This model was used to simulate the watershed; accordingly, two models were developed based on hourly rainfall data for Yatta area in 2014/2015 rainy season.

As a result, the runoff coefficient was estimated at (1.6 - 2.4) % which is considered very low due to the low intensity of rainfall as well as its annual amount. The analysis concluded that an average of 90,000 m^3/yr of storm water could be collected and stored in earth pools and cisterns at different locations within the boundary of the watersheds. This amount can be a supplementary source to irrigate around 300 dunums of olives, almond and grape trees in addition to more than 60 dumuns of vegetables. Therefore, this study proved that storm water can still be considered as a potential source of water which could contribute to solving water problems and improving the socio-economic situation.

الخلاصة

كما هو الحال في العديد من المجتمعات الفلسطينية فإن منطقة يطا التي تقع في الجزء الجنوبي من الضفة الغربية تستقبل كميات محدودة من الأمطار. يسكن البلدة ما يزيد عن 70000 نسمة ، وتحتوي على أكثر من 37000 دونم من الأراضي الزراعية المزروعة بعدة أنواع من المحاصيل بالإضافة الى الأنشطة التجارية والصناعية المختلفة (بلدية يطا، 2015).

الهدف الرئيسي من هذا البحث هو تقدير كمية الجريان في مستجمع المياه في منطقة يطا لاستخدامها في الأراضي الزراعية وتقييم تأثيرها على الوضع الإجتماعي الإقتصادي في منطقة الدراسة. في هذا البحث ، المطر المستقبل في يطا متضمنا الكميه والتوزيع تم تحليله باستخدام طرق احصائية. عندما تم فحص قيم الإنحراف المعياري ، فإن قيمه وجدت على أنها بعيدة عن الوسط، وهذا يعكس التغير في بيانات المطر السنوي خلال فترة التحليل.

هذا البحث ركز على تقدير كمية مياه المطر التي يمكن جمعها من مستجمع الماء على حدود البلدة لاستخدامها لتعزيز الأراضي الزراعية في المنطقة. الماء يساعد في تطوير إنتاجية المحاصيل ، دخل الأسر ، توفير فرص عمل وإيقاف تدهور الغطاء النباتي في البلدة. لهذا السبب ، تم تطوير نموذج لمستجمع الماء باستخدام برنامج نظام نمذجة مستجمعات الماء وبرنامج نظام النمذجة المائية. وفقا لذلك ، التوزيع المطري ، التبخر ، والخصائص الفيزيائية لمستجمع الماء تم تحديدها.

مستجمعات الماء في هذه المنطقة وخصائصها تم تعريفها. وقد تم استخدام برنامج نظام نمذجة مستجمعات الماء لتعريف المستجمعات ورسم الخطوط وتقسيمها إلى خمس أحواض فرعية باستخدام نموذج الإرتفاعات الرقمي ، استخدامات الاراضي ، وأنواع التربة في بلدة يطا. تم عمل استخدامات الأراضي وأنواع التربة بواسطة نظم المعلومات الجغرافية. حدود مستجمع الماء والتقسيمات الفرعية بالإضافة إلى الخصائص الفيزيائية تم حفظها وتصديرها إلى برنامج نظم النمذجة المائية. هذا النموذج استخدم لمحاكاة مستجمع الماء ، وفقا لذلك، تم تطوير نموذجين بناء على بيانات المطر لكل ساعة في بلدة يطا للموسم المطري 2015/2014.

كنتيجة لذلك ، تم تقدير معامل الجريان والذي يساوي من(1.6 -2.4)% والذي يعتبر قليل جدا بسبب قلة حدة المطر. التحليل تضمن معدل كمية مطر 90000 متر مكعب/ سنة يمكن تجميعها وتخزينها في البرك الترابية ، الآبار ، والخزانات في مواقع مختلفة داخل حدود المستجمع. هذه الكمية يمكن أن تكون مصدر تكميلي لري ما يقارب 300 دونم من أشجار الزيتون ، اللوز ، والعنب بالإضافة إلى أكثر من 60 دونم من الخضار. وفقا لذلك ، هذه الدراسة أثبتت أن مياه الأمطار سوف تبقى معتبرة على أنها مصدر مهم للماء التي يمكن أن تساهم في حل مشاكل المياه وتطوير الوضع الإجتماعي الأقتصادي في المناطق المشابهة.

إهداء

إلى قدري الأجمل والأوفر حظا ..

إلى من يخجل الفؤاد أن يهديهما مثل هذا العمل المتواضع فهما أعظم من ذلك

~ أمي وأبي ~

إلى من أناروا لي الطريق بمعرفتهم وبمجهودهم

~ أساتذتي الأفاضل ~

إلى مهجة روحي التي لها دق قلبي وأغلى ما أملك

~ خطيبتي وزوجتي المستقبلية الغالية ~

إلى من أستند بهم فهم رفاق العمر وحبهم ولد منذ خلقي

~ إخوتي وأخواتي ~

إلى تراب هذا الوطن إلى أقصانا الشريف

إلى لغة القرآن التى نفتخر بها

إلى الأصدقاء والزملاء الأوفياء

إلى كل من وقف بجانبي وأحبني ومنحني البسمة وساعدني للوصول إلى هنا ولم أتمكن من تذكره

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List of Symbols

A: Area

ca: Capita

CN: Runoff Curve Number

d: Day

DEM: Digital Elevation Model

DSS: Decision Support Systems

FAO: Food and Agricultural Organization

GIS: Geographical Information System

HEC-HMS: Hydrological Engineering Center- Hydrological modeling system

hr: Hour

in: Inch

km^2: Kilometer Square

l: Liter

m^3: Cubic Meter

mm^3: Cubic Millimeter

n: Gauckler–Manning's formula

P: Porosity

Q: Flow

RMS: Root Mean Square

SD: Standard Deviation

SCS: Soil Conservation Service

SRTM DEM: Shuttle Radar Topography Mission, Digital Elevation Model

TIN: Triangulated irregular network

USEPA: United States Environmental Protection Agency

V: Velocity

WCMS: Watershed characterization and modeling system

WHO: World Health Organization

WMS: Watershed Modeling System

yr: Year

Chapter One
Introduction

1.1 Introduction

The West Bank in Palestine suffers from scarcity of water supply due to many reasons including; limited water resources, Israeli occupation which controls most of the water resources in Palestine, increase of water demands due to population growth. For that, increasing stress continues to be placed on the available water resources thus generating a need to find alternative nonconventional water resources (ARIJ, 2010).

The main water resources in Palestine are the Jordan River, wadis and groundwater. Groundwater resources include in Palestine: the Eastern, Northeastern, Western, and Coastal Basins. However, Israel controls all aquifers in Palestine. The West Bank aquifer system discharges approximately 600-660 MCM/yr. Many communities are not connected to sewage network, so a small portion of the wastewater generated reaches treatment plants. The Palestinian water sector is challenged with many problems including: deteriorated infrastructure and services, lack of cooperation and coordination and weakness of existing joint management institutions, and lack of financial resources (Jayyousi & Srouji, 2009).

There are three major uses of water in the West Bank: domestic, agricultural, and industrial. Average water consumption in the West Bank is approximately 64 l/capita/day, which is very low. Many houses have rainwater harvesting systems used to collect rainfall and store it in tanks or cisterns. This water needs treatment to be useful for domestic and agricultural activities (EWASH, 2011).

Climate change influences the Mediterranean countries as many other countries (Meyer et al., 2016). In Yatta area the area of study small and the time period of study is short so no climate change study applied but the weather change in the area studied. There are a number of factors indicating change in weather trends in the Yatta area such as: the amount of rainfall in the last four seasons was less than the historical average rainfall amount (based on an average of 25 years), the summer temperature increased and that of winter decreased, and the number of hot days in summer also increased. As a result of weather change crop productivity also reduced. To solve the problem of water scarcity there is a need to harvest rainfall in proper facilities (ARIJ, 2010).

Without proper management of water resources, excess rainfall can be lost quickly without any proper use due to the high evaporative environment. This situation warrants the focus on planning and implementation of an integrated water resources management plan.

Rainwater harvesting is well-known in Palestine where rainfall is collected from building roof tops and stored in underground cisterns. This water is normally used for domestic and agricultural activities often leading to increase in food production. The system is inexpensive and needs modest amounts of energy to transport the harvested water. People in the West Bank have used this system for many years. Rainwater harvesting systems in Palestine include cisterns, ponds, and other facilities. Water supply in many localities in the West Bank is intermittent, and people use harvested rainwater as a main water source for their uses (Shadeed et al., 2010; Mehrabadi et al., 2013).

1.2 Research objectives

1.2.1 General objectives

The general objectives of this research are to estimate the potential amount of total direct runoff from Yatta that could be used in the agricultural sector and to evaluate its impact on the socio-economic situation in the study area.

1.2.2 Specific objectives

The specific objectives of this research are:

1- Determine the characteristics of the rainfall including: the annual, monthly, average, maximum and minimum rainfall.

2- Estimate the direct surface runoff hydrographs.

3- Estimate the potential quantity of water that can be harvested from Yatta area.

1.3 Problem statement

Water scarcity in Yatta including the limited water supply for agriculture and other sectors needs to be solved. The consequences from these problems are that: agricultural activities and the plant cover are decreased day by day, decreasing of job opportunities and reducing family income**.** To solve these problems there is a need to find additional resources that would provide the residents with the required water. Increasing water harvesting through watersheds could be a good option for solving this problem.

This thesis has addressed Yatta area and its characteristics and suggests the best water management practices. In order to complete this study; an assessment for Yatta area watershed is worked and the amount of total direct runoff is estimated using HEC-HMS model.

1.4 Research questions

This research tries to respond to the following questions:

1- How do rainfall characteristics affect flood events?

2- How do the characteristics of Yatta watershed affect the runoff in the subbasin?

3- How much surface runoff does Yatta area receive from its watershed?

4- How can this runoff affect the socioeconomic situation of Yatta area?

1.5 Risks and Limitations

- The model can only perform with the available data input and will give satisfactory results only if the data is of good quality.
- Changes in physical characteristics of the subbasin and human activities within the sub-basins were not considered in the model simulation.

1.6 Research methodology

The methodology of this research is divided into five main steps:

1- Data gathering: Data collected from many resources depending on the type. The Palestinian Meteorological Department, literature review, and Yatta Municipality were the main resources of collected data including: meteorological and physical data.

2- Data analysis: Rainfall analysis was carried out by analyzing and simulating the records from the rainfall station in Yatta area and surrounding stations. The analysis was conducted with the aid of Geographical Information System (GIS) and Microsoft office (MS) Excel.

3- Conceptual model building: The conceptual model describes the process of runoff within the subbasin, and bulds on simplified concepts derived from physical processes of rainfall-runoff phenomena using Watershed Modeling System (WMS).

4- Numerical model building and analysis: The Hydrologic Engineering Centre - Hydrologic Modelling System (HEC-HMS) application was used to develop a surface water model for Yatta area watershed. Data analysis was made for the output of the model including the flood peak and volume.

5- The final step was to suggest storage facilities for the quantity of runoff volume (size, location and type). After that an assessment of the impact of using harvested water on the socio-economic conditions was conducted.

1.7 Thesis structure

Chapter One: Introduction: introduces the research, its objectives, and problem statement.

Chapter Two: Study area of Yatta area: describes the location and population, climate, water situation, socio-economic conditions, and geomorphologic characteristics of Yatta area.

Chapter Three: Literature review: is a review of relevant technical literature; it includes introduction of watersheds and their characteristics, and an introduction to hydrologic modeling and detailed information about the modeling environment and rainfalldata set selected for this study. This application is Hydrologic Engineering Center's- Hydrologic Modeling System (HEC-HMS).

Chapter Four: Rainfall analysis: presents the results generated from the statistical analysis of the rainfall data collected. The characteristics of the rainfall and possible weather change were studied using MS. Excel.

Chapter Five: Conceptual model: describes the process of runoff within the subbasin.The Conceptual model was built on simplified concepts derived from physical processes of rainfall runoff phenomena.

Chapter Six: Numerical modeling: The HEC-HMS software was used to develop a surface water model for Yatta watershed. The final results of the model are presented and discussed.

Chapter Seven: Best management practices: presents the best methods to manage the amount of storm water that can be collected, and the impacts of harvested water on the socio-economic conditions.

Chapter Eight: Conclusions and Recommendations: draws conclusions from the study and offers recommendations for further research efforts.

Chapter Two

Study area

2.1 Location and population

Yatta is a Palestinian area located 12 km south of Hebron City. It's bounded from Alsamou' in the south, Dora from the west and the Dead Sea from the east. The total area of Yatta area is approximately 185km^2, including an urban area of approximately 32km^2. The population is about 70,000 people with a population growth rate of 3.8%, a population density of3.47 person/dunum, and an average family size of 5 persons/family. The total urban areas are about housing9892 units (Yatta Municipality, 2015). The study area is located between 157211 – 163786East Longitude, and between 91583 – 98133North Latitude. There are a number of villages under the jurisdiction of Yatta area: Alrehiah, Qinan Alnejmah, Zeef, Hriez, Alheilah, Alsadah Wadi, Alma Wadi, Bayyar Al'arous, Aldweer, Khraisah, Qurnat Alras, Almuntar, e'zaiz, Alhadediah, Alkarmel, Qinan Jaber, Khalet Saleh, M'een, Raq''ah, Alqafeer, and Khalet Almiah (Yatta Municipality, 2015; Palestinian Central Bureau of Statistics, 2015). Figure 2.1 shows Yatta area watershed.

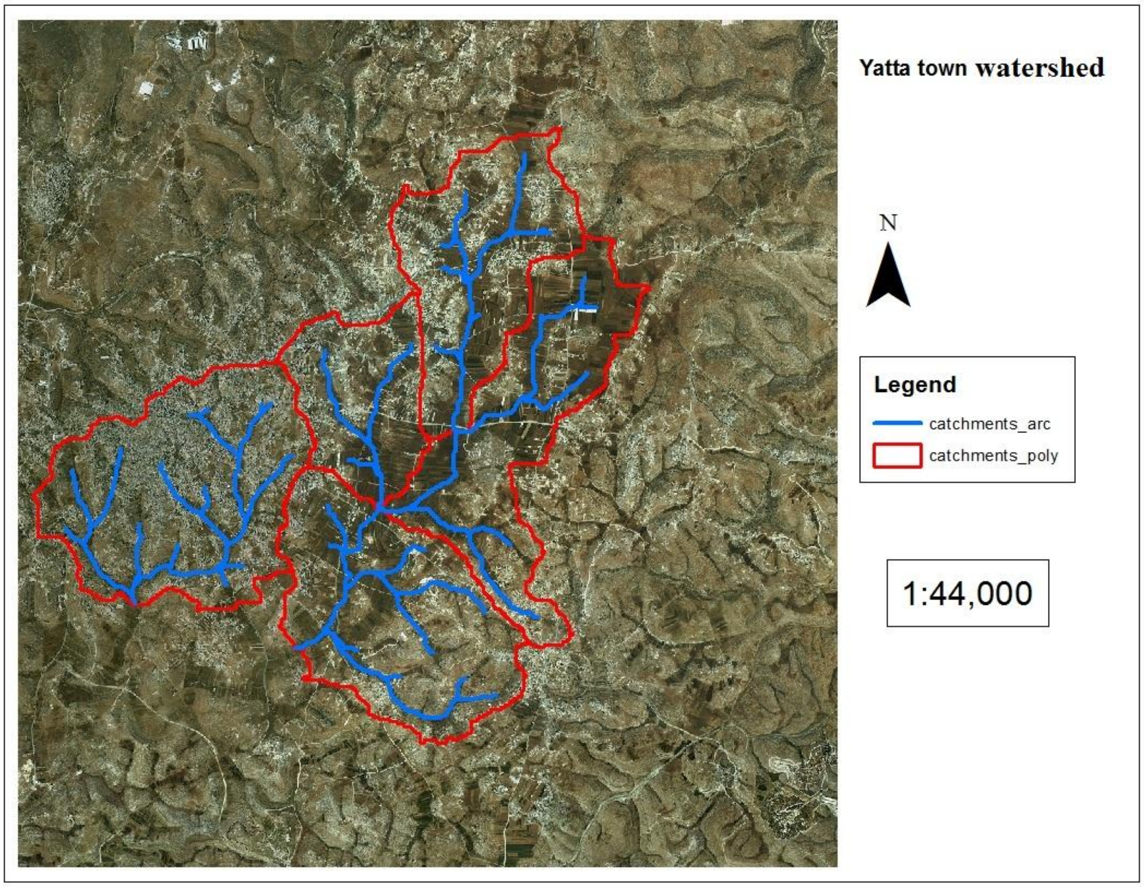

Figure 2.1: Yatta area watershed.

2.2 Climate

In Yatta, the Mediterranean climate is prevalent. The average temperature in the summer is $25C^o$, and in the winter is $8C^o$ (Figure 2.2), the average humidity ratio equals 61% while the mean rainfall is about 370 mm. Figure 2.3 shows Rainfall in mm per month for Yatta area, and average rainfall days per month for seasons 2000 - 2012. The average monthly evapotranspiration (water loss from soil and water bodies - evaporation, and water loss from plants- transpiration) rate ranges from 50 mm/month during the winter season to 200 mm/month in the summer time, see figure 2.4 (Yatta Municipality, 2015; PMD, 2015).

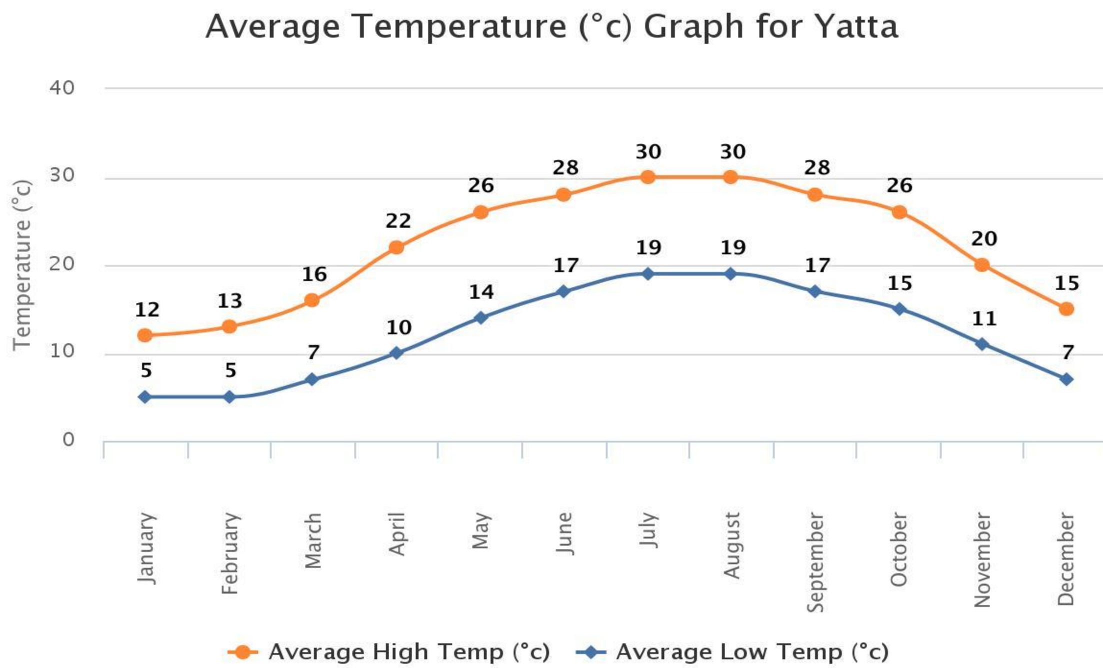

Figure 2.2: Average monthly temperature in Yatta area (World Weather Online, 2016).

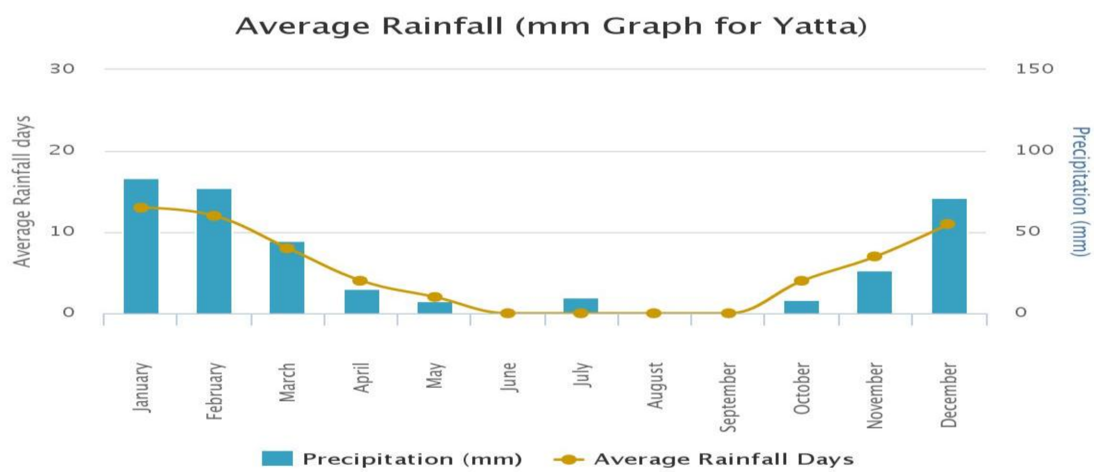

Figure 2.3: Rainfall in mm per month for Yatta area, and average rainfall days per month for seasons 2000 - 2012 (World Weather Online, 2016).

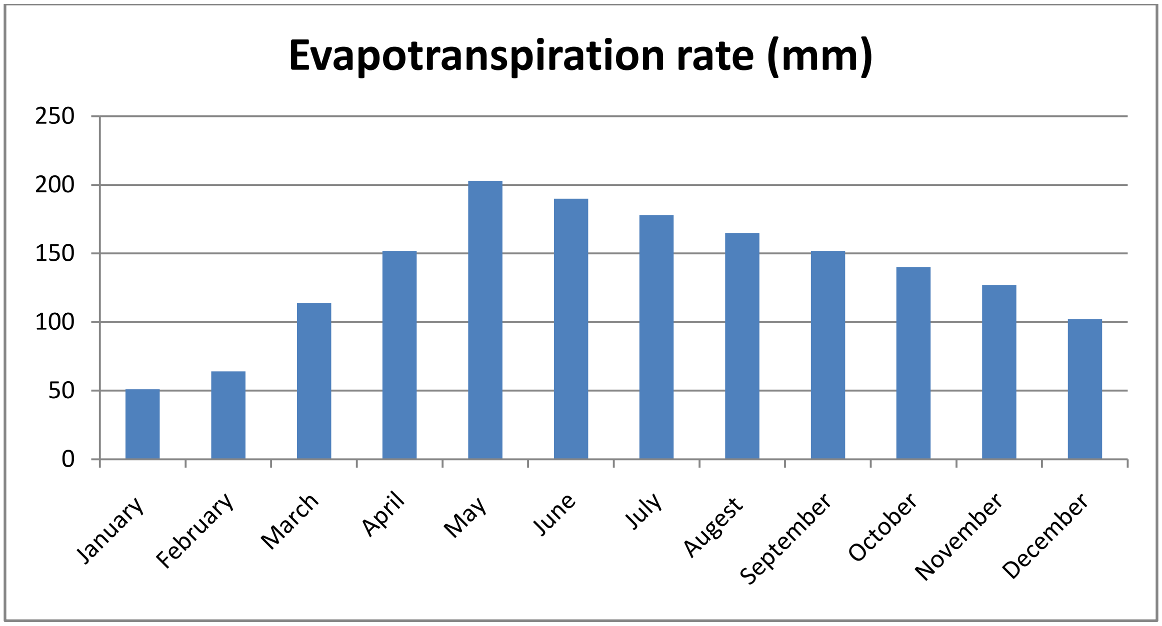

Figure 2.4: Monthly evapotranspiration rate in Yatta area (PMD, 2015).

2.3 Topography

Yatta area is a mountainous area. The average elevation of Yatta area is about 800 m above sea level (Yatta Municipality, 2015). Figure 2.5 shows the contour map of Yatta area.

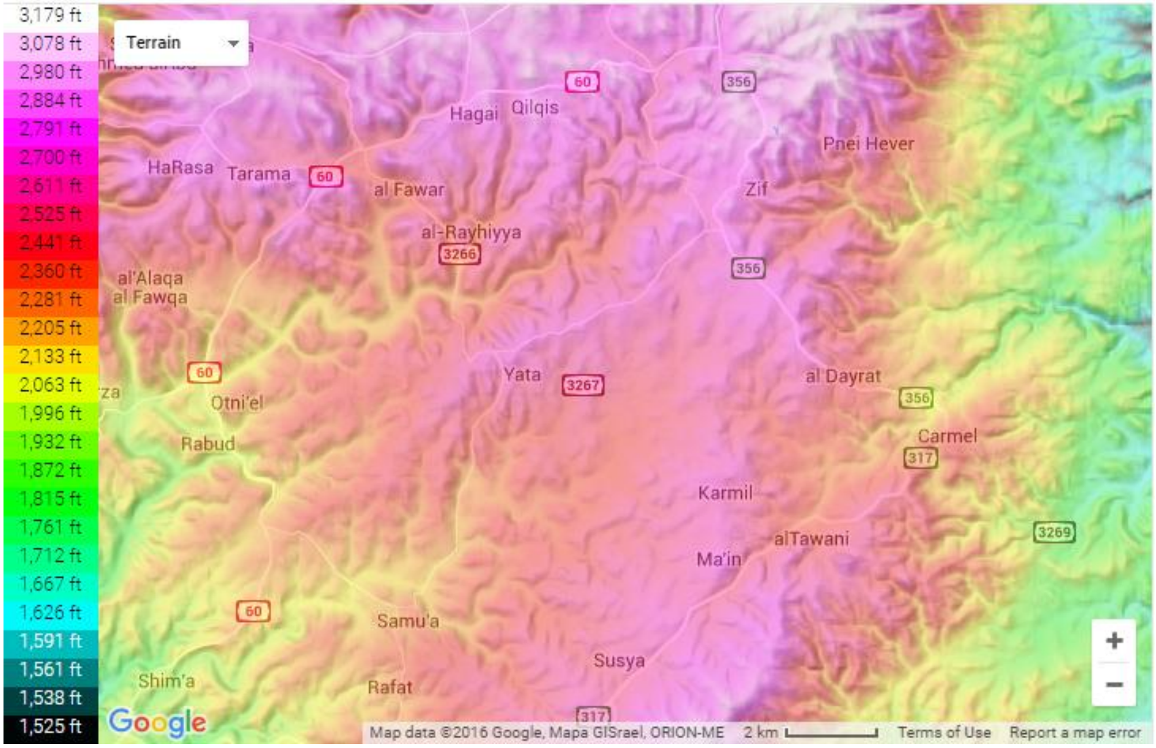

Figure 2.5: Yatta area contour map (Topographic-map, 2016).

2.4 Land use

Land use depends on the various uses for lands in a specific area such as; built up, industrial, agricultural, etc. Impervious, and curve number (CN) (indicates to the amount of rainfall that infiltrates and runoff that is generated) are a physical properties for the area and depends on the land use. Considered as one of the most important properties for watershed modeling and runoff estimation, land use was determined using a GIS application.

Yatta area lies on a total area of 270,000 dunums. 115,000 dunums are considered arable land; however, only 37,578 dunums are cultivated (ARIJ, 2009). Figure 2.6 shows Land use/land cover and the segregation wall in Yatta area.

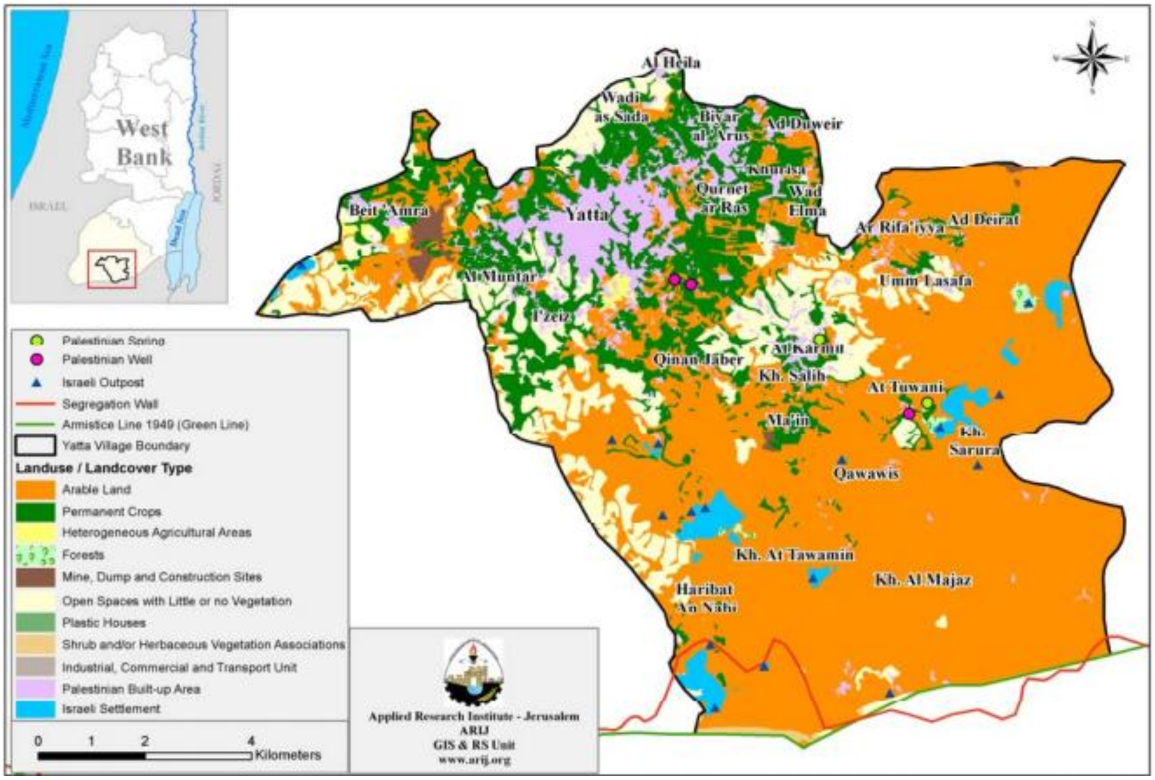

Figure 2.6: Land use/land cover and the segregation wall in Yatta area (ARIJ, 2009).

2.5 Soil

Yatta watershed is mostly hilly and rocky, and soils are often shallow. The main soil type is Terra Rossa. The trend has moved towards non-irrigated annual crops due to the type of soil and the quantity of water available. The main soil constraint is erosion in uncultivated hills (Smith, 2013).

There are four main types of soil which are: Loam, Clay, Sand, and Silt. Other types of soil are a mixture between the main types such as: sandy clay loam, silt clay loam, sandy loam, etc. Each type has its own characteristics such as: Saturation Hydraulic Conductivity (indicates infiltration constant rate), wilting point (indicates moisture deficit; the small amount of water in the soil that leads to canopy death), field capacity (when the small pores are filled with water and the larger are filled with water and air, at this level the growth of canopies is perfect), moisture (amount of water in the soil), salinity, organic matter, potential saturation (if soil pores are filled with water), etc (Smith, 2013).

The soil types, their formulas and their variation in Yatta area shown in figure 2.7. There are four main groups of soils depending on the hydrological behavior:

a- Group A: The hydrologic characteristics of this type are high infiltration rates, and the transmission of water through it is very fast.

b- Group B: The hydrologic characteristics of this type are average infiltration rates, and the transmission of water through it is in average rates.

c- Group C: The hydrologic characteristics of this type are slow infiltration rates, and the transmission of water through it is slow.

d- Group D (K): The hydrologic characteristics of this type are very slow infiltration rates, and the transmission of water through it is very slow (Hydro- Engineering Consultancy, 2015).

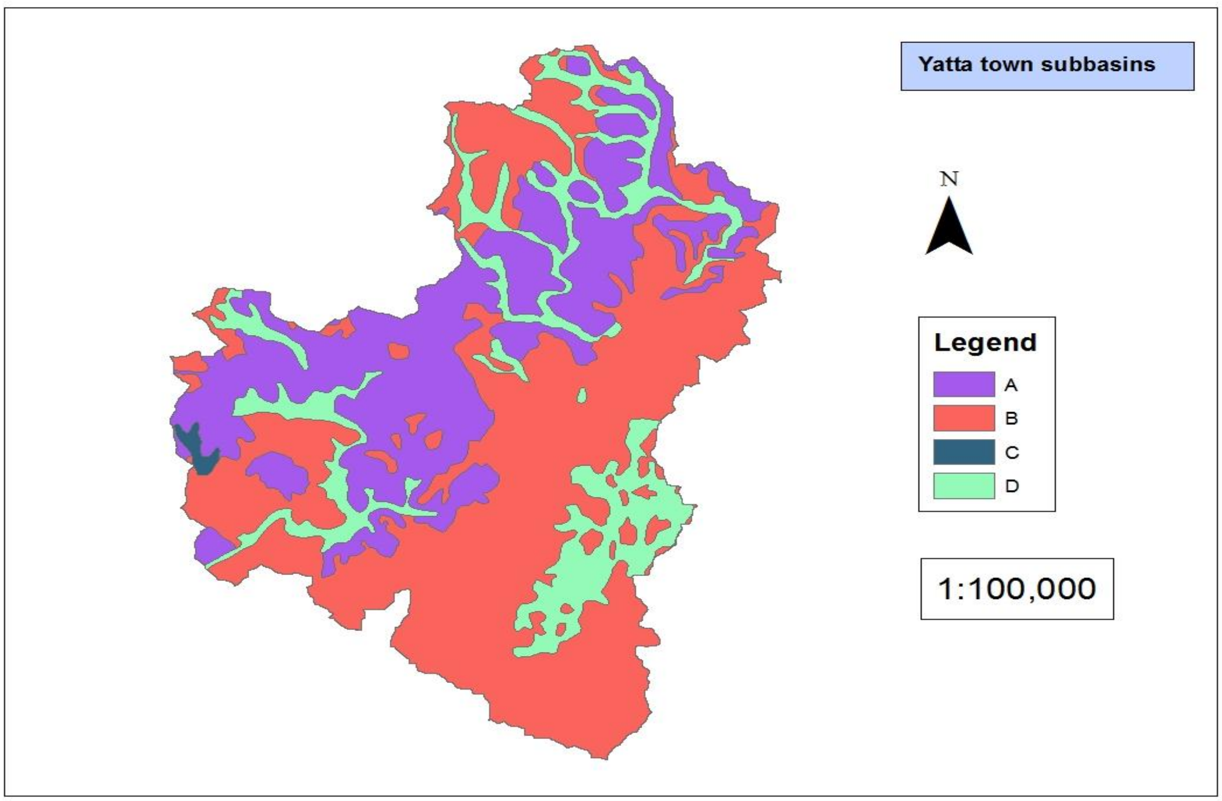

Figure 2.7: Soil types and their formulas in Yatta area (Hydro- Engineering Consultancy, 2015).

2.6 Wastewater and environmental problems

The study area suffers from many environmental problems. It contains a number of industries such as stone cutting companies and other sources of environmental problems such as: untreated wastewater, incorrect and excessive use of pesticides and fertilizers, and leachate from solid waste. Figure 2.8 shows the main pollution sources in the study area. Wadi Alsamn, wastewater stream generated from Hebron City and the adjacent areas, poses as an environmental hazard in Yatta area. Many farmers use this wastewater for irrigation. The wastewater affects soil fertility, produces odors, spreads harmful insects, and causes salt accumulation in the adjacent soil. The total area of lands negatively affected from this wastewater is about 500 dunums (ARIJ, 2015).

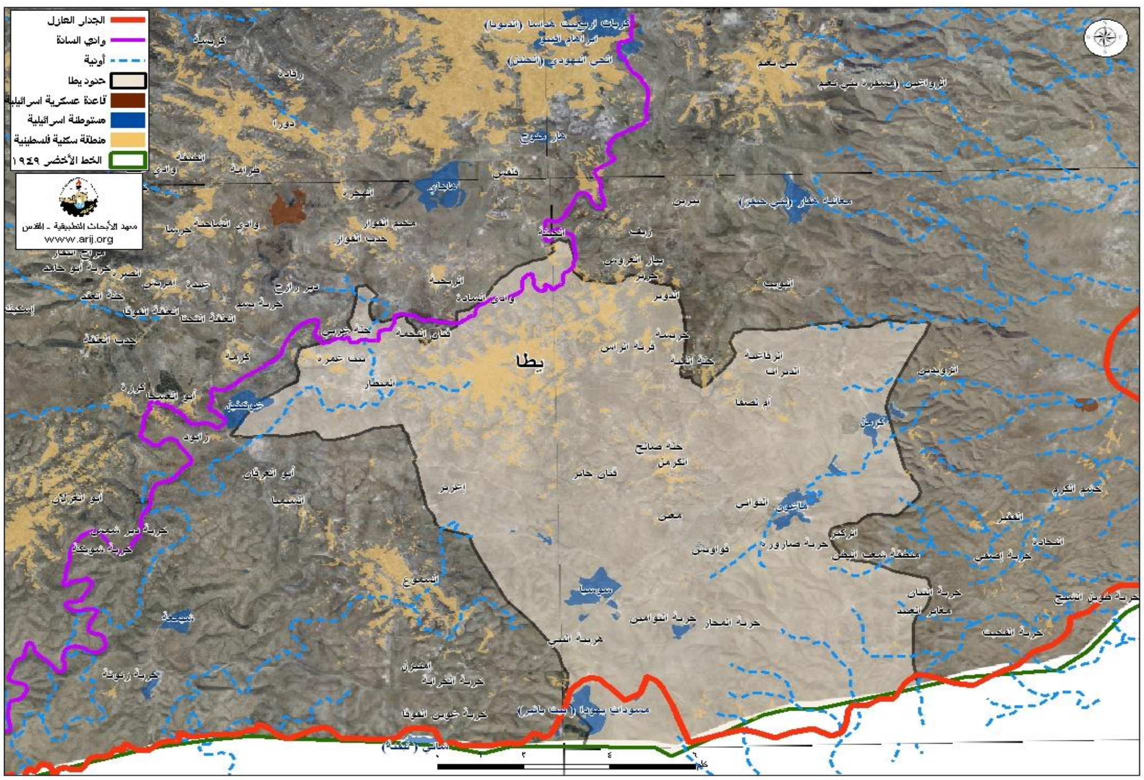

Figure 2.8: Wadi Alsamn stream from Hebron to Yatta area (ARIJ, 2015).

2.7 Water Status

Water is the main source for human life used for many activities such as domestic, agricultural, and industrial activities.

2.7.1 Water Supply

Yatta area has been connected to a water network since 1974, to which almost 85% of the households are connected. The West Bank Water Department is the main provider of purchased from the Israeli Water Company (Mekorot) . The water network supplies water three days a week. The area also has three water reservoirs with total capacity $2{,}700m^3$. These are primarily used to provide water for the area once per week in the summer time. The alternative sources to the water network are cisterns (Yatta Municipality, 2015). Figure 2.9 shows water supply system in Yatta area.

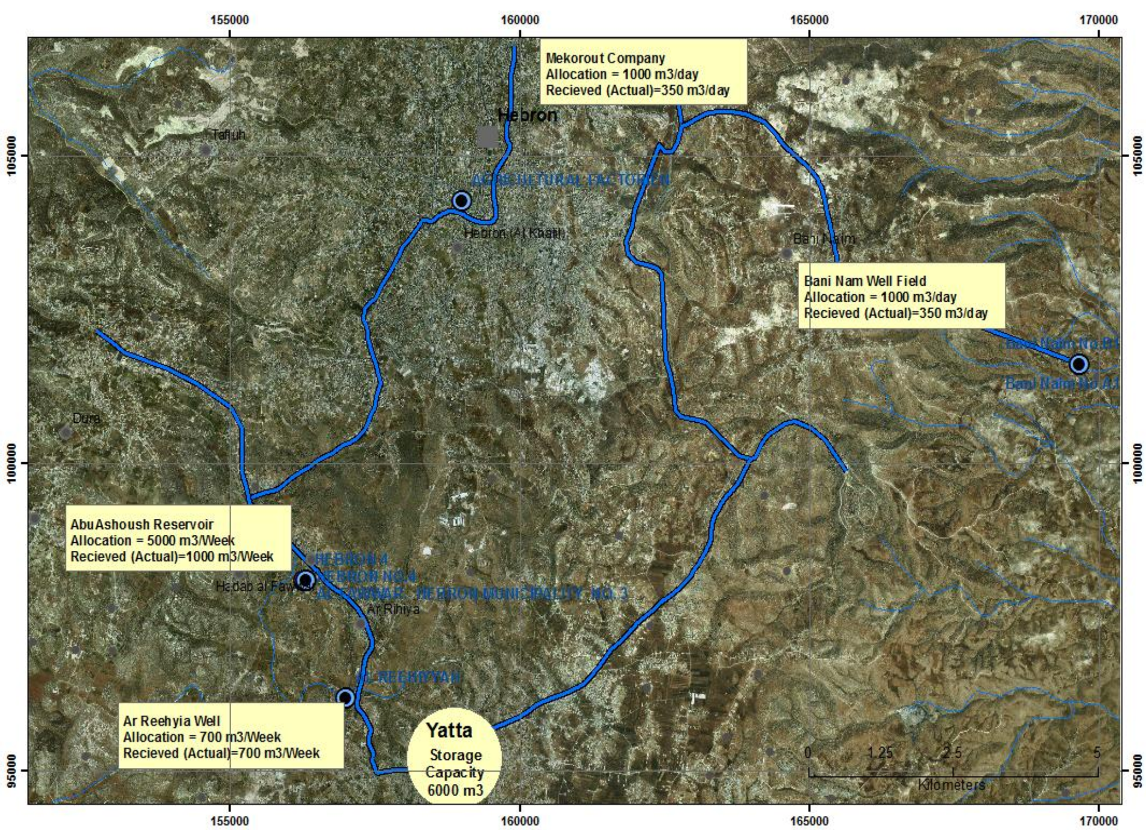

Figure 2.9: Supply system in Yatta area (Hydro- Engineering Consultancy, 2015).

Household expenditure on water in the summer exceeds that in the winter as human activity that depends on water increases during warm weather. However, water sources are scarce in the summer while water availability in the network, cisterns, and springs increases in the winter. It is thus important to collect rainwater in earthen ponds and cisterns to be used in the summer times when there is a lack of water resources.

2.7.2 Water Demand

Water demand is divided into domestic, agricultural and industrial demands.

2.7.2.1 Domestic and industrial demands

Parameters used to estimate the domestic demand include the number of inhabitants, demand per capita per day, industrial demand as a percentage of domestic demand, season, availability of water sources, income etc. The amount of water that people in Yatta need for domestic activities is 7,000 m^3/d (Yatta Municipality, 2015).

To estimate water demand in the future; first there is a need to estimate the number of people in the future through the following equation (Steven et al., 2015):

P= $P_0(1+R)^T$ 2.1

Where:

P: Number of people in the future

P_0: Present number of people

R: Population growth rate =3.8%, and

T: Time period.

To calculate average water demand per day in the future the following equation is used (Steven et al., 2015):

Q= $\frac{qxP}{1000}$ 2.2

Where:

Q: Average water demand (m^3/d)

q: Water demand = 100 l/c/d, and

P: Number of people in the future

Table 2.1: Estimation of water demand in the future for Yatta area.

Year	P (people)	Q (m^3/d)
2020	72660	7266
2030	75421	7542
2040	78287	7829
2050	81262	8126

2.7.2.2 Agricultural demand

In Yatta area water resources are limited while the agricultural land requires a high quantity of water to irrigate plants in this area. Agricultural activities include animal herding and vegetable production.

The cultivated area in Yatta area is nearly 37,578 dunums, mostly (29,425 dunums) rain fed. Assuming that the average agricultural water demand equals 3,000 m^3/dunum/yr (ARIJ, 2009), the total water demand for irrigation equals 24,459,000 m^3/yr.

2.7.3 Consumption

The total amount of water supply through the network is about 1,000 m^3/d, this is equivalent to 14 l/c/d. Water consumption is slightly higher as people supplement their water needs from tanks and water stored in cisterns. The total water consumption equals 41 l/c/d in the summer and 28 l/c/d in the winter (Yatta Municipality, 2015).

2.7.4 Water costs

The cost of water in Yatta area from the water network equals 2.38 NIS/m^3 (NIS=0.26 $US) (Yatta Municipality, 2015). Most of the people in Yatta purchase water from tankers and the vast majority of the households contain cisterns with different sizes. The rainwater harvested in cisterns is mostly collected off of roofs but could also be caught off of roads, open areas and concrete floors. More than 99% of the people do not save the first rainfall in cisterns to clean the roofs and the collection areas, and increase the quality of water in cisterns (Albatsh, 2016).

2.7.5 Water shortage consequences

The lack of water leads to a decrease in plant cover and its yield, meaning that the cost of food increases. People in Yatta area adapt to the shortage of water by: installing special tanks that store rainwater for irrigation, and use drip irrigation and water pumps for more efficient watering. There are many impacts from water shortage on health, land cover, crops yield, employment, and family income. Sometimes people drink low quality water from flowing streams, many of which are contaminated.

2.8 Socioeconomic situation

Most of the people in Yatta area rely on work in Israel as a main income source. The governmental sector is the second largest employer, followed by agriculture (Albatsh, 2016). Figure 2.10 shows the primary income sources of people in Yatta area.

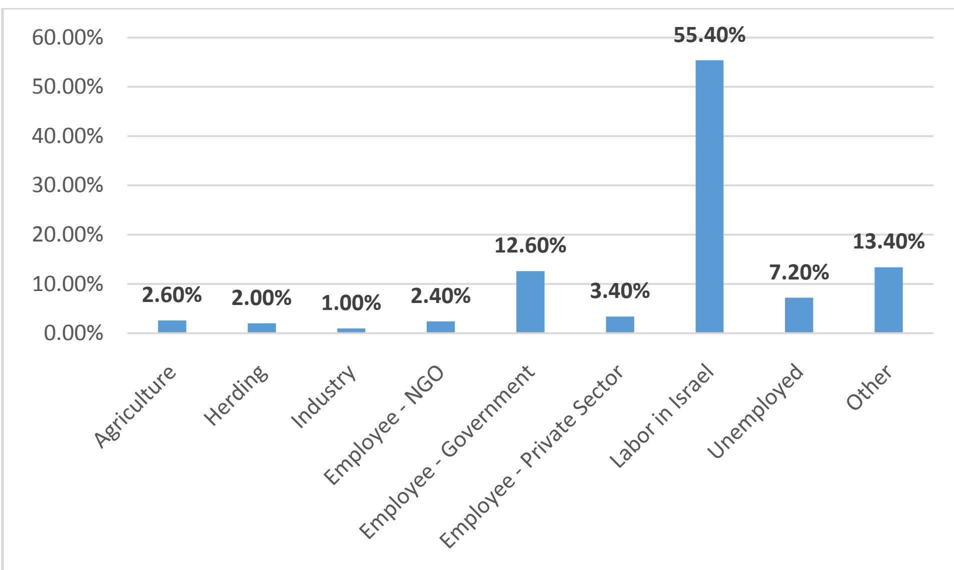

Figure 2.10: Primary income sources of people in Yatta area (Albatsh, 2016).

Agriculture is an important source of income for many people in this area. However, more than half of the arable area is not exploited. Efforts need to be invested to increase the interests and create the adequate conditions for it to improve the economical conditions and provide job opportunities for the people in this area.

Most of the households do not have cisterns dedicated to agricultural activities due to its high cost, or the lack of a subbasin area to collect rain water. More than a half of population have agricultural lands and mostly need water to provide it (Albatsh, 2016). Earth ponds and cisterns could be used to solve this problem. Olive trees and grape vines are more widely cultivated than irrigated crops.

Figures 2.11 and 2.12 show many areas of Yatta area and its agricultural lands.

Figure 2.11: Yatta area.

Figure 2.12: Agricultural land in Yatta area.

Chapter Three
Literature Review

3.1Watershed modeling and storm water generation

A subbasin is the total geographical area contributing to runoff from a given rainfall event as illustrated in Figure 3.1. It may contain flat lands, slopes, forests, wetlands, lakes, and rivers. Runoff as a function of time can be estimated by the evaluation of the subbasin water balance over a long period or with simple as well as sophisticated models (Bengtsson, 1997).

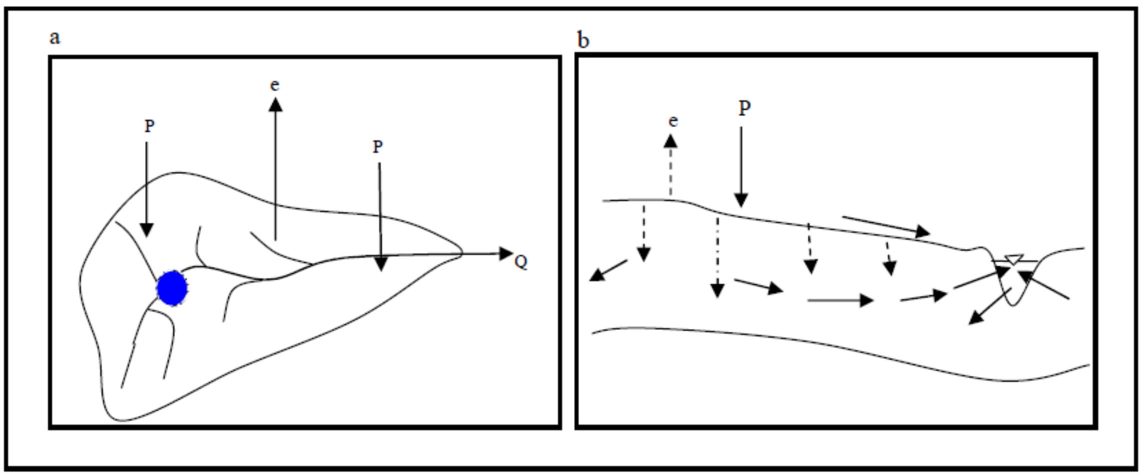

Figure 3.1: Subbasin water balance (Bengtsson, 1997).

The hydrological processes in a subbasin with an area A in m^2 are represented by the simple water balance theory (Bengtsson, 1997):

$\frac{dS}{dt}$= p - e - q.. 3.1

Where:

q: Specific runoff= Q/A (mm/d)

Q: Runoff at the outlet m^3/s.

p: Rainfall intensity (mm/d)

e: Rate of evaporation (mm/d)

t: Time in days

S: Water storage in the area.

Over a long period, storage change is small and runoff can be estimated as p - e. When runoff, precipitation, and storage have been measured, the evaporation can also be estimated over a shorter time scale (Bengtsson, 1997).

3.1.1 Rainfall

Rainfall is the atmospheric input to the landscape and subbasin. Rainfall controlled by the climatic conditions of the atmosphere and the topographical variation of the land. The output to atmosphere is evapotranspiration. The quantity of Rainfall depends on the spatial and temporal variations in the area. These quantities could be estimated using physical and statistical rules (Kilsby, 2000). The amount of Rainfall in Yatta area is not high; however, the evapotranspiration is high especially in the summer.

Rainfall has many forms such as rain, snow, sleet and hail. Rainfall intensity determines many factors such as runoff, flooding, and erosion washing off sediments and pollutants. Rainfall is one of the inputs to hydrological modeling, so the rainfall intensity in Yatta area must be determined. The form of rainfall depends on the temperature of clouds and ground surface. Rainfall in Yatta is mostly received in the form of rain and hail. The rate of rainfall depends on the humidity and vertical speed of the clouds. Clouds with high humidity and high speed produce a high rate of rainfall, but these conditions are not available in Yatta area. Occurrence of rainfall depends on the weather system (Kilsby, 2000).

Spatial variations have many factors such as climate, and topography. Temporal variation is clearer than spatial variation. Time scales in these variations are in minutes-hours, day-night, daily, monthly and annually. As with spatial occurrence of rainfall, there is a substantial random component in the occurrence of rainfall in time at a point. A probabilistic approach (depth-area-duration of intensity-duration-frequency analysis) for describing the temporal variations in rainfall is therefore often used by hydrologists

(Kilsby, 2000). There are many methods to estimate rainfall such as: average rainfall at a site and areal average rainfall over a subbasin (Kilsby, 2000).

3.1.2 Topography

Topography drives watershed boundaries because surface water flows downhill. A watershed is bounded by ridgelines, mountains, and hills. The boundary, or watershed divide, can be defined by connecting the highest points surrounding the drainage area. Figure 3.2 shows a typical watershed and its components. Each particular watershed has its own network of stream channels that drain water from and through the basin. The characteristics of that drainage network play a great part in determining how water moves through the basin and the consequent impacts on water quantity and quality. Large watersheds as Yatta can be broken into smaller drainage basins, called sub-basins, in order to better assess the topographic and hydrologic characteristics of the watershed. It is important to grasp the concept that individual drainage basins are not self-contained entities; they are pieces of a puzzle incorporated into larger surrounding watersheds that represent only a small portion of the greater hydrologic cycle (Environmental Protection Agency, 2012). There are many factors effects and characterized watersheds such as: surface and ground water, and meteorology. These factors affect the time of water flow, and the flow of water (McCammon, 1998). In Yatta watershed there is no ground water flow.

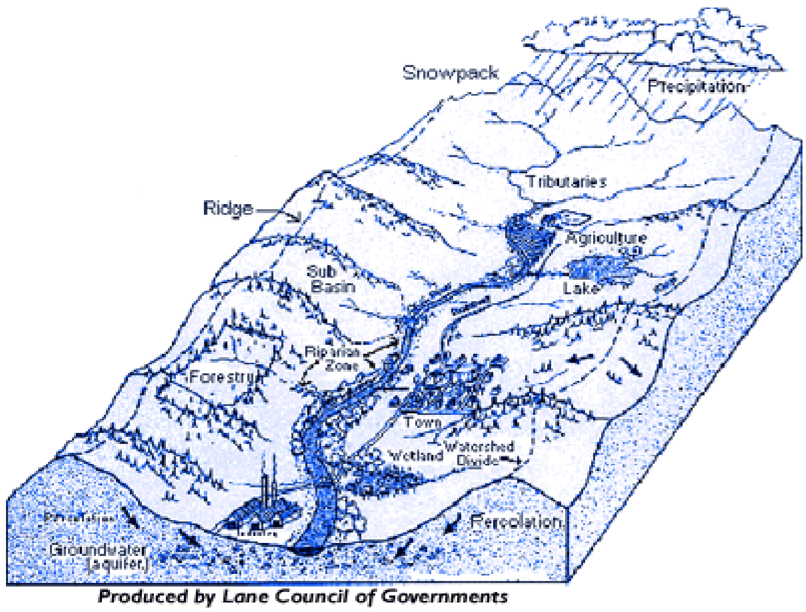

Figure 3.2 Graphical Depiction of a Watershed (U.S. Environmental Protection Agency, 2012)

3.1.3 Land use and soil type

Examining the different types of land use within a watershed can reveal important information about the amount and behavior of runoff on it. GIS (Geographical Information System) based tools help determine land use in Yatta watershed. In the Yatta watershed, land is classified into the following categories: built up area, roads, agricultural areas, and rocky areas. Roads generate the highest amount of runoff while agricultural areas give the lowest amount due to the nature of this area (Kulkarni et al., 2014).

Knowing soil characteristics in Yatta watershed is important to understand the nature of runoff and infiltration through soil in this area. Runoff is sensitive to land use and climate change. The relationship between rainfall and runoff connected with soil, hill slopes, and other characteristics of the subbasin (Quinn, 2000).

The unsaturated zone located between the ground surface and the water table which is very deep. The main components of the near surface zone are soil and rocks, it also contains spaces with water, air and plant roots. Flow in rocks and soil takes place through void spaces. The hydrological properties of rocks and soil depend on the void spaces (Ewen, 2000).

The soil data set provides a good indication of the initial peak flow after the dry period (Wahren et al., 2016). The information about the soil in the area is very important to make decisions about watershed management

3.1.4 Runoff

Runoff is part of rainfall running on the soil surface going into the river, lake and sea. Runoff occurs when rainfall intensity is bigger than infiltration (Nikolopoulos et al., 2013).

3.1.4.1 Subbasin Runoff Generation

When a subbasin receives precipitation; the evapo-transpiration, initial loss, infiltration and detention storage requirements must be satisfied first. The excess rainfall after these abstractions moves over the land surfaces to reach smaller channels. This portion of the runoff is called overland flow. Flows from several small channels join bigger and bigger channels till the flow reaches the subbasin outlet. The flow in this mode, where it travels all the time over the surface as overland flow and through the channels as open channel flow and reaches the subbasin out let is called surface runoff (Subramanya, 2008).

3.1.4.2 Runoff Hydrograph

When a concentrated storm producing a uniform rainfall over a subbasin for duration of hours, the excess rainfall reaches the stream through overland and channel flows after the initial and infiltration losses are met. In the process of translation a certain amount of storage is built up in the first phase of flows and gradually depletes after the rainfall has ceased. The runoff measured at the stream gauging station gives a typical hydrograph, due to an isolated storm, which is known as the runoff hydrograph or storm hydrograph (Chow et al., 1988).

Figure 3.3 shows the hydrograph portraying the relationship between flow and the time. A hydrograph is very important to study flow characteristics and to determine peak flow and its time.

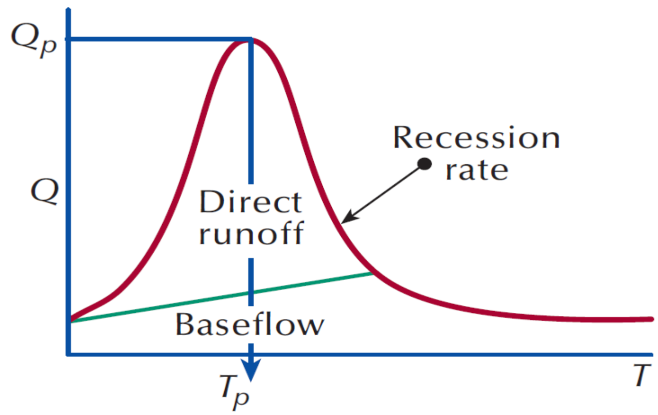

Figure 3.3: Hydrograph (Quinn, 2000).

Where:

Q_p: Peak flow.

T_p: Peak flow time.

Direct runoff: is the rapid runoff and includes: channel precipitation, overland flow, and interflow.

Base flow: is a slow and longer flow and includes: groundwater flow, dry weather flow, and the release of water stored in reservoirs and lakes (Quinn, 2000). There is no base flow in Yatta watershed because there is no groundwater in this area. So the hydrograph start from zero flow and end at zero flow.

3.1.4.3 Effective Rainfall

Effective rainfall is the total rainfall in a given duration from which the rainfall abstractions are deducted. It is part of the total rainfall on Yatta area which becomes direct runoff at the outlet of the Yatta subbasin. When the initial loss and infiltration losses are subtracted from the total rainfall hyetograph the resulting hyetograph is the effective rainfall or excess rainfall hyetograph (ERH) (Chow et al., 1988).

3.2 Parameters used in modeling

Hydrologic parameters include: runoff curve number, time of concentration, lag time, and percent impervious (Petroselli et al., 2013). Time of concentration, lag time, and runoff curve number calculation are initially estimated using the WMS.

3.2.1 Runoff curve number

Runoff curve number indicates the amount of rainfall that infiltrates and runoff that is generated. The runoff curve number depends on the area, soil group and land use. The Soil Conservation Service Curve Number (SCS-CN) is a method developed to estimate the Runoff Curve Number, and is the most widely used method. Curve Number (CN) ranges from 30 to 100. The lower value of curve number indicates lower runoff and higher soil permeability (Petroselli et al., 2013). This number was determined for Yatta watershed based on soil types and land use data using the WMS application to estimate the amount of loss in this watershed.

3.2.2 Travel time basic concepts

1- Time of concentration: Time from the end of rainfall excess to the inflection point on the hydrograph recession curve (as considered in Soil Conservation Service (SCS) method).

2- Lag time: Time from the center of mass of rainfall excess to hydrograph peak (Bill Alley, 1976).

3.3 Best management practices

The geometry of the area, slope, land use, and drainage network are essential factors to manage watersheds (Umrikar, 2013).Watershed management requires cooperation between federal, state, and local stakeholders to integrate bio- physical and socioeconomic processes (Miller et al., 2003).

The improved management of Yatta watershed is expected to have the following impact:
1) Crop yield and productivity, land use and cropping style will change
2) The income of people will increase

3) Unemployment will decrease

4) The awareness about health and education will rise (Shah, 1998; Khajuria et al, 2013).

The intended impacts of watershed management in Yatta area are to raise overall water resources availability, increase the agricultural land area and reduce the erosion of soil (Khajuria et al., 2013).

The storage facilities suggested in Yatta area should be constructed to hold water for domestic, agricultural (irrigation) and industrial purposes (Hagan, 2007).

3.4 Modelling Software

Four software applications were used to develop the model for Yatta watershed; Watershed Modelling System (WMS), Hydrologic Engineering Centre - Hydrologic Modelling System (HEC-HMS), the Geographical Information System (GIS) and Microsoft Excel were used for estimating different model parameters and features for the model.

3.4.1 Watershed Modelling System (WMS)

The Watershed Modelling System (WMS) was developed by the Environmental Modelling Research Laboratory (EMRL) at Brigham Young University in April 2007. At the time, the main software development team at EMRL entered private enterprise as Aquaveo, LLC. It is a comprehensive graphical modelling environment for all phases of watershed hydrology and hydraulics.WMS includes powerful tools to automate modelling processes such as automated basin delineation, geometric parameter calculations; GIS overlay computations (CN, rainfall depth, roughness coefficients, etc.), cross-section extraction from terrain data, and many other tools. WMS supports hydrologic modelling with HEC-HMS. WMS enables the user to select modules in custom combinations, allowing the user to choose only those hydrologic modelling capabilities that are required.

3.4.1.1 WMS steps

Multiple steps are required to produce the necessary layers in WMS Tools (WMS user manual, 2010):

1. A Triangulated Irregular Network (TIN network for Yatta area was inserted to WMS then Converted to Digital Elevation Model (DEM).

2. Flow direction was computed.

3. Flow accumulation is the process that creates the initial stream network. The minimum accumulation was set to $0.25km^2$. The Minimum accumulation area is the minimum drainage area or number of cells that must flow to a single point for a stream to begin. This value was chosen by the analyst based on the topography and extent of the study area.

Figure 3.4 shows the DEM model for Yatta area, the flow direction, and stream network.

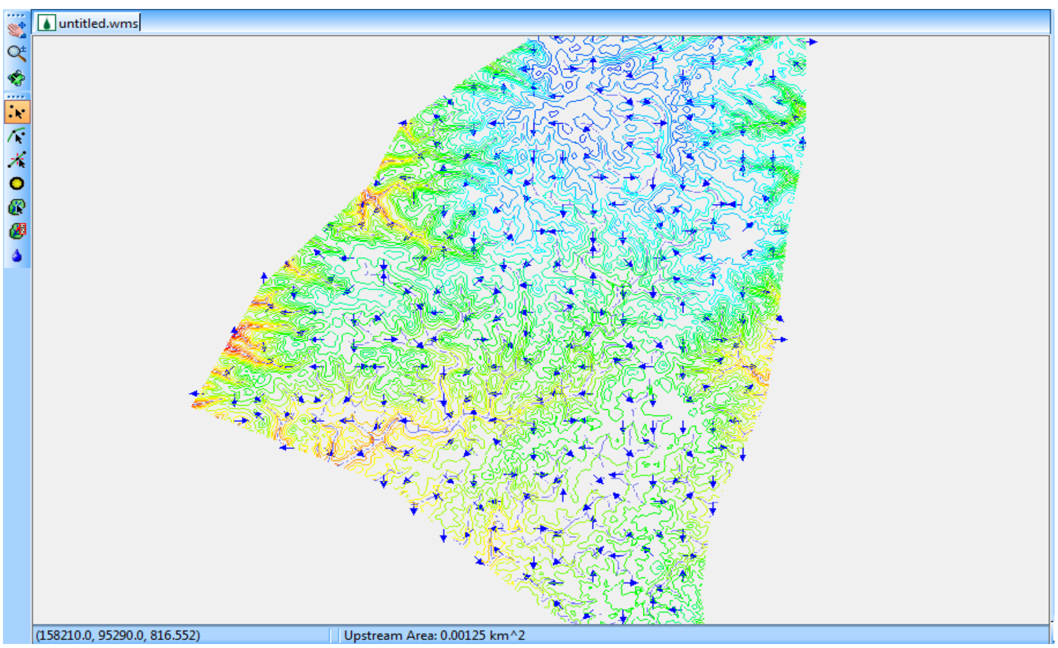

Figure 3.4: Yatta area digital elevation model, flow direction, and stream network.

4. The outlet point for each subbasin was determined to define subbasin polygons.

- **Calculation of CN**

Depending on the soil groups (A, B, C and D) and land use in Yatta area watershed CN was estimated. Table 3.1 shows the CN, land use and soil type for Yatta area watershed. When the runoff CN increases; the amount of runoff will increase due to the nature of land use and the type of soil in this area. Roads have the largest CN values due to the high impermeability of it (United States Department of Agriculture, Natural Resources Conservation Service, 2004).

Table 3.1: Runoff Curve Number depending on the land use and soil group (United States Department of Agriculture, Natural Resources Conservation Service, 2004).

Soil group/ Land use	A	B	C	D
Road	98	98	98	98
Agricultural area	49	69	79	84
Rock area	76	85	89	91
Built up area - high density	61	75	83	87
Built up area - low density	59	74	82	86
Built up	98	98	98	98

- **Calculation of watershed slope**

Slope of the main stream and that of the land slope affect the shape of the hydrograph. Watershed slope has a pronounced effect on the velocity of overland flow, watershed erosion potential, and local wind systems. Average basin slope is defined as (Singh, 1992).

To calculate the slope of Yatta area watershed the following equation will use:

$S = h/L$ 3.2

Where:

S: the average basin slope (m/m),

h: difference between maximum and minimum elevations (m) and

L: the horizontal distance (m) over which the fall occurs.

Larger slopes generate more velocity than smaller slopes and hence can dispose runoff faster.

3.4.2 Hydrologic Engineering Centre- Hydrologic Modelling System (HEC-HMS)

HEC-HMS is designed to simulate the precipitation-runoff processes of dendrite watershed systems. It is designed to be applicable in a wide range of geographic areas for solving a broad range of problems, from large river basin water supply and flood hydrology to small urban or natural watershed runoff. Hydrographs produced by the program can be used directly or in conjunction with other software for studies of water availability, urban drainage, flow forecasting, future urbanization impact, reservoir spillway design, flood damage reduction, floodplain regulation, wetlands hydrology, and systems operation. The HEC-HMS modeling environment was developed by the U.S. Army Corps of Engineers (Feldman, 2000; Hydrologic Engineering Center, 2010; Halwatura et al., 2013).

Evapotranspiration, Rainfall, and snow melt were included as meteorological data. But in this model snow melt was not considered because there was no snow fall on Yatta area during the winter season 2013-2014 (Hydrologic Engineering Center, 2010). Many researchers have used rainfall--runoff simulation methods in HEC-HMS (Arekhi et al., 2011). To calculate the peak of flood and the nature of flood the Unit Hydrograph Methods and Watershed Models are used (Kalita, 2008). HMS model was used to study the effect of rainfall on watershed hydrology. The type of model to be used was selected based on the aim of the model and the characteristics of the basin (Hunukumbura et. al., 2008; Bajwa and Tim, 2002). The characteristics of Yatta area watershed were determined using WMS.

3.4.2.1 Subbasins process

A sub-basin is an element that usually has no inflow and only one outflow. It is one of only two ways to produce flow in the watershed model. Outflow was computed from meteorological data by subtracting losses, transforming excess rainfall and adding base flow. Sub-basin elements represent the subdivided areas of a watershed (Hydrologic Engineering Center, 2010). Yatta watershed sub-basins methods are:

1. Canopy method

This method was used to represent the presence of plants in the landscape and for reductions in rainfall based on plant interception. When rainfall occurs, the canopy interception storage fills first. Intercepted rainfall is mostly evaporated, thereby reducing the rainfall available for direct flow (Huang et al., 2005).

Two of the substantial components on the water balance are the canopy interception and evapotranspiration from plants. Moisten plants have the highest evaporation rates (Stewart, 1977). Canopy interception loss is 10%–30% of the total rainfall (Zinke, 1967; Crockford and Richardson, 2000; Gash et al., 1979).

Yatta area is an agricultural area and has many canopies and plants. These plants reduce the amount of rainfall that reaches to the surface due to canopy interception. This leads to a decrease in the amount of surface runoff.

Canopy methods are:

a. Simple Canopy

All the rainfall will be objected while the storage ability becomes full. When the storage capacity is full rainfall drops to the surface or to the soil directly depending on the land cover. The excess evapo-transpiration from this process is emptied to the surface and soil. During rainfall there is no evapo-transpiration and the storage of canopy is filled. If there is no rainfall the storage is empty (Hydrologic Engineering Center, 2010; Irmak et al., 2013).

b. Gridded simple canopy

Gridded simple canopy is an implementation of simple canopy on network cell foundations. Every network cell has a unique value compared to others (Hydrologic Engineering Center, 2010).

2. Surface method

The surface method is used to represent the ground surface where water may accumulate in depression storage areas. Net rainfall accumulates in the depression storage areas and infiltrates as the soil has capacity to accept water, thereby reducing the rainfall available for direct flow. Water in surface interception storage is rainfall not captured by canopy interception and in excess of the infiltration rate. Rainfall is held in surface interception storage until it is removed by infiltration and evapotranspiration (Hydrologic Engineering Center, 2010; Ge et al., 2015).

Surface methods are:

a. Gridded simple surface

Gridded simple surface is an implementation of simple surface on network cell foundations. Every cell has different value from the others, and separate rainfall through fall (Hydrologic Engineering Center, 2010).

b. Simple surface

In this method all rainfall received is stored in the soil until the storage capacity becomes full. In this case the rainfall rate is greater than the infiltration rate (Hydrologic Engineering Center, 2010). Effective depth is the amount of water stored in the in soil (Hydrologic Engineering Center, 2010).

3. Loss method

The Loss method represents the actual infiltration within the sub-basin. A total of ten different loss methods are provided within HEC-HMS. Some of the methods are designed primarily for simulating events while others are intended for continuous simulation. Deficit and constant loss were used to estimate the amount of loss. This method was used to calculate the change in moisture contents using one soil layer.

a. Deficit and Constant Loss

This method is used to calculate the change in moisture contents using one soil layer. If the soil layer is saturated infiltration will begin. This method uses with evapo-transpiration calculation in the meteorological model to drain the soil stratum during rainfall (Hydrologic Engineering Center, 2010). This method is the best method to estimate the amount of loss and depends on the impervious percent for the area (Halwatura et al., 2013).

Figure 3.5 shows the conditions of deficit and constant loss method. The first condition is the initial deficit in mm which is the quantity of water to needed to fill the soil stratum to the largest value. The second condition is the maximum deficit in mm which points to the quantity of water that could be held by the soil stratum. The infiltration rate after saturation is the constant rate, this value depends on the soil type (for example the Loam Silt soil the saturation hydraulic conductivity is 0.138 in/hr (3.5 mm/hr)) as shown in Figure 3.6 which represents the soil water characteristics for this type of soil (Hydrologic Engineering Center, 2010).

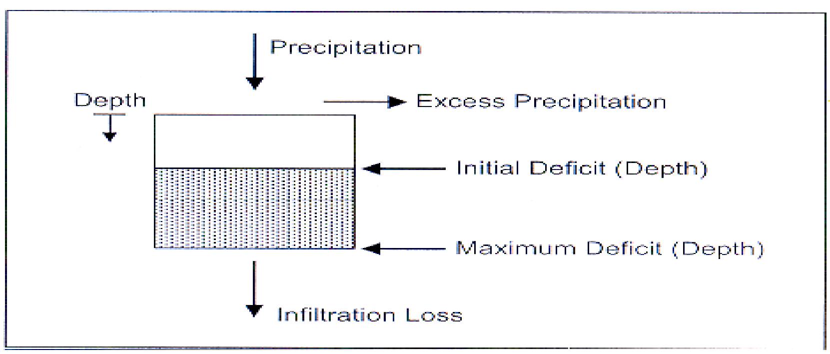

Figure 3.5: Deficit and Constant Loss Method.

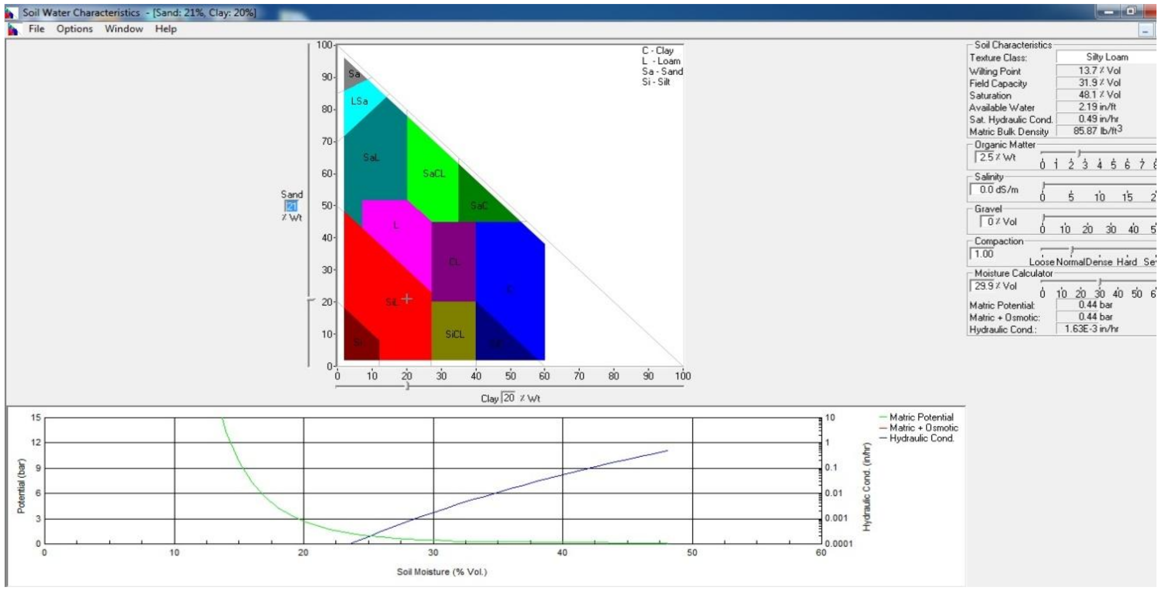

Figure 3.6: Soil water characteristics for Silt Loam soil.

An impervious area is the area where the rainfall flow is not absorbed or drained. Roads, roofs, and rocks are examples for impervious areas (Center for Watershed Protection, 2003). This area increases the amount of runoff and the peak discharge (Page et al., 2015).

4. Transform method

Surface runoff calculations are performed by the Transform Method. Seven methods are available in HEC-HMS. One of which was used in this study was the SCS Unit Hydrograph (UH) (Hydrologic Engineering Center, 2010).

a. SCS Unit Hydrograph Transform

The SCS Unit Hydrograph Transform Method has been evaluated for HEC-HMS using gauge rainfall data; noting that it is not well suited for gridded rainfall data (Hydrologic Engineering Center, 2010; B´ardossy, 2000). The SCS Unit Hydrograph Transform Method was used to estimate the amount of transformation of excess rainfall to direct runoff on the surface (Hydrologic Engineering Center, 2010).

5. Base flow Method

Subsurface calculations are performed by a base flow method. Four methods are available in HEC-HMS (Hydrologic Engineering Center, 2010). It indicates groundwater and wastewater flow through the watershed.

3.4.2.2 Reach process

Reach element is a system which contains inputs (one or more than one inflow) and one output (outflow). To compute outflow the Open Channel Methods can be used (Hydrologic Engineering Center, 2010).

1. Routing method

While a reach conceptually represents a segment of stream, the calculations are performed by a routing method contained within the reach. Six methods are available in HEC-HMS one of which was investigated for use in this study was the Muskingum-Cunge. The Kinematic Wave Routing Method is best suited to steep slopes and engineered channels (Hydrologic Engineering Center, 2010). The Muskingum-Cunge is applicable to a wide range of applications; therefore this routing method was used for this study. The Muskingum-Cunge routing method is based on the conservation of mass and the diffusion representative of the conservation of momentum. It is sometimes referred to as a variable coefficient method because the routing parameters are recalculated every time step based on channel properties and depth of flow (Chow et al., 1988; Crago et al., 2000; Fallah-Mehdipour et al., 2013).

Surface coarseness and tortuosity are the major factors that the Manning Coefficient (n) depends on. The n value changes through the reach of channel and decreases when the phase of flow increases in natural streams. In this model its equals to 0.05 depending on the natural of the channel (The United States Department of Transportation – Federal Highway Administration, 2008).

The Routing procedure is used to move the discharge hydrograph from one sub-basin through the channel network to the outlet of the next sub-basin downstream. This method requires the following parameters:

1. Length: equal to the total length of the reach element. This value is usually measured from maps of the watershed.
2. Manning's n roughness coefficient: is the average value for the whole reach. This value can be estimated from pictures of streams with known roughness coefficient, equal to 0.05.
3. Shape of the reach: represents the general shape of the reach cross section. The HEC-HMS provides five options of cross section shapes; circle, eight point, rectangle, trapezoid, and triangle. Depending on the selected shape, additional information will have to be entered to describe the size of the cross section shape. In Yatta area watershed, the trapezoidal shape was selected. Accordingly, the average cross section width and side slope were entered (Song et al., 2011; Fallah-Mehdipour et al., 2013).

The resulting flow at the outlet for each sub-basin, represented by the direct runoff hydrograph, is routed to the outlet of the watershed by using routing model (Yawson et al., 2005).

2. Loss/ Gain Method

While a reach element conceptually represents a segment of stream or river, optional modeling of interactions with the subsurface is performed by the Loss/Gain method contained within the reach. The Loss/Gain method represents losses from the channel to the deep soil/groundwater. There are two different Loss/Gain methods provided by HEC-HMS.

By using the Muskingum- Cunge method:

Submerged area= wetted perimeter* reach length... 3.3

The rate indicates flow rate per area. Submerged area multiplied by this rate results in the channel loss for a specific interval of time (Hydrologic Engineering Center, 2010).

This rate indicates infiltration capacity per area and depends on the porosity of soil, and the moisture content of soil (Food and Agriculture Organization of the United Nations, 2015). Figure 3.7 displays this rate estimated to equal 0.0005 m^3/s/1000 m^2 at 30 minutes and a clay soil type. The X- axis represents the time in minutes and Y- axis represents the infiltration capacity for the soil types (clay, loam, sandy loam and sand) in mm/hour.

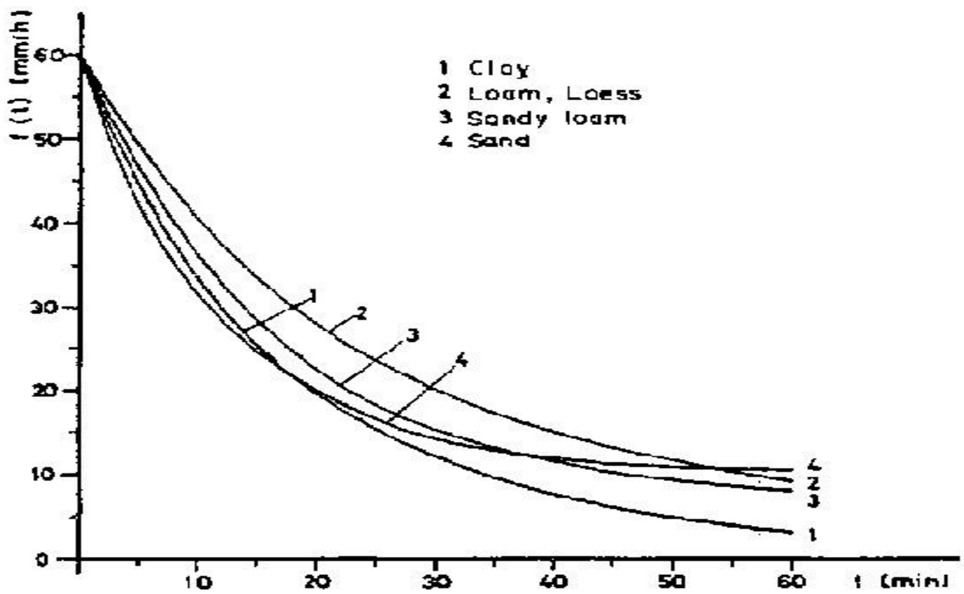

Figure 3.7: Infiltration capacity curves for different soil types (Food and Agriculture Organization of the United Nations, 2015).

Chapter Four

Rainfall Analysis

4.1 Data collection

All data and information regarding rainfall values needed for modeling have been gathered from: (1) Palestinian Meteorological Department (PMD), (2) Yatta Municipality, (3) field visits, (4) interviews, and (5) literature review. The data collected is needed to analyze rainfall, study the possibility of weather change in Yatta area, and apply the suitable model to estimate the amount of runoff in Yatta area watershed.

4.1.1 Rainfall and meteorological data collection

Rainfall and meteorological data for Yatta area were collected during field visits, from Yatta Municipality, and the PMD.

4.1.1.1 Hourly rainfall data for Yatta area watershed for rainy season 2014-2015

The first part of rainfall data was obtained during a field visit to Yatta area and Yatta municipality. The data contains hourly rainfall measurements for Yatta area for the 2014-2015season, and were used in the model. To measure the amount of rainfall (mm) on the Yatta area a rain gauge was used. This device measures the hourly rainfall data (mm/h). The information is needed to complete this research and make the model and reach the final results. Figure 4.1 shows the main part of a rain gauge which gives the following data: Temperature (room temperature, outside temperature), humidity, wind speed, elevation from sea level, the geographical location, time, sunrise and sunset time, moon phase, and wind speed and direction. The gauge gives the hourly rainfall data for Yatta area.

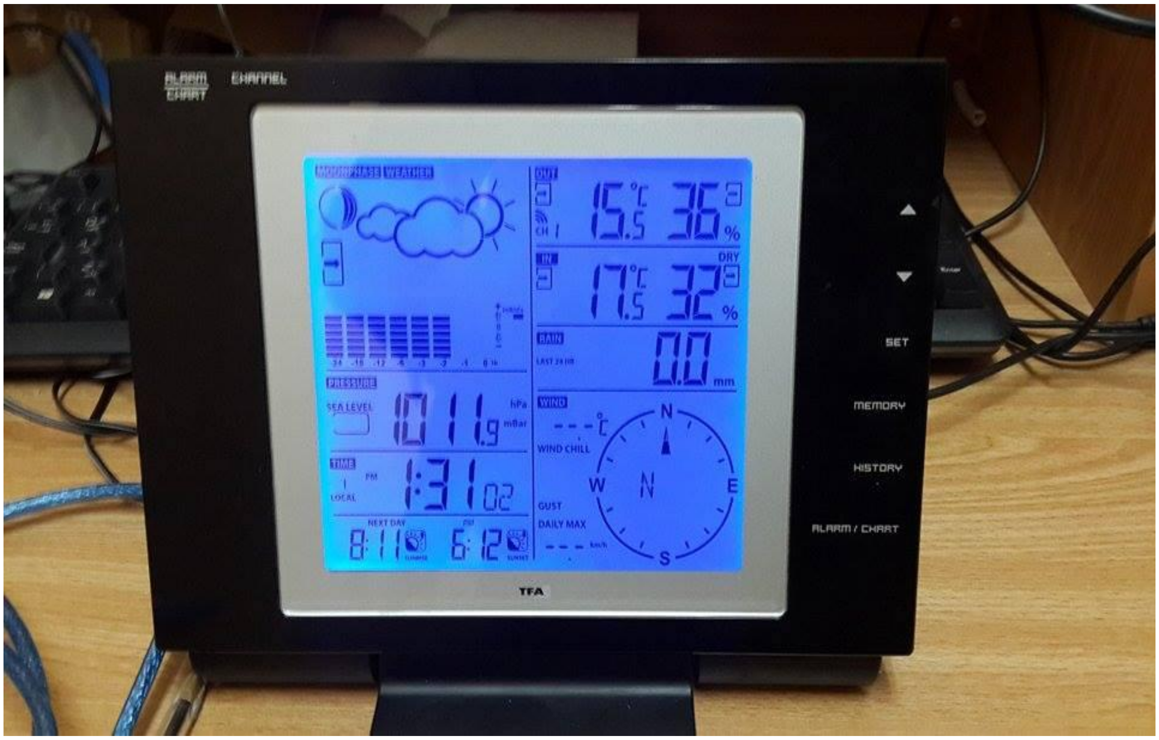

Figure 4.1: Rain gauge.

4.1.1.2Annual, monthl, and daily rainfall data for Yatta area watershed

These data obtained from PMD contain daily, monthly and yearly rainfall data. Rainfall data was collected from five stations surrounding the watershed: Yatta, Hebron, Bani Na'im, Dura, and Al Samou') for the past sixteen years (2000-2015). Yatta station located at elevation 810 m above sea level, and at coordinates 158594.249 in latitude and 95131.395 in longitude. Figure 4.2 shows the location of rainfall stations in Yatta and adjacent areas.

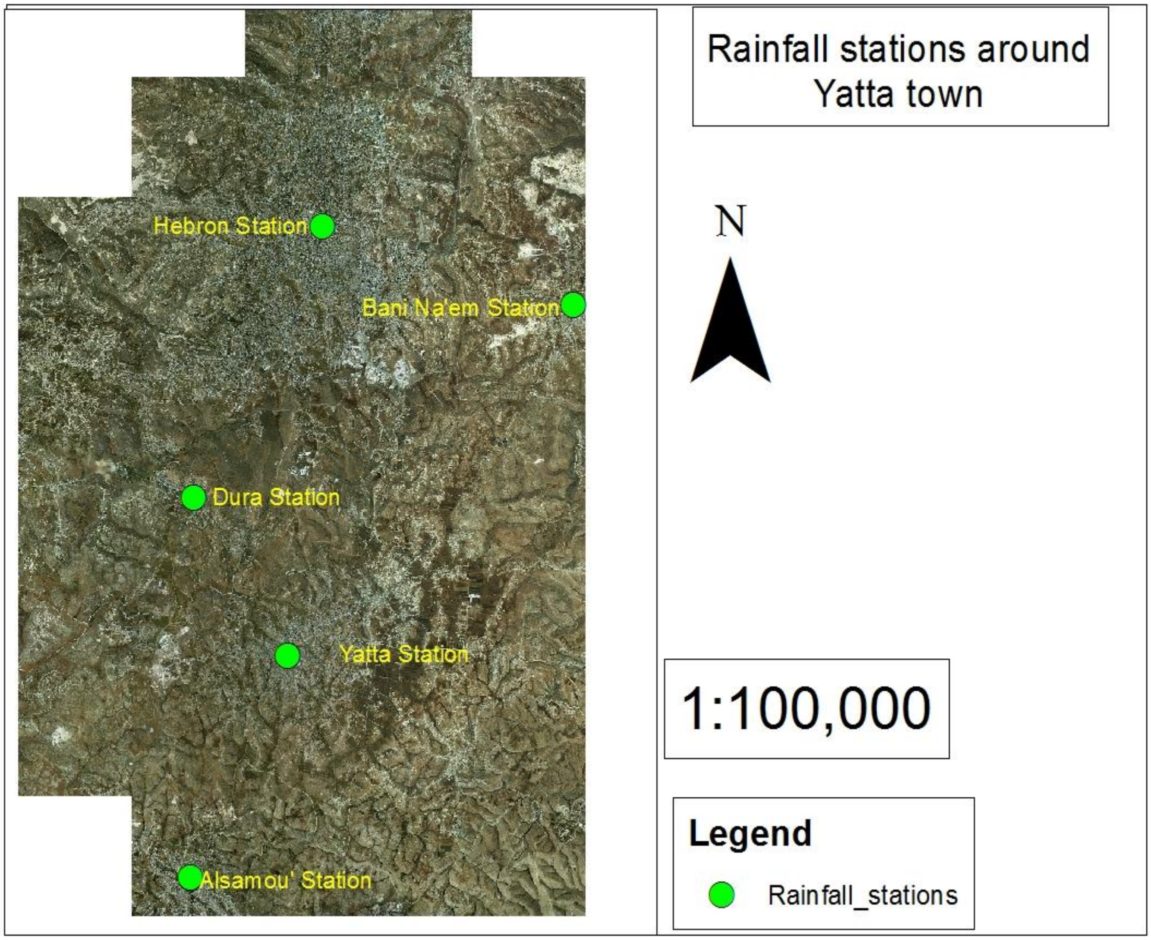

Figure 4.2: Location of Rainfall stations in Yatta and adjacent watersheds.

4.1.1.3 Monthly evapotranspiration rate data for Yatta area watershed

In this model the monthly average evapotranspiration was used. This method depends on the measured evaporation and depends on many factors such as precipitation, moisture content, temperature, etc. The monthly evapotranspiration rate data were obtained from PMD. These values are ((51, 64. 114, 152, 203, 190, 178, 165, 152, 140, 127, 102) mm/ month) respectively from January to December. The maximum rate was recorded in the summer and the minimum rate was in the winter due to the previous factors for each season (PMD, 2015).

4.2 Statistical analysis for rainfall data

This section presents the results of rainfall data analysis for Yatta area. This analysis aims to determine the main characteristics of rainfall and possible weather change, and was carried out using MS. Excel.

4.2.1 Annual rainfall data

Since one of the main distinctive features of arid and semi-arid areas is the temporal variability of rainfall; statistical analysis was conducted on the available data to determine the mean, standard deviation (SD), as well as maximum and minimum rainfall data records. Table 4.1 summarizes the statistical analysis of annual rainfall data records from the five stations.

Table 4.1: Statistical analysis for the annual rainfall data for the selected stations.

Parameter (mm)	Yatta Station	Bani Na'im Station	Hebron Station	Dura Station	Al Samou' Station
Mean	385	403.2	482.3	432.2	305.5
SD	116.2	97.4	123.8	116.6	106.1
Maximum	537	572.4	721.6	654.3	516.5
Minimum	218.8	266.6	329.3	316.1	174.2

From Table 4.1 it is noticed that the values of standard deviation are far away from the mean, indicating the variability of annual rainfall data during the analysis period. There is a noticeable difference between the maximum and minimum rainfall records. The maximum values in the five stations were recorded in the wet season 2002-2003, while the minimum values were recorded in the dry season 2010-2011 (Shadeed et al., 2008).

Table 4.1 and figure 4.3 show the annual rainfall in Yatta and adjacent cities during rainy seasons 2000-2001 to 2014-2015 except 2004-2005, 2012-2013, 2013-2014 seasons. The mean annual rainfall in Al Samou' is smaller than that of Yatta, the mean annual rainfall in Yatta is smaller than that in Bani Na'im, the mean annual rainfall in Bani Na'im is smaller than Dura, while the mean annual rainfall of Dura is smaller than in Hebron.

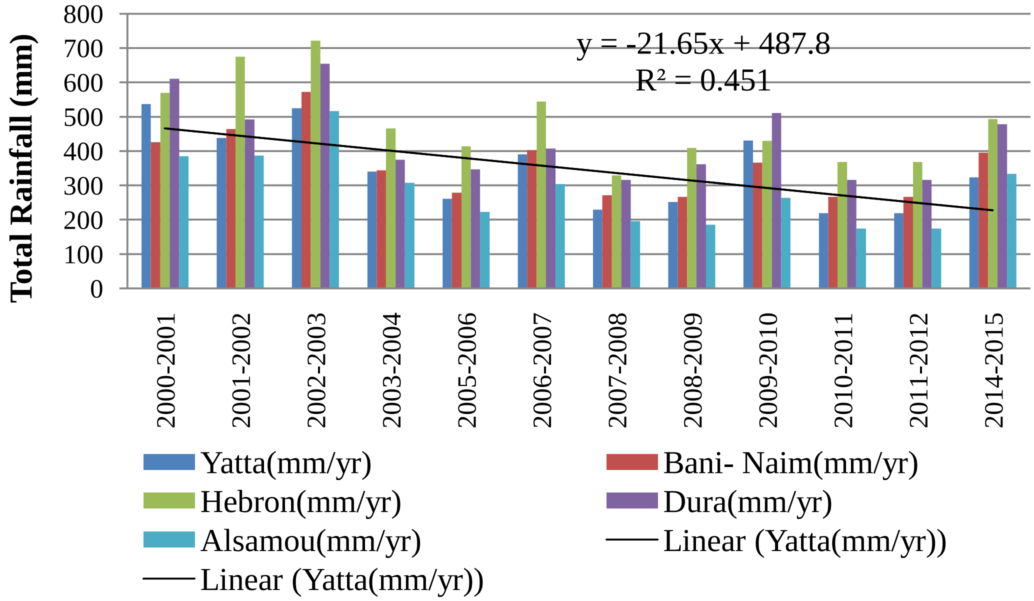

Figure 4.3: Variation of annual rainfall in Yatta and adjacent cities (PMD, 2015).

Figure 4.4 shows the annual rainfall for Yatta area from season 1967/1968 to season 2012/2013. It is evident that the annual rainfall among the zones under consideration could best be described as oscillatory. The trend line is straight and indicates that the average annual rainfall for these years equals 385 mm/yr. Season 1973/1974 has the highest amount of annual rainfall and equals 600 mm/yr, while season 2010/2011 has the lowest amount which equals 218.8 mm/yr (PMD, 2015). Figure infers that in 7 out of 23 years the annual rainfall was above average.

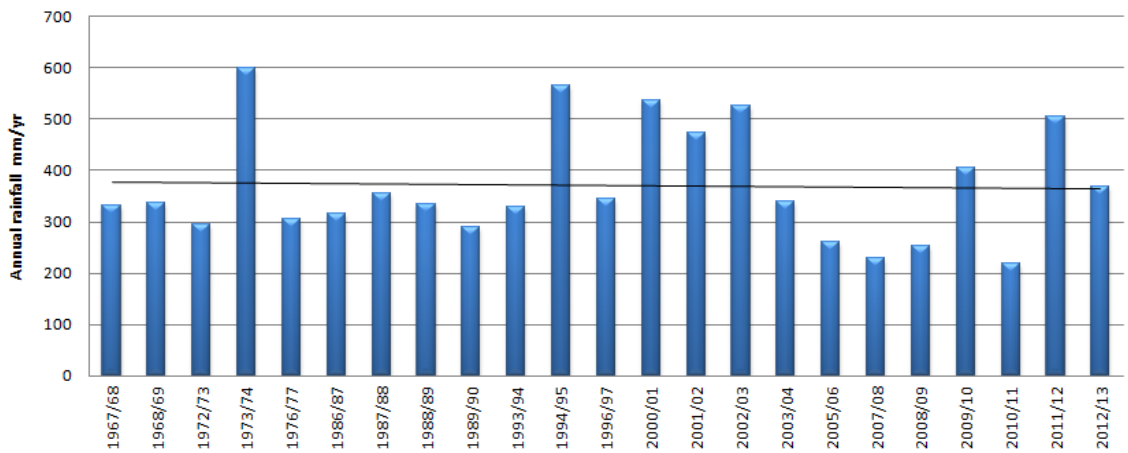

Figure 4.4: Annual and average rainfall in Yatta area (PMD, 2015).

4.2.2 Monthly Rainfall Data

Table 4.3 shows the average monthly rainfall in Yatta area during twelve rainy seasons 2000-2001 to 2014-2015 except 2004-2005, 2012-2013, 2013-2014 seasons, and the value of standard deviation (SD) for each month calculated using MS Excel. Table 5.1 clearly revealed that the values of standard deviation and average monthly rainfall are close to each other, January had the highest standard deviation and the highest amount of average monthly rainfall (115 mm), followed by February, while the lowest was in September followed by May. From the analysis, it was observed that rainfall is usually at its peak between December and February in the rainy season as shown in Figure 4.5. It was also noted that the distribution of monthly rainfall is almost symmetric.

Changes in rainfall from month to month are considerable. It is observed that the standard deviation values of most months (September, October, November, April, and May) are higher than the averages of these months. This relation between the standard deviation and the average values indicates that the deviation from the normal distribution cannot be ignored. These show that, in Yatta area. When the values of average monthly rainfall and standard deviation are close to each other (September, October, , April, and May); this reflects no significant variability of monthly rainfall data during the analysis period, namely during the summer, spring, and autumn seasons which are dry and have low rainfall. However, the winter season months (November, December, January, February and March) have standard deviation values that differ from the average; reflecting the variability of the monthly rainfall data during the analysis period.

Table 4.2: Average monthly rainfall and standard deviation for Yatta area during rainy seasons 2000-2001 to 2014-2015 (PMD, 2015).

	Sep. (mm)	Oct. (mm)	Nov. (mm)	Dec. (mm)	Jan. (mm)	Feb. (mm)	Mar. (mm)	Apr .(mm)	May (mm)
Average	1	9	43	72	115	85	37	20	4
Standard Deviation (SD) percent	0.87	12.05	28.81	61.20	70.67	34.67	28.70	20.98	9.36

Figure 4.5 shows that the highest average monthly rainfall for Yatta area was recorded in January and the lowest in September. This graph revealed that the summer months were the driest months.

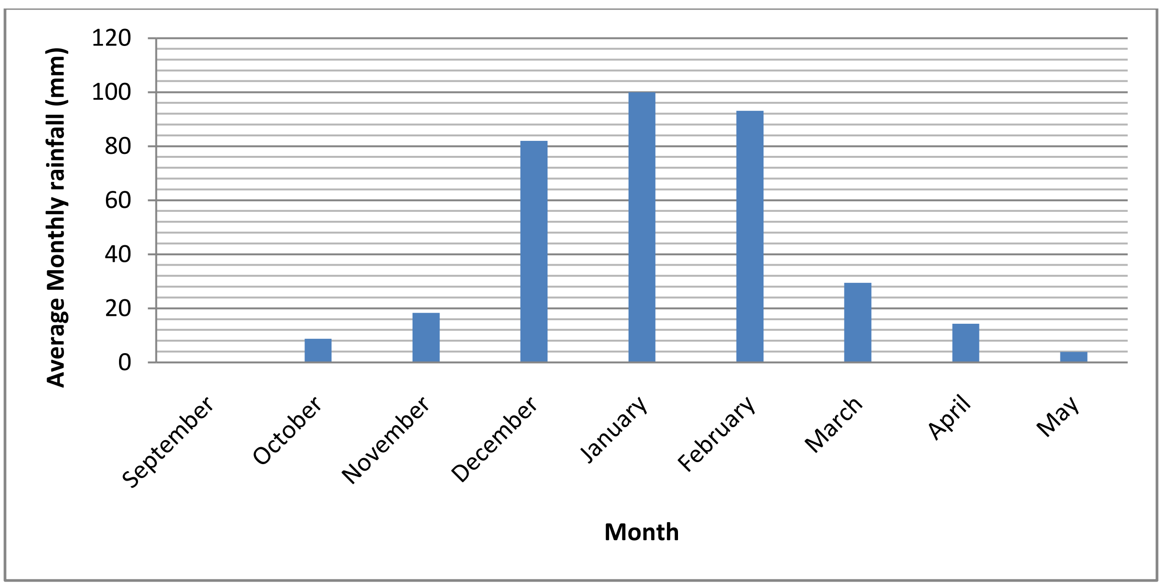

Figure 4.5: Average monthly rainfall (mm) in Yatta area for seasons 2000-2001 to 2014-2015 (PMD, 2015).

When comparing the results from this research with Figure 2.2 it is clear that the results are similar. January has the largest amount of rainfall and number of rainy days.

Figure 4.6 shows the minimum, average, and maximum monthly rainfall. There is a noticeable difference between minimum and maximum monthly rainfall data: January has the largest amount of maximum rainfall (296 mm) and average (115 mm), September has the lowest values of maximum (7 mm) and average (1 mm) while December has the largest amount of minimum rainfall (12 mm).

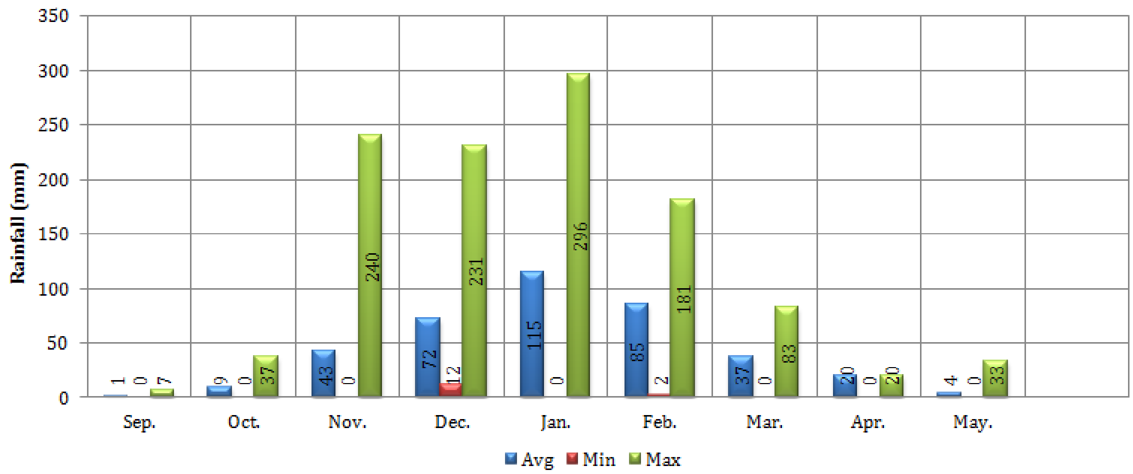

Figure 4.6: Minimum, average, and maximum monthly rainfall for Yatta area for seasons 2000-2001 to 2014-2015 (PMD, 2015).

4.2.3 Frequency of monthly rainfall

The frequency of total monthly rainfall was summarized in Table 4.4. It is apparent from the table that rainfall concentrated in three months (December, January, and February), where approximately more than two thirds of annual rainfall was received.

Figure 4.7 shows the monthly rainfall frequency in Yatta area. The slope of the trend line is negative (-0.0129), meaning that the number of months that have an increasing amount of average monthly rainfall decrease, and the number of months that have large amount of average monthly rainfall is small. R^2= 0.882 is obtained from the linear regression developed and called correlation coefficient. A high R-square value means that this relationship is strong and is directed downwards showing a close proximity of the data fitted between frequency and average monthly rainfall.

Table 4.3: Frequency of total monthly rainfall occurrence for Yatta area for seasons 2000-2001 to 2014-2015 (PMD, 2015).

Rainfall interval (mm/month)	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	March	April	May
0- 5	12	7	5	0	1	0	3	7	9
5- 50	0	5	6	3	3	0	6	4	3
50- 100	0	0	1	6	2	7	3	1	0
100- 130	0	0	0	1	4	2	0	0	0
130- 200	0	0	0	1	1	3	0	0	0
Over 200	0	0	0	1	1	0	0	0	0

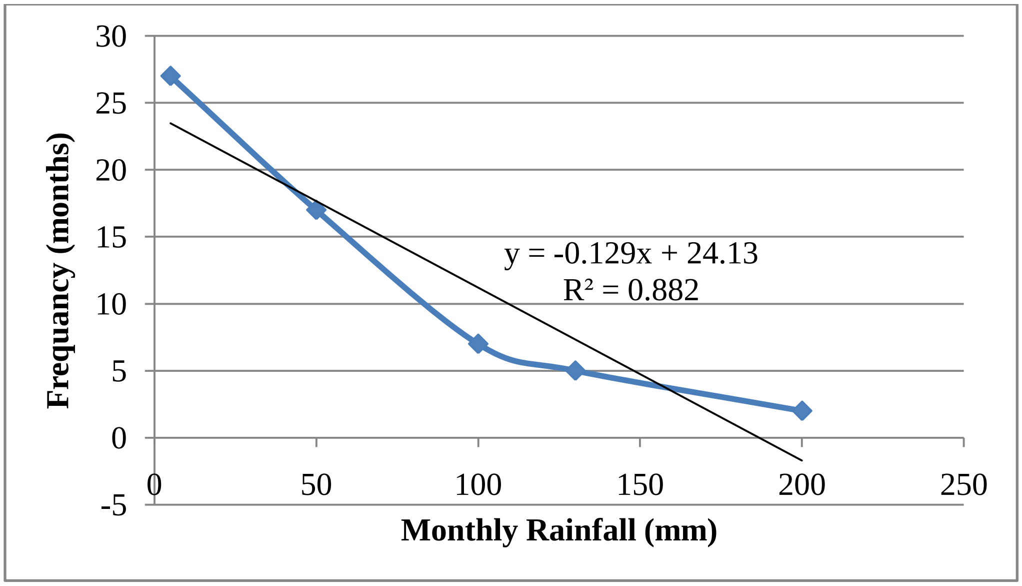

Figure 4.7: Monthly rainfall frequency (mm/day) for Yatta area for seasons 2000-2001 to 2014-2015 (PMD, 2015).

4.2.4 Extreme hydrological events

Analyzing the extreme hydrological events requires the selection of the largest and smallest events. However, for the purpose of rainfall-runoff hydrological modeling, the researcher is more interested in the largest extreme events that will most probably create runoff. Literature review indicated that the surface runoff in the West Bank occurs when rainfall exceeds 50 mm in one day or in two consecutive days (Al Yaqoubi, 2007). Table 4.5 summarizes the number of these events and their corresponding values.

Table 4.4: Extreme hydrological events during 2014/2015 rainy season in Yatta area (PMD, 2015).

Date	Rainfall (mm)
26/11/2014	55
10/1/2015	72
21/2/2015	60

Figure 4.8 shows the dates of daily rainfall in Yatta area for the rainy season 2014/2015 and the amount of rainfall in each day. The maximum amount of daily rainfall was recorded in 14/1/2015 and equals 72 mm. The number of rainy days in 2014/2015 season was 25 days (PMD, 2015).

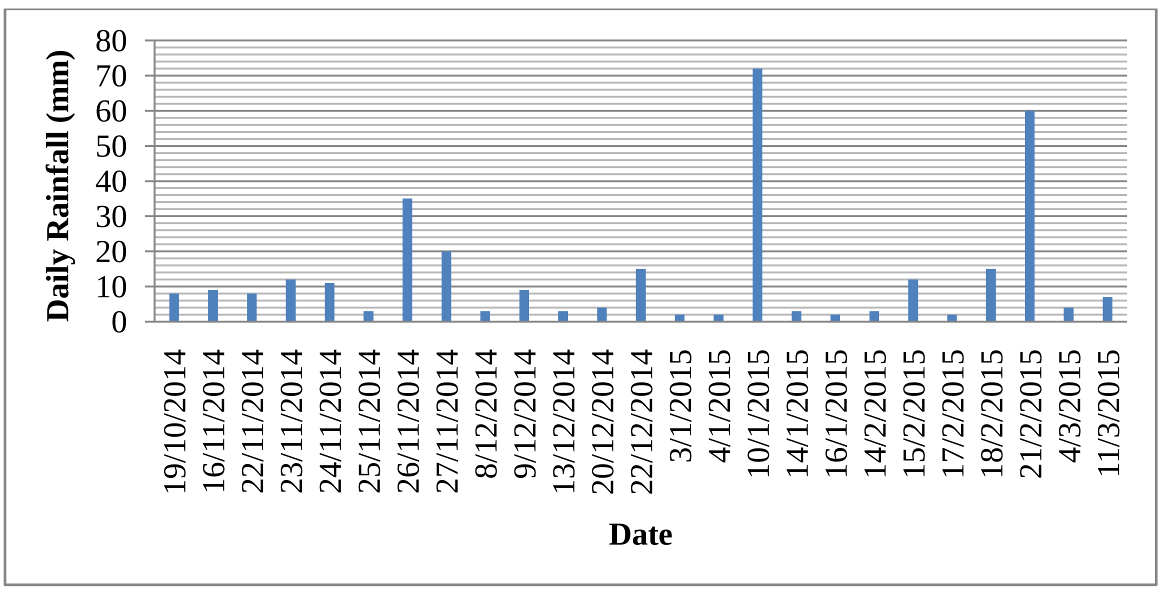

Figure 4.8: Daily rainfall for rainy season 2014-2015 for Yatta area (PMD, 2015).

4.2.5 Weather change in Yatta area

There is a prediction for rising temperature in Yatta area with increased warming higher in the summer than the winter, thus; forecasted to cause higher losses from evaporation. From rainfall data analysis for Yatta area, rainfall amounts had decreased.

From previous sections and rainfall data analyses for Yatta area there are indicators for change in weather including: change in annual and monthly rainfall, the trend line in frequency of monthly rainfall is negative, change in number of rainy days, number of hydrological extreme events is small, decrease in temperature, and high evaporation rates especially in the summer leading to high evapo-transpiration rates. However, these indicators can be classified as minor due to the small change in the amount of rainfall, and temperature. So there are no major indicators for the change in weather in Yatta area.

4.2.6 Areal rainfall

Rainfall events recorded by gauges, are generally expressed in the form of point rainfall values which is the rainfall depth at a location. In order to obtain real average values for an area; hydrologists require techniques whereby point rainfall amounts can be transformed to average rainfall amounts over a specified area. This point to area rainfall conversion can be addressed using numerous methods such as: Arithmetic average, Thiesssen polygon, Isohyetal, and Interpolation to a grid method (Gill, 2005). In this research the local polynomial interpolation method was used to convert point rainfall to areal rainfall for Yatta watershed.

Local polynomial interpolation is a method used to estimate values between known data points. When graphical data contains a gap, but data is available on either side of the gap or at a few specific points within the gap, an estimate of values within the gap can be made by interpolation. The main problem with polynomial interpolation arises from the fact that even when a certain polynomial function passes through all known data points, the resulting graph might not reflect the actual state of affairs. It is possible that a polynomial function, although accurate at specific points, will differ wildly from the true values at some regions between those points. This problem most often arises when "spikes" or "dips" occur in a graph, reflecting unusual or unexpected events in a real-world situation. Figure 4.9 shows the local polynomial interpolation map for Yatta watershed created using GIS tools. This map includes the shape file of stations (location and amount of annual rainfall), and the boundary of Yatta watershed.

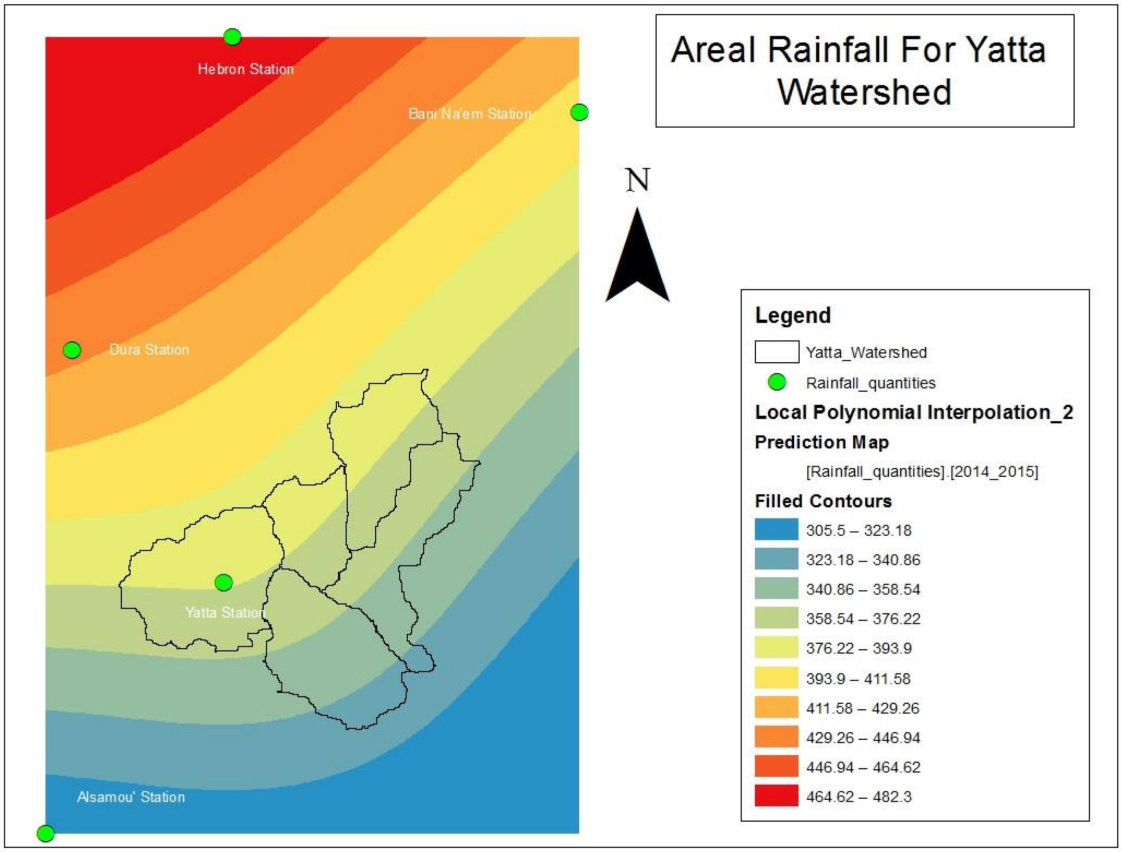

Figure 4.9: Areal annual rainfall for Yatta watershed.

The root mean square for this interpolation equals 43.45 which is a high value, but when other interpolation methods are applied the value of the root mean square is larger, the exact reason why local polynomial interpolation was selected for the purpose of this research. Table 4.6 shows the cross validation of this method which includes the measured amount of rainfall, the predicted amount rainfall, and the error at each station.

Table 4.5: Cross validation for local polynomial interpolation for annual rainfall for seasons 2000-2001 to 2014-2015 (PMD, 2015)

Station	Measured amount of rainfall (mm)	Predicted amount of rainfall (mm)	Error
Yatta	385	340.9	-44.1
Hebron	482	466.4	-15.9
Bani Na'em	403.2	463.7	60.5
Dura	432.2	435.4	3.2
Alsamou'	305.5	365.2	59.7

Table 4.7 shows the areal rainfall for Yatta area watershed and its area. The average areal rainfall was then estimated using the following equation:

Average areal rainfall= $\frac{\sum_{i=1}^{n} A_i P_i}{\sum_{i=1}^{n} A_i}$.. 4.1

Where:

A_i: Area of the watershed (Km^2)

P_i: Rainfall (mm).

Table 4.6: Areal rainfall for Yatta watershed.

Rainfall- P_i (mm)	Area- A_i (Km^2)	A_i*P_i
332.02	2.79	926.34
349.7	3.93	1374.32
367.38	8.05	2957.41
385.05	5.83	2244.84

From equation 4.3, the average areal rainfall for Yatta watershed equals 364.22 mm/year. This value is close to the average annual rainfall for Yatta area which equals 385 mm/year.

Chapter Five

Conceptual Model

A conceptual model describes the process of runoff within the subbasin and is built on simplified concepts derived from physical processes of rainfall runoff phenomena. In conceptual models the relationships between hydrological characteristics and responses are loosely based on physical processes and do not use their strict representation. To develop a conceptual model for Yatta land use, soil types, topography, and meteorological characteristics of Yatta area represent the data required for the model. A conceptual model was developed using WMS applications.

The Geographical Information System (GIS) is software designed to capture, store, manipulate, analyze, manage, and present all types of spatial or geographical data. In hydrology this system is used to analyze the hydrological functions to provide decision support capabilities to all users. The system helped develop the flow path and pollutant level loading models, and map water quality sampling locations. The main objectives of this system are: to illustrate the nature of watershed processes, and help decision makers manage watersheds (Strager et al., 2010).

5.1 Data map needed for modeling

There are four data maps needed for Yatta watershed modeling. These data includes: the Triangulated Irregular Network (TIN), land use, soil type, and the areal map for Yatta area. A TIN is a vector-based representation of the physical land surface or sea bottom, made up of irregularly distributed nodes and lines with three-dimensional coordinates (x, y, and z) that are arranged in a network of non-overlapping triangles (Hydro- Engineering Consultancy, 2015).

5.2 Subbasin delineation

The WMS software was used to define the boundaries of the watershed and its subbasins. The Digital Elevation Model (DEM) was also used to calculate some physical parameters for each subbasin. The runoff hydrologic response of a drainage basin mostly depends on its watershed characteristics. Therefore it is important to understand the different characteristics of the basin in order to be able to work with different estimation models. Geomorphological characteristics of a stream basin area among the most important parameters as far as run off estimation is concerned. The geomorphological characteristics of a watershed entails the physical characteristics which include watershed shape, drainage area, ground slope and centroid of the watershed, and the channel characteristics including channel length, channel order, channel slope and drainage density. Collectively, this will be used as input to the mathematical model composed to determine the quantity of water in watersheds (Kutílek and Nielsen, 1994).

The general steps of this system are as follows:

1. Terrain Processing – This step includes computing flow direction and accumulation, defining streams and delineating watersheds/sub-basins based on the DEM. DEM is the most suitable and applicable method to assess watersheds, and is widely used to calculate the slope and the sides of the map for the watershed (Singh et al., 2014).

2. HMS Project Setup – This step includes defining the study area in WMS that will be used to develop the HEC-HMS hydrologic model. The user defines the outlet of the watershed to be analyzed and WMS copies all data upstream of that location to a new workspace.

3. Basin Processing – At this step, the stream and sub-basin delineations as determined in Terrain Processing can be modified as necessary to meet the study objectives. For example, during this step, the sub-basins can be modified to capture stream gauge locations.

4. Stream and Watershed Characteristics – This step includes determining the physical characteristics of sub-basins, including longest flow paths and river and sub-basin slopes.

By delineating Yatta watershed using WMS; the overall subbasin area was found to be equal to20.59km^2. The flow direction for runoff was also computed. Yatta-1 and Yatta-3 have the same outlet point. Figure 5.1 shows Yatta watershed subbasins, boundaries, and areas.

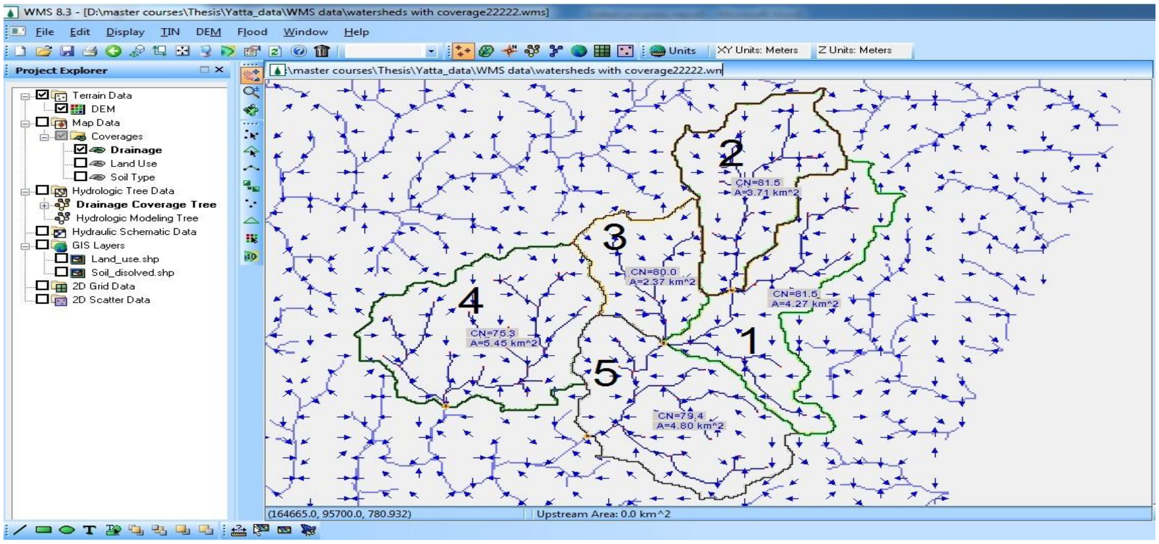

Figure 5.1: Yatta watershed subbasins: boundaries, and areas.

Table 5.1 shows the maximum and minimum elevation, horizontal distance, and slope for each subbasin. subbasin -4 has the highest slope equal to 4% while subbasin -1 has the lowest slope equal to 2.1%.

Table 5.1: Slope of Yatta watershed subbasins.

subbasin No.	Maximum elevation (m)	Minimum elevation (m)	Average elevation (m)	Horizontal distance (m)	Average Slope (%)
1	830	750	790	3794	2.1
2	881	771	826	3445	3.2
3	832	750	791	2317	3.54
4	830.4	709.2	769.8	3013	4
5	820	729.3	774.65	2448	3.7

5.3 Estimating model parameters

5.3.1 Data used for estimating model parameters

Land use and soil type for Yatta watershed are the most important data for estimating the model parameters. The soil types data Map was described in study area chapter.

Yatta watershed land use was determined using GIS.The land use of Yatta watershed is classified into six types: roads, built up - low density, built up - high density, agricultural, rocky, and built up like (green houses, and portable houses-barracks). The watersheds shape file from WMS which contains the subbasins boundary and streams flow in each subbasin; was exported to GIS with an areal photo for Yatta area. Figure 5.2 shows the land use of Yatta area in the subbasins.

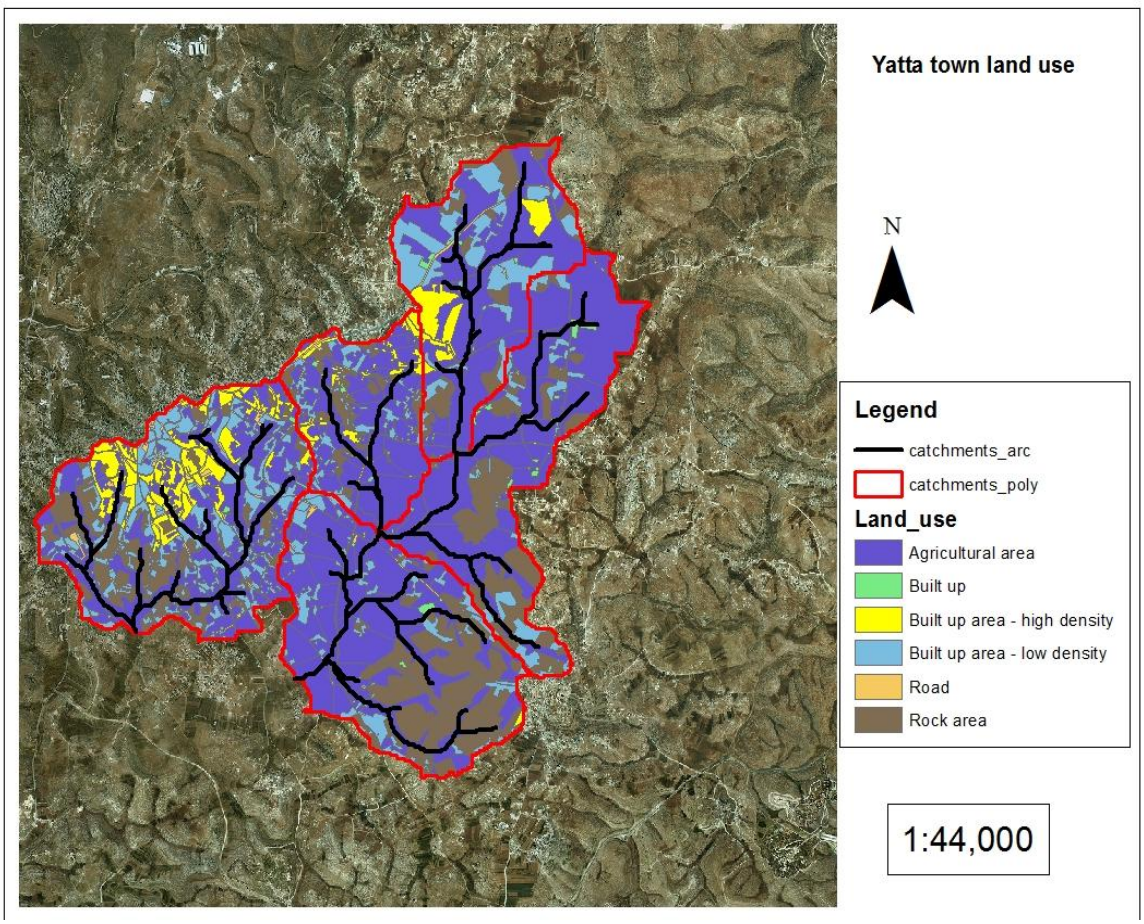

Figure 5.2: Land use of Yatta area for the identified subbasins.

5.3.2 Physical characteristics of Yatta watershed

Table 5.2 shows Yatta area watershed subbasins and their characteristics: area, curve number, and lag time. These characteristics describe the physical processes in the subbasins. Yatta-1 has the longest lag time due to the long distance between the center of mass of rainfall to the highest value of flow, so the flow in Yatta-2 requires more time to reach the highest value compared to other subbasins. The area for each subbasin resulted from delineated watershed. The average curve number for each subbasin estimated from WMS by inserting the curve number values for land use and soil type existing in each subbasin then calculates the average curve number for the subbasin.

Table 5.2: Yatta subbasins and their characteristics.

Yatta watershed subbasin No.	Area (Km^2)	Avg. Curve number	SCS lag time (min)
1	4.27	81.5	51.21
2	3.71	81.5	41.32
3	2.36	80	26.60
4	5.45	75.3	42.57
5	4.80	79.4	35.68

5.3.3 Impervious

Table 5.3 shows the percentage of impervious areas of each subbasin. Yatta-5 has the largest impervious area (2.7%) and percent since it has the largest amount of houses and roads (impervious areas). This will consequently result in the quantity of direct runoff. The lowest impervious area equals 1.8% for Yatta-1.

Table 5.3: Impervious percent.

Subbasin No.	Impervious (%)
1	1.8
2	1.9
3	2.1
4	2.5
5	2.7

5.4 Modeling period and time steps

Two models were built: The first one is a model for rainy season 2014/2015 depends on hourly rainfall data and the second is an hourly model for each storm event in the same rainy season. These models are based on hourly time step rainfall data for the 2014/2015 rainy season, because the hourly rainfall data are available for this rainy season only. The models were built to compare between the results of direct runoff for each model.

The time period, as in start and end dates must be specified before running the model.

5.5 Meteorological data

Meteorology: Is the study of weather, including all the daily changes in temperature, wind, moisture, and air pressure. When the heat from the sun strikes water, some of the water evaporates into the air. The evaporation, condensation, and rainfallof water are an on-going cycle essential to the existence of life on Earth (Sori Nezhad, 2001). Meteorological data prepare the meteorological boundary conditions that act in the watersheds during simulation. These conditions include rainfall, evapo-transpiration, and snowmelt which is an optional condition depending on snowfall. To create a meteorological model there is a need to develop at least one basin model. Its principal purpose is to prepare meteorological inputs for sub-basins (Hydrologic Engineering Center, 2010). For Yatta, watershed rainfalland evapo-transpiration were determined to complete this model.

Temperature of air, frequency of moist days, and vapor pressure are the meteorological parameters that influence precipitation. Monthly rainfall is estimated by simulating a model. The frequency of moist days is the parameter that most effects rainfallforecasting (Hashim et al., 2015).

5.5.1 Rainfall data

The rainfall data used in hydrological modeling for Yatta watershed is hourly rainfall data for rainy season 2014/2015.

Figure 5.3 shows the accumulative hourly rainfall for Yatta area and the number of storms recorded in the rainy season 2014/2015 (data obtained from Yatta Municipality).The total amount of rainfall in this period for rainy season 2014/2015 equals 210 mm. This is not the total amount of rainfall for season 2014/2015, but the amount of rainfall from 1/11/2014 at 12:00 AM to 22/2/2015 at 12:00 AM, because the device just worked at this period. Five significant storms occurred during this period.

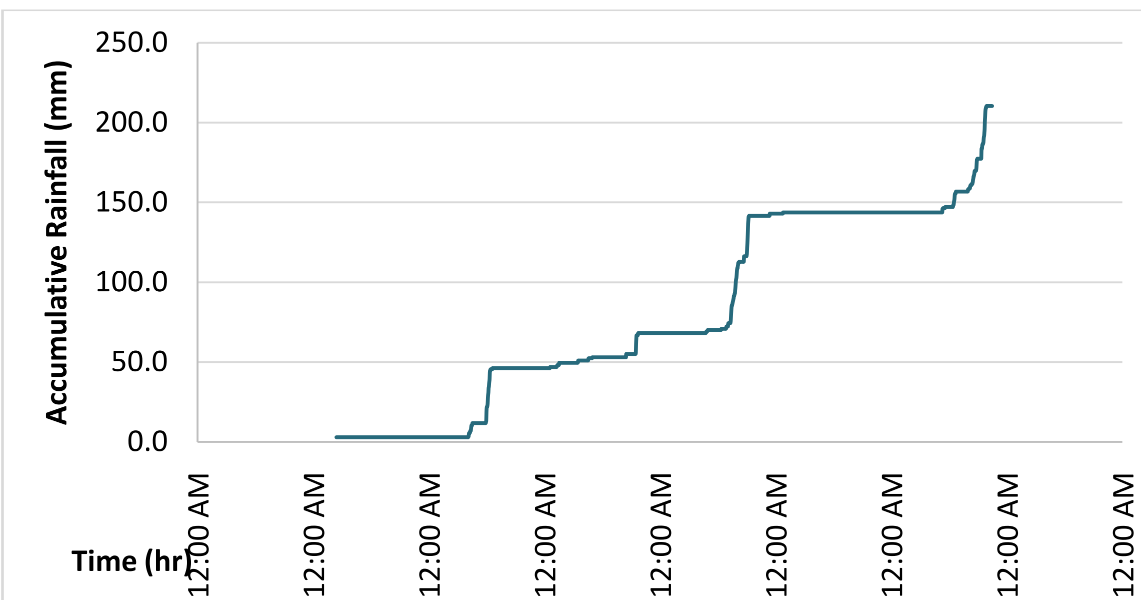

Figure 5.3: Accumulative rainfall and storm events (1/11/2014 at 12:00 AM to 22/2/2015 at 12:00 AM).

If the basin model contains sub-basins the rainfall method must be used. The specified the hyetograph method is used for rainfall data.

- **Specified Hyetograph**

Hyetographs (rainfall-intensity curves) represent the rainfall at a specific point with its distribution of time. Hyetographs are important for hydrologic and hydraulic design questions (Cowpertwait et al., 2007). This method is based on the rainfall data from Yatta municipality.

5.5.2 Evapo-transpiration Data

Evapo-transpiration means the loss of water from both plants (transpiration) and water bodies and soil evaporation (evaporation). Both soil evaporation and plant transpiration represent evaporative processes. Evapo-transpiration is often responsible for returning 50% of rainfall back to the environment. The monthly average method is designed to work with average depth of evapotranspiration water each month (Allen et al., 2005). The monthly evapo-transpiration rate in Yatta area is high in the summer (200mm/month), and low in the winter (50mm/month) (PMD, 2015).

The evapo-transpiration rates per month were used are: (51, 64, 114, 152, 203, 190, 178, 165, 152, 140, 127, and102) from January to December respectively (PMD, 2015).

5.6 Yatta watershed boundary and its properties

Figure 5.4 shows the boundary of Yatta watershed and its subbasins, and the physical properties of the watershed. This data is the final results from WMS, saved and exported to HMS.

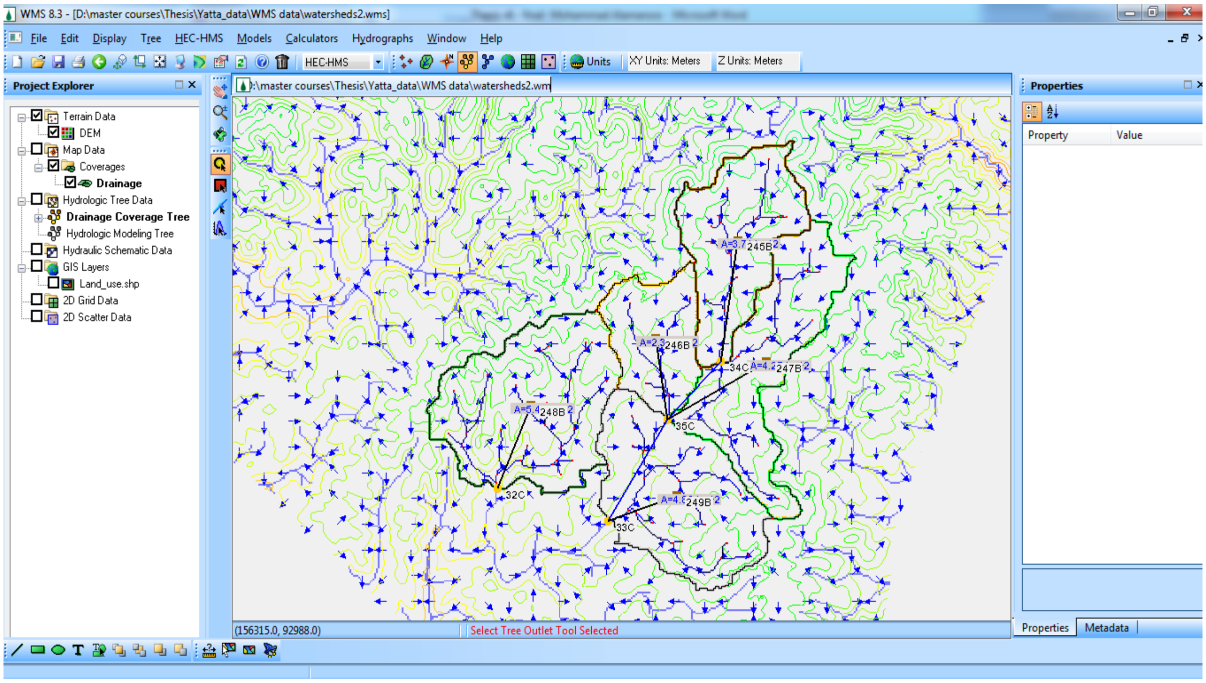

Figure 5.4: Yatta watershed boundary and its properties.

Chapter Six

Numerical Modeling

The HEC-HMS software was used to develop a runoff model for Yatta area watershed. This application is linked with WMS. Consequently, the model components (i.e. basins, reaches, junctions) with all estimated parameters were transferred to the HMS model. At this stage, all processes (e.g. losses, transform, routing, etc.) and their parameters as well as meteorological data were transferred.

6.1 Model setup

The HMS procedure was used to prepare the Yatta watershed boundary and its properties. The process included a conversion from WMS map units to units appropriate for HEC-HMS. English units were used in the HEC-HMS models. This software computes the runoff. The meteorological data and the information about the watershed were entered to emulate hydrologic responses. Basin model, rainfall data (hourly, daily), monthly evapotranspiration data, impervious area, lag time, initial and maximum deficit, and control specification (the time pattern for the simulation) are the data required for the hydrological modeling of Yatta watershed. These values were taken considering the prominent soil type in the subbasin area. Soil water characteristics (SWC) were used to determine the hydrological characteristics.

Two HEC-HMS hydrologic models were developed as part of this study. The same rainfall and evaporation data was used for all models; all other parameters used in the hydrologic models were also identical. The final results from these models were the hydrological response in the watershed, and the total amount of direct runoff in each subbasin.

6.2 Basin Model

The Basin Model is the physical representation of the watershed, the sub-basins, outlets, and river segments. This representation was produced using a node-link system. The nodes represent the sub-basins and the sub-basin outlets. The links represent the river segment (reaches) through which upstream runoff is routed to downstream outlets. Coordinates indicating the position of each element and their respective elevations were calculated and assigned to each component of the system.

Figure 6.1 shows the basin model of Yatta area, which includes the subbasins and the hydrologic elements in each subbasin to show the flow direction and the accumulation points for each subbasin. Subbasins 1 and 3 flow to the junction 35C as inflow. Sub-basin 2 flows to junction 34C as inflow the outflow from which is directed to junction 35C as inflow. The outflow from junction 35C flows to junction 33C as inflow, sub-basin 5 also flows to junction 33C as inflow. Subbasin four flows to junction 32C as inflow. The blue lines indicate routing reach elements (34R, 35R).

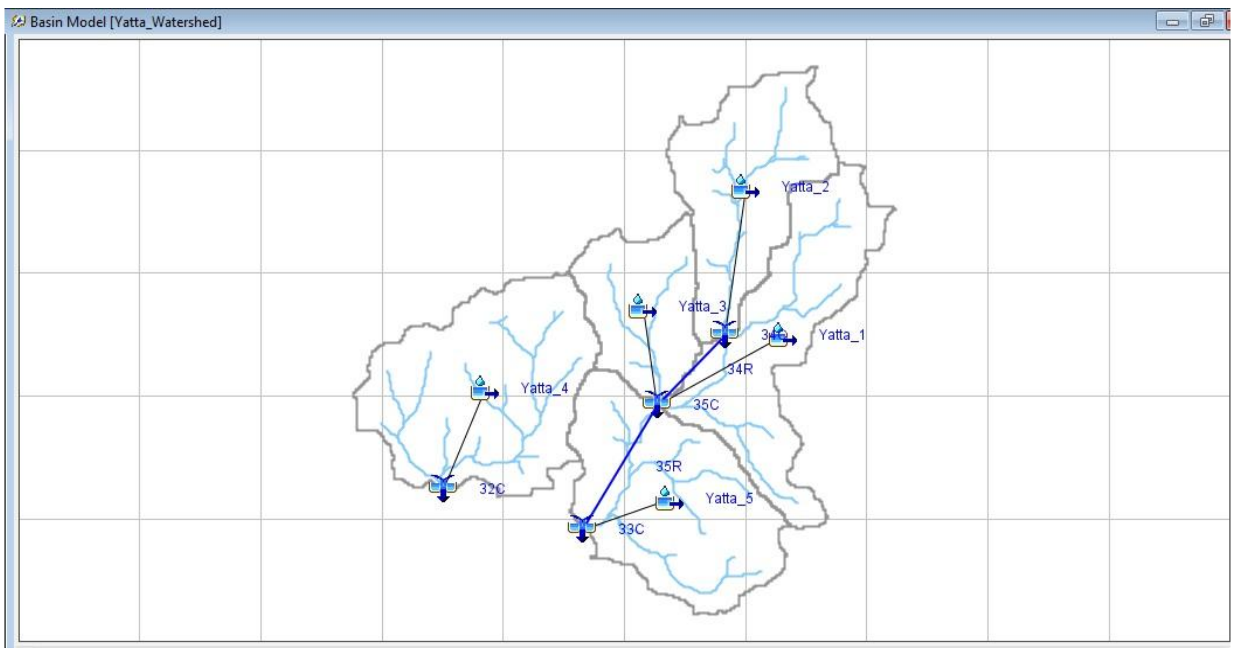

Figure 6.1: Basin model for Yatta area (HEC-HMS).

6.3 Setting model processes

A HEC-HMS model is composed of four elements: sub-basin, reach, reservoir, and network elements. These four elements, in addition to the meteorological model, wholly represent a modeled watershed and are introduced in this section. For each model element, HEC-HMS offers a variety of methods to calculate the hydrological response to input data, including rainfall (Hydrologic Engineering Center, 2010). All elements were used in the Yatta watershed model except for the reservoir element because the storage facilities for the amount of runoff were suggested after completing the model.

6.3.1 Sub basin elements

1. Canopy method

Simple canopy method were used for canopy method. For this method two values were determined including the:

- initial storage representing the percentage of the canopy storage full of water at the beginning of the simulation. The mean of the initial storage is 28% (Pypker et al., 2012).
- , in the model the initial storage was equal to zero.
- maximum storage in mm quantifying the largest amounts of water that can be caught on leaves before falling to the surface(0.8 in early spring) (Pypker et al., 2012).

2. Surface method

For Yatta watershed the simple surface method was used and the values of this method were determined, these values are the:

- initial storage representing the percent value of the surface storage filled with water at the start of the emulation (equal to 0%).
- maximum storage in mm representing the largest amounts of water caught on the soil surface before the flow starts (4 mm).

These values used were the most logical in Yatta area obtained from many soil tests (Hydrologic Engineering Center, 2010).

3. Loss method

Deficit and constant loss are used to estimate the amount of loss through soil infiltration. Four values were determined for this method. The first value is the initial deficit (equal to 60 mm in Yatta) obtained by measuring a sample of soil, this value decreases with an increasing amount of rainfall. The second value is maximum deficit, for Yatta subbasins equal to 120 mm, this value decreases with an increasing amount of rainfall. The third value is the constant rate and depends on soil type, for Yatta subbasins this value equals 3.5 mm/hr. The fourth value is the impervious percent. This value differs from one subbasin to another. The values of impervious areas are: 1.8%, 1.9%, 2.1%, 2.5%, and 2.7% for Yatta-1 through Yatta-5 subbasins respectively.

4. Transform method

SCS unit hydrograph transform is used to estimate the amount of transformation of excess rainfall to direct runoff on the surface of Yatta subbasins. Lag time was calculated for each subbasin, equal to: 51.21 minutes, 41.32 minutes, 26.59 minutes, 42.57 minutes, and 35.68 minutes for Yatta-1 through Yatta-5 subbasins respectively.

Figure 6.2 shows the subbasin elements used for Yatta subbasins.

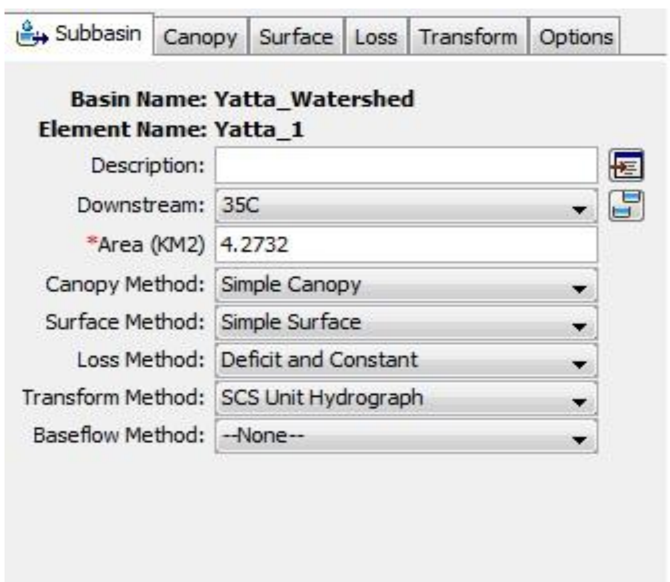

Figure 6.2: Sub-basin elements for Yatta subbasins (HEC-HMS).

6.3.2 Reach elements

1. Routing Method

Muskingum-Cunge routing method was used to model Yatta subbasins based on the properties of channel and wave floods in Yatta watershed (Song et al., 2011).

Figure 6.3 shows the values of Muskingum-Cunge routing method for reach elements 34R and 35R. The values for this method were mentioned in the literature review chapter section 3.4.2.2.

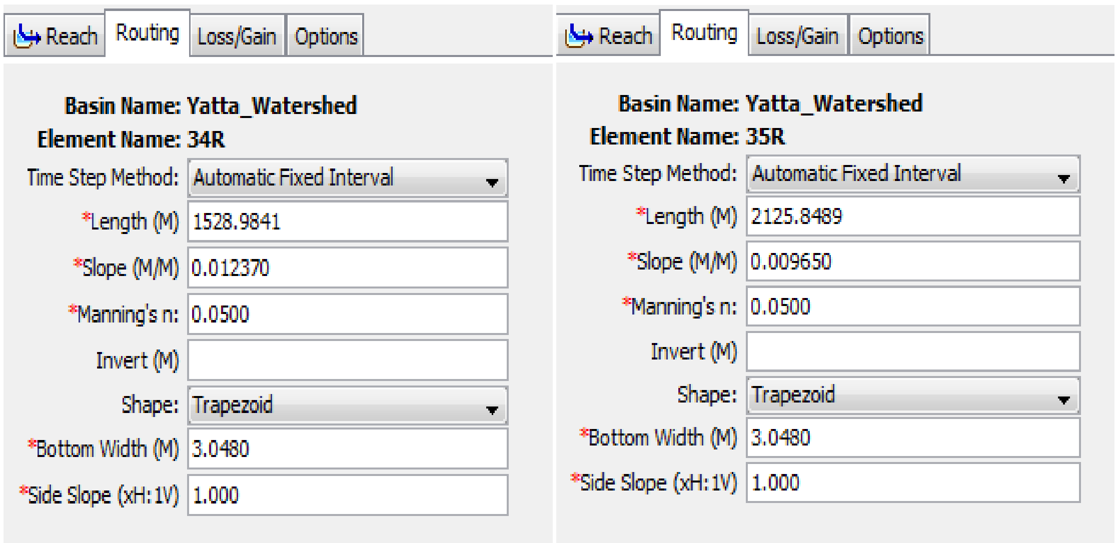

Figure 6.3: Muskingum-Cunge routing method for reach elements 34R and 35R (HEC-HMS).

2. Loss/ Gain Method

The percolation Loss/ Gain method was used to calculate the loss from channels by using the constant infiltration rate in addition to the submerged area (calculated by the routing method). One value was estimated for this method and indicates infiltration capacity per area. For Yatta subbasins this value equals 0.0005 m^3/s/1000 m^2 .

6.4 Hourly models

6.4.1 Hourly model for season 2014/2015

The first model in this thesis depends on hourly rainfall data for Yatta area for the 2014/2015 rainy season. The time period extends from 1/11/2014 at 12:00 AM to 22/2/2015 at 12:00 AM. A major component was used to control the model when simulation starts and stops is the time period, and determines the time interval used in the simulation. The data used in this model was based on rainfall information per hour. The start date was 1/11/2014 at 12:00 AM and the end date was 22/2/2015 at 12:00 AM.

6.4.2 Hourly model for the five storm events

For additional accuracy and to have clearer results two models were compared with each other. The first model was divided to five models for the five significant storms in time interval, because there are five storm events in rainy season 2014/2015. Each model has the time interval for the storm which occurred in the corresponding timeframe. Storm 5 was the strongest, while storm 3 had the shortest time interval and a large depth. Table 6.1 shows the time period and the depth of rainfall for each storm.

Table 6.1: Time period and rainfall depth for each storm in Yatta area (HEC-HMS).

Storm	Time Period	Rainfall depth in mm
1	1/11/2014 - 9/12/2014	40.1
2	9/12/2014 - 5/1/2015	21
3	5/1/2015 - 10/1/2015	42.7
4	10/1/2015 - 5/2/2015	28.9
5	5/2/2015 - 22/2/2015	77.7

6.5 Model results

6.5.1 Water balance analysis

Table 6.2 shows the water balance for hourly rainfall data in Yatta sub-basins which includes total depth of precipitation, loss, and excess rainfall for the 2014/2015 rainy season. The loss in rainfall happened due to canopy loss, loss in soil, infiltration, and evapo-transpiration. The depth of excess rainfall equals the total depth of rainfall minus depth of loss in each subbasin. Excess rainfall is not only dependent on sub-basin area, but also on watershed characteristics and the distribution of rainfall over time. The model predicted high losses of the total rainfall. The main reason for the high losses is the fact that the model would have predicted the exact same overall losses for long storm durations instead of short storm duration for the same total rainfall depth (the time period for the model is equal to four months, but the rainfall and storm events did not happen in all this period, and not all days in this period were rainy). The reason for this is that the deficit and constant loss model does not directly account for the intensity and duration of the rainfall. The absolute loss of a certain event is only a function of the deficit values and the absolute rainfall depth regardless of the intensity distribution. Nevertheless, a hour time component is introduced in the model when it is applied for the estimation of runoff from successive intervals in a storm as done in this study. HEC-HMS first calculated the accumulated discharge Q from the accumulated rainfall P of each time step and then derived the runoff for each time step as the difference between the accumulated Q at the beginning and end of each time interval (Schoener, 2010).

Table 6.2: Rainfall, loss, and excess inYatta watershed for the 2014/2015rainy season (HEC-HMS).

Subbasin	Rainfall (mm)	Loss (mm)	Excess (mm)
Yatta-1	210.4	207.02	3.38
Yatta-2	210.4	206.97	3.43
Yatta-3	210.4	206.7	3.7
Yatta-4	210.4	205.68	4.72
Yatta-5	210.4	205.18	5.22

6.5.2 Direct runoff from hourly Model for season 2014/2015

The first model in this research is a model which depends on hourly rainfall data over Yatta area for the 2014/2015 rainy season. A major component is that it is used to control when simulation starts and stops, and determines the time interval used in the simulation. The control specification for Yatta area for this model is: the start date is 23/11/2014 at 11 am; the end date is 11/3/2015 at 12 am.

The results generated from running this model contain the hydrologic elements, peak discharge (peak flow), drainage area, the time of peak discharge and the total direct runoff for each subbasin. Table 6-3 shows a summary of the results produced by the model. The runoff volume is directly related to the CN, which determines the amount of rainfall that will turn into runoff. Yatta-4 has a large amount of total direct runoff (26,500m^3) due to the large area, and the impervious percentage. Yatta-3 has the smallest amount of total direct runoff (9,700m^3). The peak discharge ranges from 0.1 to 0.2 m^3/s. The time of peak discharge is the time of the strongest storm in this interval which is 11/1/2015 at 10 am. The value of peak discharge gives an indication about flood forecasting (Bartholmes et al., 2005). Direct runoff is impacted by numerous factors beyond cumulative precipitation. These factors include evapo-transpiration, slope, soil properties, and land cover of the sub-basin. An inventory of parameters with a possible influence on flow was compiled including: area, sub-basin's curve number, overall slope, and rainfall depth (Halwatura et al., 2013; Straub et al., 2000; Song et al., 2011; Oleyiblo et al., 2010).

Table 6.3: Summary results for direct runoff from hourly model for season 2014/2015 (HEC-HMS).

Subbasin	Total direct runoff (1000 m^3)	Peak Discharge (m^3/s)
Yatta-1	15	0.1
Yatta-2	13.7	0.1
Yatta-3	9.7	0.1
Yatta-4	26.5	0.2
Yatta-5	25.2	0.2

Figure 6.4 shows the total direct runoff for each subbasin inthe 2014/2015 rainy season.

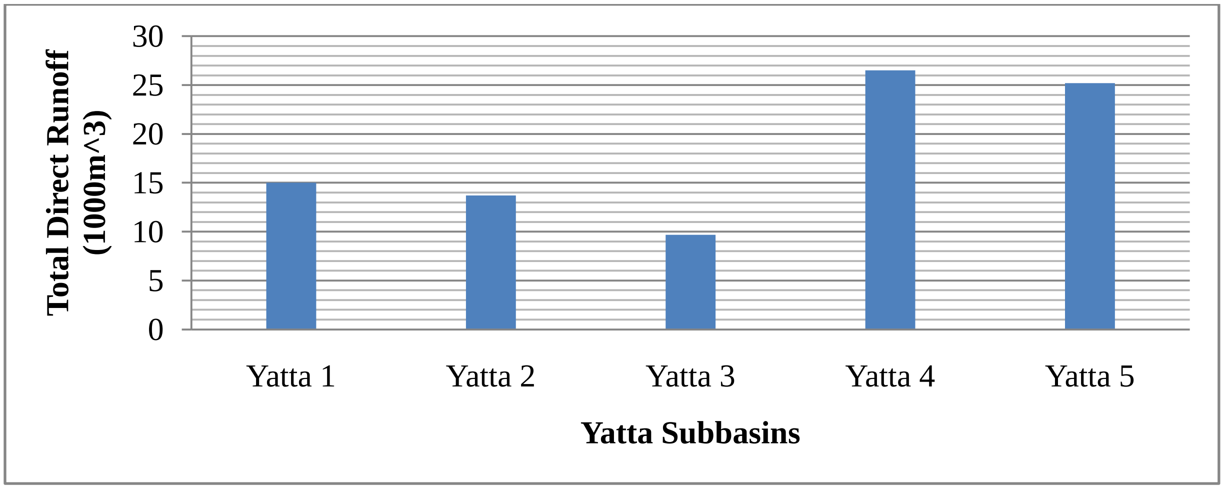

Figure 6.4: Total direct runoff for each subbasin for direct runoff from hourly model for season 2014/2015 (HEC-HMS).

- **Hydrographs**

The hydrographs (flow versus time) for the sub-basins and reach elements show the volume of rainwater reaching a particular outfall. Maximum flow represents the peak discharge in the hydrograph. These graphs are important to design the storm and combined sewerage systems and are also used to characterize the hydraulic functioning and conduit network geometry. The recession (falling) and rising (surface runoff feeding water for the streams) of the hydrograph is a response to rainfall event and indicate change in flow. These hydrographs predict that no large floods will be witnessed which is important to know in order to manage sub-basins. The time of the peak flow is shown in the figures noting that lag time is the distance between peak flows. The regime represents the average annual discharge of a river; and is an important resource for understanding the nature and response of a drainage basin. High rates of evapo-transpiration reduce amounts of discharge. The flow in this case is unsteady due to the change in flow and depth. This indicates that discharge is an aggregated measure with limited sensitivity to spatially distributed input, as already identified by Stisen et al., 2011. As expected, observed peaks in the dry periods which are initiated by preferential flow are mostly missed by the models. There are responses to single rainfall events and an overall overestimated flow in dry periods. The model correctly produces peak flows, the timing and shape of storm events and also the recession behavior in the periods between two consecutive rainfall events.

Figures 6.5 to 6.9 show the flow hydrograph (flow in m^3/s) for Yatta sub-basins. A hydrograph is a measure of the integrated response of the watershed upstream to a storm event. Analysis of a storm hydrograph is used to determine peak discharge, and total runoff volume. The maximum flow in Yatta-1is equal to 0.093 m^3/s, while that in Yatta-2 equals 0.088 m^3/s,0.063 m^3/s in Yatta-3 ,0.17 m^3/s in Yatta-4 and 0.162 m^3/s in Yatta-5. The rises in discharge are caused by storm events, followed by a gradual return to low flow (zero flow). These hydrographs show that five storm events occurred during the rainy season.

The time of peak discharge - represents the number of hours for the peak discharge to arrive at the outlet- which was marked by the strongest storm event (on 11 January, 2015) and is the same for all sub-basins. Yatta-4 and Yatta-5 have the maximum value of flow due to the large amount of precipitation, high impervious area, and high intensity of rainfall. The behavior of these graphs is similar to each other and similar to the actual flow graph. After the beginning of the rain event, no runoff begins until the accumulated rainfall equals the initial abstraction(I_a). After the accumulated rainfall exceeds the initial abstraction, runoff is calculated by subtracting water retained in the watershed (F) from the accumulated rainfall. S is the maximum potential retention which is only reached in very long storms. The development of F after $I_a$is exceeded during a storm, is approximated by linear regression until $I_a + F$ equal the maximum retention S.

Since the losses for each time interval are proportional to the difference in accumulated rainfall at the beginning and end of each time interval, the infiltration increases drastically if the rainfall intensity does. Hereby, the maximum infiltration rate of the top soil is neglected. The flood hydrographs were created based on the assumption that no solid transport occurs during the flood runoff.

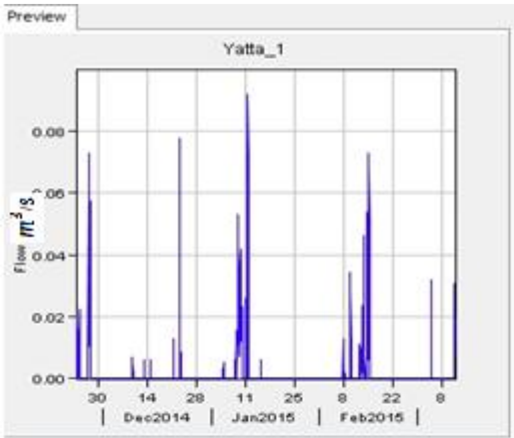

Figure 6.5: Yatta-1 flow.

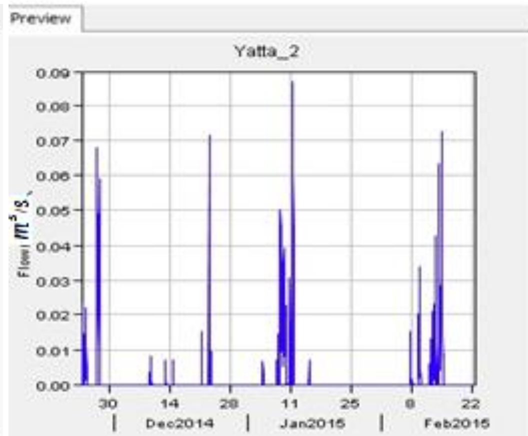

Figure 6.6: Yatta-2 flow.

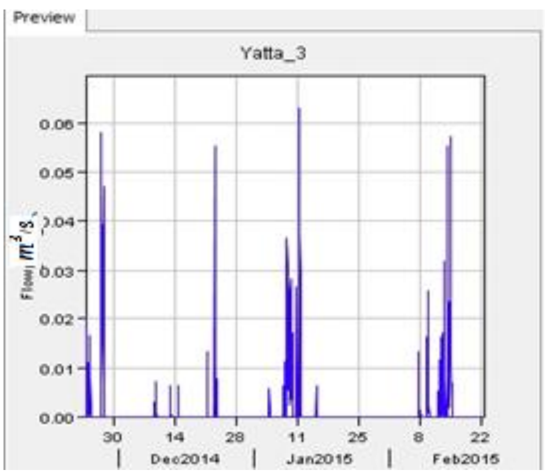

Figure 6.7: Yatta-3 flow.

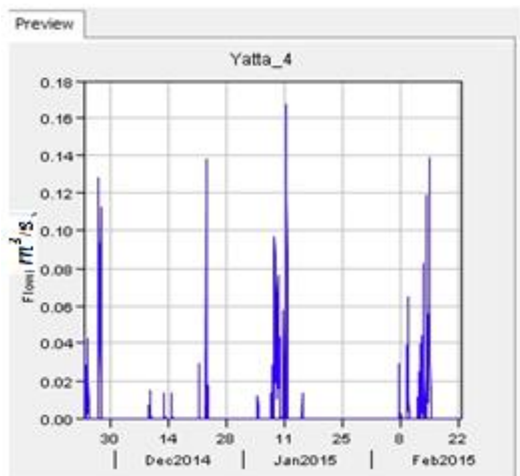

Figure 6.8: Yatta-4 flow.

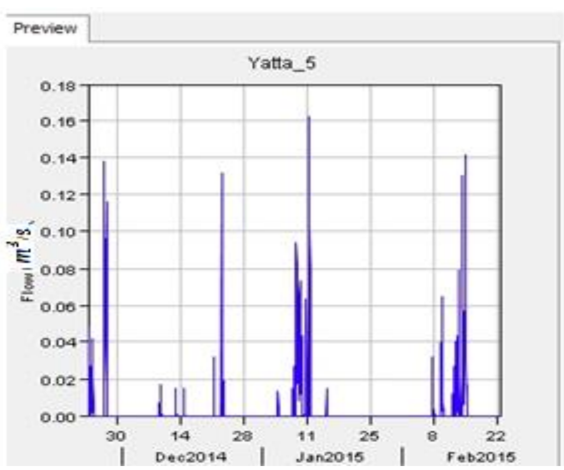

Figure 6.9: Yatta-5 flow.

The total rainfall depth in mm calculated by dividing runoff volume (m^3) by the watershed area (m^2). Figure 6.10 shows the total rainfall depth in mm for Yatta-1 which represents the storm hydrograph. The maximum depth is equals to 6.2 mm/hr, and occurs at the time of peak flow at the largest storm event. This figure shows that the simulated and observed peak discharges occurred at almost the same hour on 14/2/2015. This value is an indicator used in flood forecasting, however it was too small to anticipate a flood event in this area. An understanding of the nature of the storm hydrograph is vital for flood management and control. There are a large number of variables that go together to produce different hydrographs, including size and shape of the drainage basin, amount and intensity of precipitation, and land use.

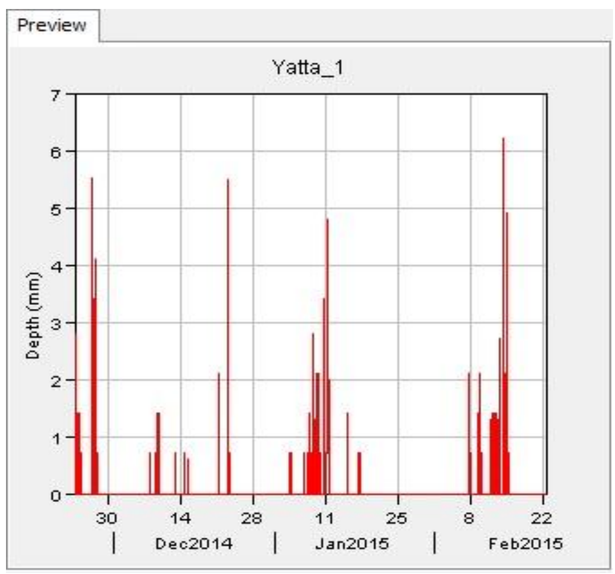

Figure 6.10: Rainfall depth for Yatta-1.

Figure 6.11 shows the evapo-transpiration in mm for Yatta-1. The maximum value is 0.133 mm/hr, recorded in October. The minimum value is 0.051mm/hr which took place in January. The average monthly evapo-transpiration was estimated to be between 0.051 mm to 0.133 mm for the existing months in model.

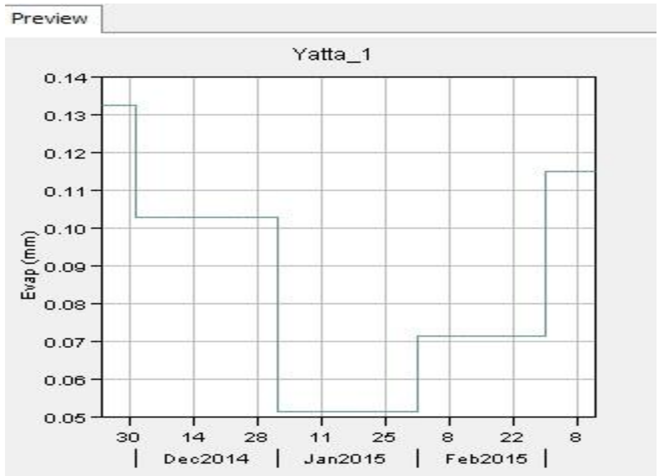

Figure 6.11: Evapo-transpiration rate for Yatta-1 subbasin for direct runoff from hourly model for season 2014/2015 (HEC-HMS).

Figure 6.12 and 6.13 show loss channel for reach elements 34R and 35R and depending on the characteristics of the channel. The maximum loss flow is 0.09 m^3/s for 34R, and 0.22 m^3/s for 35R. The combined inflow on reach element is greater than outflow from it. This is due to the loss in flow through reach elements.

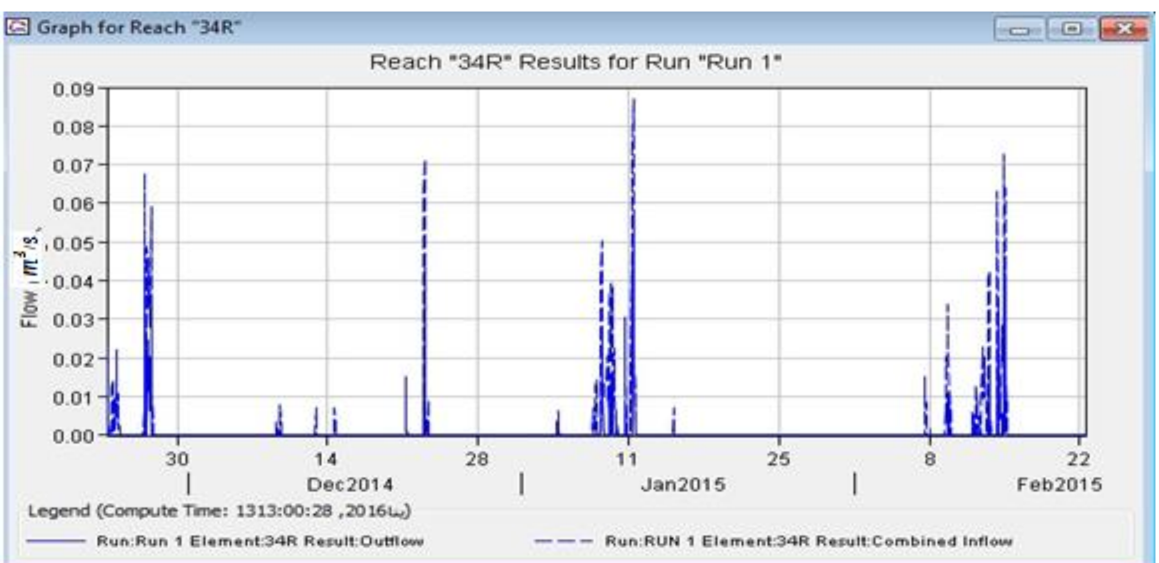

Figure 6.12: Flow for reach element 34R for direct runoff from hourly model for season 2014/2015 (HEC-HMS).

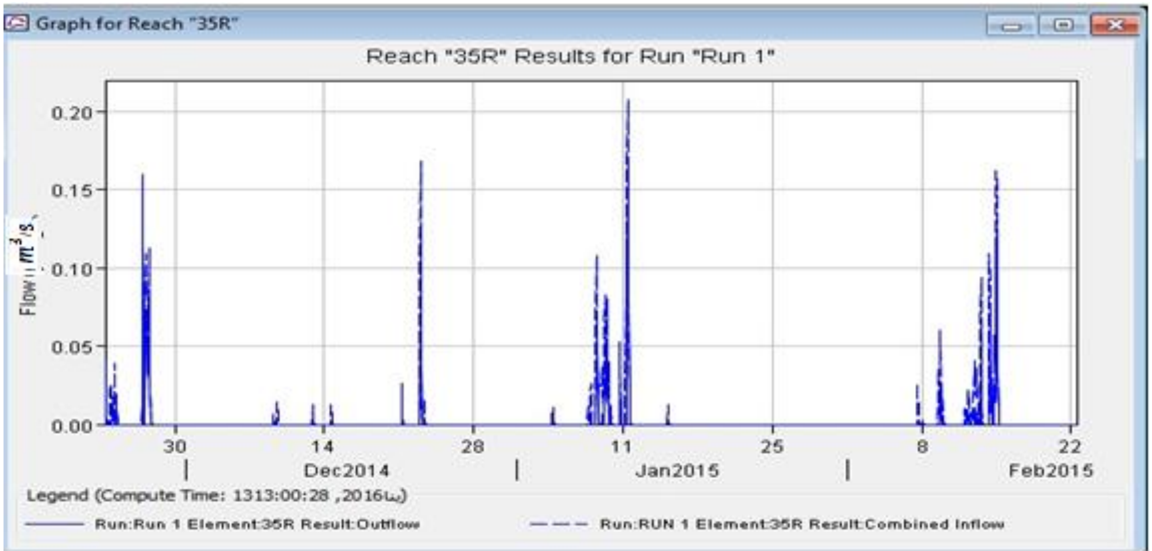

Figure 6.13: Flow for reach element 35R for direct runoff from hourly model for season 2014/2015 (HEC-HMS).

Figure 6.14 and 6.15 show the flow velocity (the velocity of water during the flow in the reach element) for reach elements 34R and 35R. The maximum velocity is 0.32 m/s for 34R, and 0.45 m/s for 35R. The maximum velocity occurred at the maximum flow for the reach element on11January, 2015. This value is small and acceptable due to small values of runoff and peak flow. It is required when designing flow channels and studying the characteristics of flow and floods in an area.

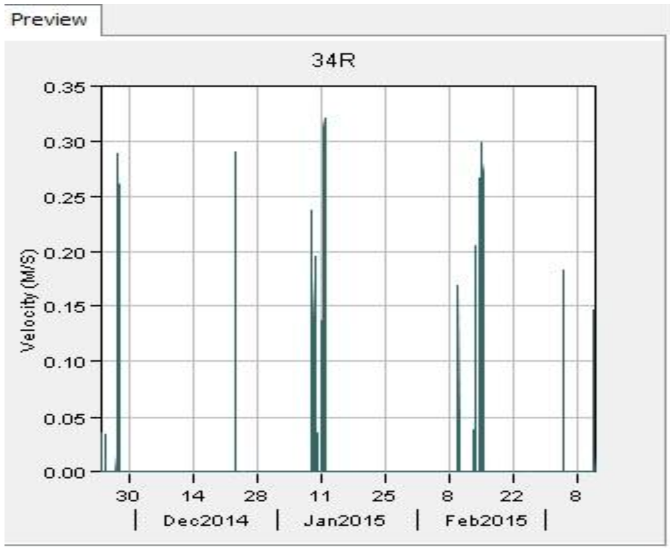

Figure 6.14: Flow velocity for reach element 34R for direct runoff from hourly model for season 2014/2015 (HEC-HMS).

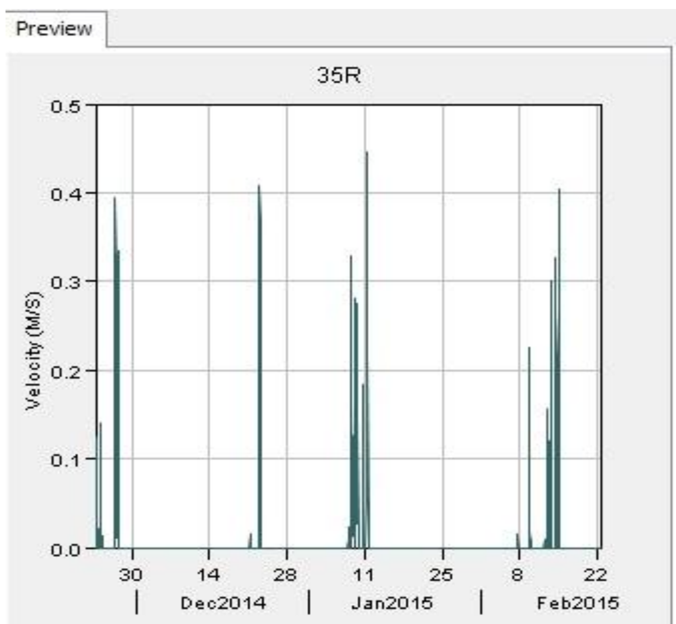

Figure 6.15: Flow velocity for reach element 35R for direct runoff from hourly model for season 2014/2015 (HEC-HMS).

6.5.3 Direct runoff from the hourly model for the five storm events

For more accuracy and clearer results; the first model was divided into five models for the five significant storms in terms of time interval. Each model has the time interval for the storm which occurred during this time. Table 6.4 shows the final results for each model. Storm 5 received the largest amount of rainfalland direct runoff because it's the strongest storm with a depth of 77.7 mm. However, this depth is relatively small and occurred within17 days, so the runoff is not large and the peak discharge is small.

Table 6.4: The final results for the five storm models for each subbasin

Subbasin		Storm 1	Storm 2	Storm 3	Storm 4	Storm 5	Total
Yatta 1	total precipitation (1000 m^3)	205.5	94	182.5	132	332	946
	total direct runoff (1000 m^3)	3.2	1.2	3.1	2.2	5.3	15
Yatta 2	total precipitation (1000 m^3)	172.2	81.5	158.2	119.5	287.9	819.3
	total direct runoff (1000 m^3)	2.8	1.1	2.8	2	4.8	13.5
Yatta 3	total precipitation (1000 m^3)	113.8	52	101	73.1	183.8	523.7
	total direct runoff (1000 m^3)	2.1	0.8	2	1.4	3.4	9.7
Yatta 4	total precipitation (1000 m^3)	262.4	120	232.9	168.5	423.8	1207.6
	total direct runoff (1000 m^3)	5.7	2.2	5.5	3.8	9.4	26.6
Yatta 5	total precipitation (1000 m^3)	230.7	105.5	204.8	148.2	372.6	1061.8
	total direct runoff (1000 m^3)	5.4	2	5.2	3.6	8.9	25.1

> **Hydrograph**

Figure 6.16 shows the hydrograph for Yatta-1sub-basin from storm event 1. The upper graph represents the total rainfall depth versus time. It's clear that the rainfall loss is high and the excess rainfall is low. At the time of peak the total rainfall is almost 5.5mm, and the rainfall loss 5.4mm, so the excess rainfall is estimated at 0.1mm. The lower graph represents the flow hydrograph in cubic meter per second versus time. At the time of peak the maximum flow occurred and was equal to $0.072m^3$/s. The time of peak at 27 November, 2014. There is no base flow in the area so the hydrograph starts from zero.

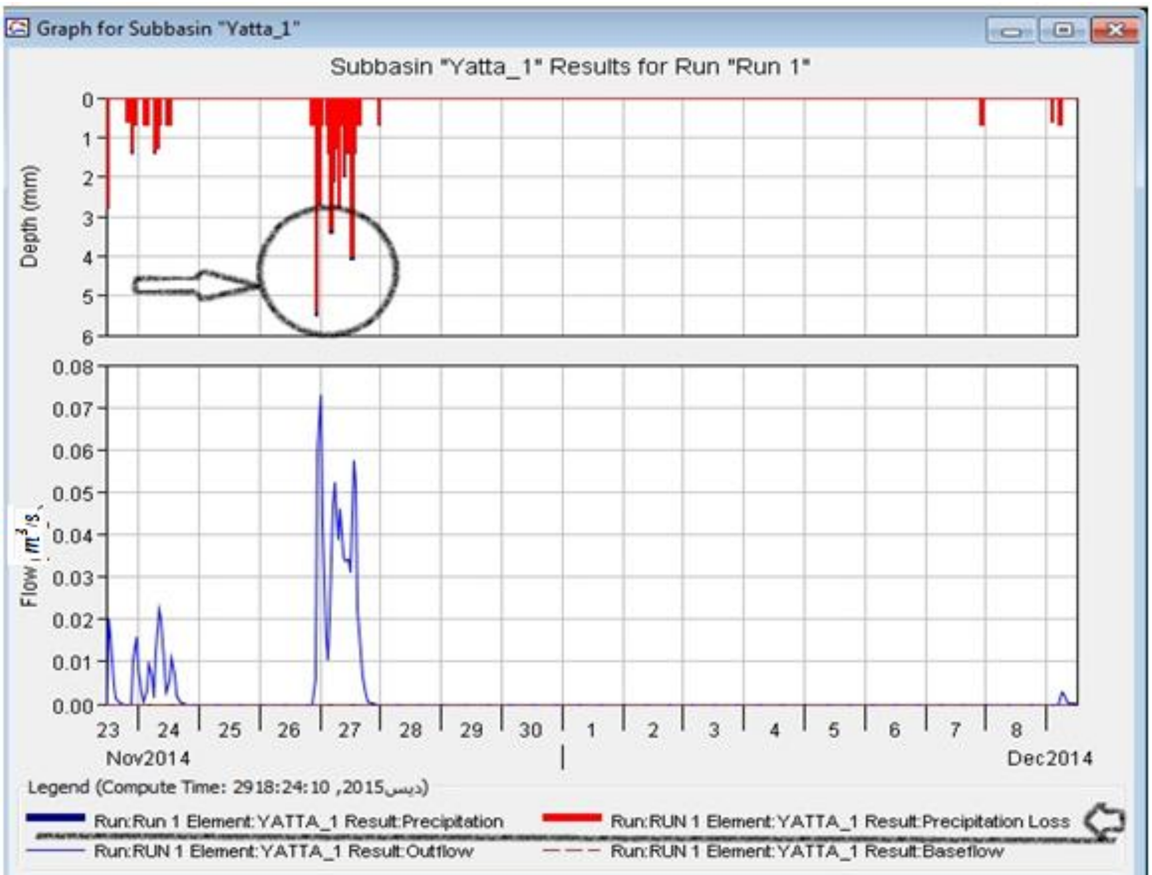

Figure 6.16: Graph for the first storm event.

6.5.4 Rainfall- Runoff relationships

Rainfall-runoff relationships are used to determine the runoff response of watersheds and its relationship to rainfall. These relationships produce runoff coefficients to determine effective rainfall.

Table 6.5 shows the total direct runoff, the total precipitation, and the runoff coefficient for each subbasin for the 2014/2015 rainy season. Runoff coefficient is range from 1.6 to 2.4%. This coefficient is dimensionless and equals the amount of total direct runoff divided by the total amount of precipitation. This value is large for areas with no infiltration and high runoff, and low for permeable and well vegetated areas. (Wei et al., 2007; Ghigliere et al., 2014). The study area has a lot of permeable soil and vegetated areas, so the runoff coefficient is low. This value also indicates no flooding incidents in the area. The amount of total rainfall and the intensity of rain directly affect the amount of total direct runoff and runoff coefficient. When the soil becomes dry; the runoff coefficient will be at its minimum values and the rate of infiltration is high (Halwatura et al., 2013; Koch et al., 2016; Ghigliere et al., 2014).

Table 6.5: Runoff coefficients for direct runoff from hourly model for season 2014/2015 (HEC-HMS).

Subbasin	Total direct runoff (1000 m^3)	Total rainfall(1000m^3)	Runoff Coefficient (%)
Yatta-1	15	946.1	1.6
Yatta-2	13.7	820.3	1.7
Yatta-3	9.7	523.6	1.9
Yatta-4	26.5	1207.6	2.2
Yatta-5	25.2	1061.7	2.4

Figure 6.17 shows the relationship between the total amount of rainfall in m^3on the X-axis and the total amount of direct runoff m^3on the Y-axis for the five storm events. This figure illustrates that the relationship between the two values is linear. If the amount of rainfall increased the amount of direct runoff will increase linearly. The Y- Interception equals -0.913*1000m^3. The slope of the line is the rainfall-runoff ratio, also known as the runoff coefficient and equals 2% (0.02). This value indicates that most (~98%) of the

rainfall infiltrates into the watershed and contributes to other runoff processes, storage, and evapo-transpirative losses. Effective rainfall refers to the amount of rainfallrequired to trigger a runoff response at each watershed location. It is estimated as the X intercept of the regression line for rainfall-runoff relationship. Effective rainfall equals 45.65*1000m^3.

R-square (R^2) = 0.988, is obtained from the developed linear regression, this shows a close proximity of the fitted data between total direct runoff and total precipitation.

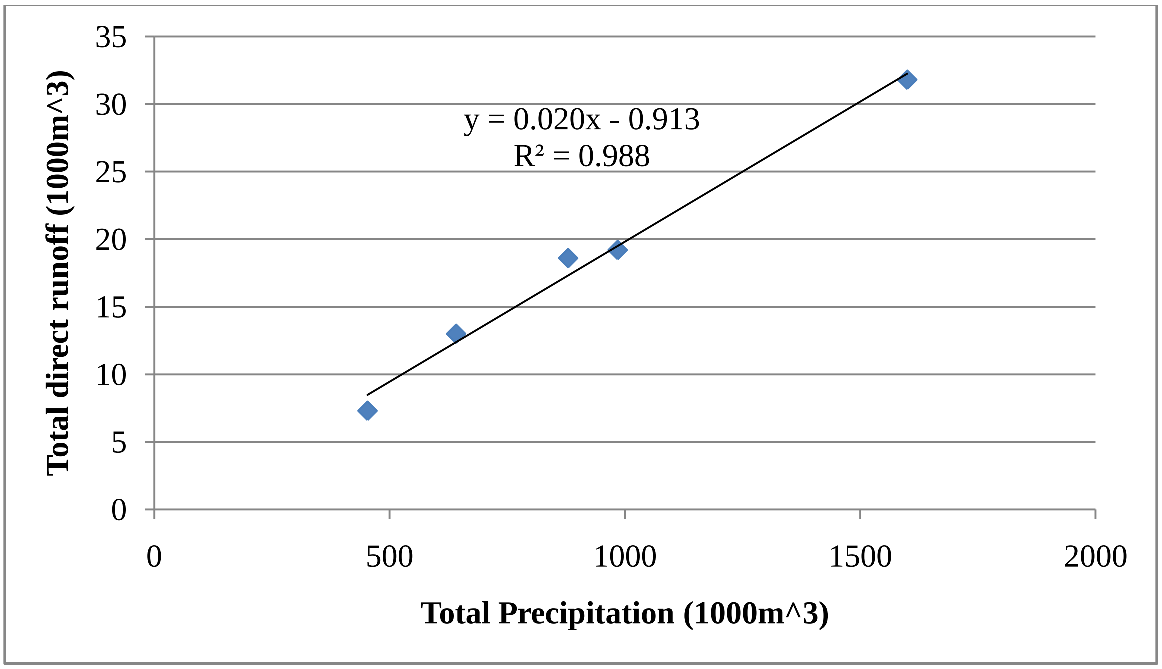

Figure 6.17: The relationship between the total amount of rainfall and the total amount of direct runoff for the five storm events.

Table 6.6 shows the runoff coefficient for the five subbasins from the five storm events. It's obviously that strom-3 and Yatta-5 subbasin have the largest values of runoff coefficient. Runoff coefficients range from 1.3 to 2.5%.

Table 6.6: Yatta watershed runoff coefficients for each subbasin from the five storm events model (HEC-HMS).

Subbasin/Storm/ Runoff coefficient (%)	Storm-1	Storm-2	Storm-3	Storm-4	Storm-5
Yatta-1	1.6	1.3	1.7	1.7	1.6
Yatta-2	1.6	1.4	1.8	1.7	1.7
Yatta-3	1.9	1.5	2	1.9	1.9
Yatta-4	2.2	1.8	2.4	2.3	2.2
Yatta-5	2.3	1.9	2.5	2.4	2.4

6.5.5 Impacts of Urbanization on storm runoff

The watershed's response to urbanization is determined by altering CN, i.e. the percent of impervious surface area in the basins. The urbanized areas in Yatta area concentrated in Yatta-4 and Yatta-5 sub-basins indicating a high percent of impervious areas and CN in these sub-basins. This leads to a higher amount of total direct runoff in these sub-basins compared to other sub-basins due to losses during transmission.

The increase in runoff associated with the increase in urbanization is proportional to the increase in impervious surface area. Areas with higher impervious area induce higher runoff and vice versa. Increasing the percentage of impervious surface area will increase the sub-basin specific runoff and total runoff.

Connected impervious surfaces generate overland flow runoff in proportion to the impervious surface area something disconnected impervious surfaces do not. A common example of high connectivity is a parking lot that is directly connected to storm sewer systems that have outfalls in perennial stream channels. Impervious surfaces that drain to pervious surfaces produce an opportunity for infiltration and they may generate less runoff. This suggests that two watersheds with similar impervious surface areas can generate different amounts of overland flow runoff depending upon impervious connectivity.

Chapter Seven

Best management practices

To manage the direct runoff; there is a need to determine the number, size, and locations of storage facilities. The storages facilities that could be used are: earthen ponds and cisterns. The location of these facilities can be determined using GIS depending on many factors. This will reflect on the socio-economic situation in Yatta area, especially in the agricultural sector.

7.1 Best management practices

There are many storage facilities to harvest the quantity of direct runoff water for watersheds namely earthen ponds and cisterns. These facilities are economical, have more benefits than others, and more suitable for this area.

7.1.1 Volume of storage facilities

Rainwater harvesting cisterns can be used in locations that are far away from the location of earthen ponds at outlet points. Table 7.1 shows the number of cisterns and the total amount of water harvested in cisterns (each with a volume of $100m^3$) for each subbasin, the remaining quantity of water can be collected in earthen ponds at outlet points.. Earthen ponds can just be used to manage these quantities, but in this case many areas will not benefit from this water due to the long distance between these areas and ponds. It is also difficult to transport the water from ponds to these sites. So some cisterns should be built in agricultural sites that are far away from ponds to harvest and use the runoff for agricultural activities. The increase in the number and distribution of these small cisterns in the basins will have a hydrological impact with respect to stream flows.

Table 7.1: Cistern and pond volumes

Subbasin	Actual amount of runoff (m^3)	Number of cisterns	Amount of water collected in cisterns (m^3)	Number of ponds	Amount of water in ponds at outlet (m^3)
Yatta-1	7600	19	1900	2	5700
Yatta-2	3050	11	1100	1	2000
Yatta-3	1850	5	500	1	1350
Yatta-4	4200	7	700	2	3500
Yatta-5	16550	21	2100	3	14450

7.1.2 Location of storage facilities

The distribution of activities is based on many factors such as: location with respect to stream flow, agricultural land, availability of area to build cisterns and ponds, soil erosion, agricultural water demand, and the focus on irrigated canopies.

Table 7.2 shows the coordinates of earthen ponds and the least amount of water collected. The first pond collects the water from subbasins Yatta-1 and Yatta-3. Pond two collects water from subbasin Yatta-4 while Pond 3 collects water from subbasin Yatta-5. There are available areas to create these ponds at the given coordinates. The locations of these facilities are concentrated in the areas with high agricultural activities in Yatta.

Table 7.2: The coordinates of earthen ponds and the least amount of water collected in Yatta area.

Earthen pond	X- coordinates	Y-coordinates	Amount of water (m^3)
1	160,901.2135	94,073.7865	3700
2	162251.0000	95093.6000	2000
3	161897.0000	96166.0000	2000
4	160798.0000	94771.7000	1350
5	158,298.4850	93,071.0580	1500
6	159275.0000	93670.6000	2000
8	159,992.0000	92,594.0000	4450
9	160556.0000	93226.1000	5000
10	160973.0000	92266.3000	5000

7.1.3 Assessment of the impacts of using harvested water on the socio-economic conditions

People in Yatta area drastically need additional water sources for agricultural purposes. Using harvested water is anticipated to have a number of positive impacts on the socio-economic conditions of the end users including:

1- The price of 1 m^3 of water is 5 NIS (Yatta municipality, 2015); the amount of water harvested is 90,100m^3. Those who exploit this water will save about 450,000 NIS on an annual basis. This money can be used to improve the economic situation of these people.

2- Crop yield and productivity will increase due to the availability of water for these targets; the land use and cropping style will also change. Most crops planted in this area are: olives, almonds, wheat, barley, and others. For example, in Yatta area one dunum produces 25 kg of olive oil, if there are other sources of water to irrigate the trees; the productivity of olive oil will increase to more than 28 kg per dunum.

3- The area of irrigated and cultivation of the land will increase.

4- Job opportunities will increase due to an increase in the productivity of crops and irrigated land area.

Table 7.3 shows irrigated agricultural crops and the economical properties of each. One dunum of olives, almond, and grapes requires 200 m^3 of water, while one dunum of vegetables needs 500m^3. In the Yatta watershed about 90,000 m^3 of stormwater can be collected and stored. This amount can supplement around 300 dunums of olives, almond and grape trees in addition to more than 60 dunums of vegetables. From the table below it can be seen that 60,000 $ can earned per year from irrigating around 300 dunums of olives, almond and grape trees, and 18,000 $ can earned per year from 60 dunums of vegetables. At least 360 job opportunities will be available to work on these lands (Palestinian Central Bureau of Statistics, 2015).

Table 7.3: Irrigated agricultural crops and their economical properties for Yatta area (Palestinian Central Bureau of Statistics, 2015).

Crop	Ton/Dunum	Price ($)	Cost ($)	Profit ($)	Number of labors per dunum
Vegetables	3-5	1500	1200	300	1
Fruits	3-4	1700	1500	200	1

All these impacts will increase the income of families in Yatta area especially those who work in the agricultural domain, decrease soil erosion, increase the agricultural value of the land in Yatta area, increase the irrigation lands, promote agricultural activities, decrease water consumption from the municipal water networks, and enhance rainwater harvesting.

Chapter Eight

Conclusions and Recommendations

8.1 Conclusions

The general objective of this research is to estimate the potential amount of total direct runoff from Yatta area watersheds to be used in the agricultural sector and to evaluate its impact on the socio-economic situation in the study area. The specific objectives are to: study the characteristics of the rainfall (i.e. the monthly, average, maximum and minimum, annual), study the Rainfall- Runoff relationship.

To achieve the objectives of this research a review of relevant literature was first performed in which some applications of the hydrological modeling approach were reported. Yatta area watershed was then studied using HEC-HMS model.

Rainfall data was thoroughly analyzed as the results were important input for hydrological model. Rainfall in Yatta watershed varies in both time and space, its gradient is steep eastward. Yatta has an average rainfall of 385 mm/yr, received mainly in December, January and February. The climatic factors of Yatta watershed affected runoff generation.

Annual, monthly, and daily rainfall for Yatta watershed were studied and analyzed. The analysis resulted with high consistency of the selected rainfall data. The values of standard deviation are far away from the mean, reflecting the variability of annual rainfall data during the long analysis period. There is a noticeable difference between the maximum and minimum rainfall records. Rainfall is usually at its peak between December and February during the rainy season.

The hydrological assessment of watersheds helps make decisions for best management. A conceptual model describes the process of runoff within a subbasin.Conceptual models build on simplified concepts derived from physical processes of rainfall runoff phenomena. A conceptual model was developed using GIS and WMS applications. The DEM was used as input for WMS application to prepare the initial model in this research. The WMS software was used to define the boundaries of the watershed and its subbasins and calculate some physical parameters for each subbasin using the DEM, land use and soil distributions for the basin. From delineating Yatta watershed using WMS; the overall subbasin area is 20.59km^2.The boundaries of the watershed and its sub-subbasins, and the physical properties of the watershed saved and exported to Hydrologic Engineering Center - Hydrologic Modeling System (HEC-HMS). The HEC-HMS software was used to develop surface water model for Yatta watershed. TheDeficit and Constant Loss method is the most appropriate to estimate the loss in the sub-basins. After running the HEC-HMS for direct runoff from hourly model for season 2014/2015 (HEC-HMS) resulted in 90,100 $m^3$of direct runoff from the total amount of precipitation, in comparison with the amount of total direct runoff for the five storm events model which is 89,900m^3. The values of peak discharge and runoff coefficient are acceptable compared to the climate conditions and land cover, and lead to no flood prediction in the area.

Developing a water balance model using HEC-HMS assists in the analysis of evapotranspiration and infiltration that occurs in the watershed, and the beginning and end of the storms.

Yatta area fulfills its domestic water requirements from direct water networks, cisterns or by purchasing water tanks. Since these collectively are all limited in terms of quantity, management of watersheds will help provide other amounts of water to decrease the request on water for domestic and agricultural activities. Although rainfall in Yatta is relatively low; water harvesting could be considered as potential sources of water. The total amount of direct runoff can be collected in 63 cisterns with an average volume of 100m^3 and 10 ponds. This management will impact the socioeconomic condition of Yatta area. 90,000m^3 of storm water that harvested and stored in Yatta watershed can supplement around 300 dunums of olives, almond and grape trees in addition to more than 60 dunums of vegetables. About 60,000 $ can be earned per year from irrigating around 300 dunums of olives, almond and grape trees, and 18,000 $ from irrigating 60 dunums of vegetables. At least 360 job opportunities will be created to work on these lands.

8.2 Recommendations

Based on the research output, the following points are recommended to be considered in future hydrological research related to rainfall- runoff modeling:

1- Stakeholders should focus on watershed management, to find alternatives for water resources.

2- There is a need to increase the interest in watershed modeling using the HEC-HMS model. Noting that it is important to define the objectives of the model early in the process.

3- Further studies have to be carried out on surface water potential and other sources to be used as alternatives to supplement water demand of the sub-basins.

4- The Ministry of Agriculture and other related ministries need to establish infrastructure (e.g. weirs) to measure storm water flow in the main wadis in Yatta watershed.

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