# Master Thesis

submitted within the UNIGIS MSc. programme
at the Department of Geoinformatics - Z_GIS
University of Salzburg, Austria
Under the provisions of UNIGIS India framework

# Assessing the Effects of Spatial Resolution of DEMs on Hydrological Modelling

## A Case Study on Wadi Uranah, Makkah Al-Mukarmah (Saudi Arabia)

by


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A thesis submitted in partial fulfilment of the requirements of
the degree of
Master of Science (Geographical Information Science & Systems) – MSc (GISc)

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January, 2018

## Science Pledge

By my signature below, I certify that my project report is entirely the result of my own work. I have cited all sources of information and data I have used in my project report and indicated their origin.

Cairo, Egypt 13-01-2018 Ramadan

Place and Date Signature

## Acknowledgements:

Firstly I am grateful to Almighty Allah for giving me the strength and knowledge to accomplish this thesis.

I would like to thank my family for their support during my study, especially my Mother that learned me walk in the road with determination and challenge and continue to strive for achievement of goals and ambition.

I wish to thank the continuous and intensive support from faculty staff in UNIGIS and I am sincerely grateful to my supervisor Dr. Shahnawaz who by being so keen on details, guided me in writing this paper. Thank you for your patience and for believing in me.

Several people assisted my efforts at various stages and places during writing this paper. I appreciate the sincere help and interest of Dr. Ibrahim Salah Eldin at National Water Research Center who gave me advice constructively.

Lastly, I further acknowledge the reliable cooperation from The General Authority of Meteorology and Environmental Protection, Water and Electricity Company and Ministry of Agriculture for providing me the data.

# Abstract:

Digital Elevation Model is major important data in many applications, DEMs are widely used for representing and analyzing surface topography, as well as, DEMs are crucial in hydrological modeling where through analysis of digital elevation models can identify the (characteristics of dry valleys) basins and drainage systems.

DEM is available from different sources and with different spatial resolution. The difference in the spatial resolution of the digital elevation models may lead to a wide variation in the analysis results Therefore, the spatial resolution of the digital elevation model represents a critical role in estimating the rainfall runoff. Where there are several factors that impact on runoff estimation some of them related to the spatial and temporal characteristics of rainfall and others are related to the physical features of the watershed that can be different depending on the DEMs resolution.

This study to assessing the influence change of digital elevation model (DEM) resolution on watershed morphometric characteristics and its effect on runoff estimation in Wadi Uranah, deboned on using different three DEMs resolution (90 meters,30 meters, and 12.5 meters) that considered in order to compare the results obtained.

The results showed that the DEM resolution could have a significant influence on the watershed delineation especially in in flat areas where demonstrate the difference was strongly in sub basin no.10 and no.11 respectively. Also, found the discrepancy in a simulated runoff in the tow sub basin 7 and 10 due to the difference in the basin area according to the DEM resolution used where the rate of differencing 11.43% despite the same rainfall event. Accordingly, the drainage area is most sensitive to changes in DEM resolution that affects the value of peak discharge.



**Key words:** DEM spatial resolution, basin, watershed, Hydrological modeling, surface runoff, HEC-HMS, peak discharge, Hydrograph.

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# Chapter-1: Introduction

## 1.1 Background

Digital elevation models (DEM) widely used in representing and analyzing surface topography and topographic analyses to determining topographic characteristics that are one of the most important exponents of hydrological attributes extraction, through analysis of digital elevation models can identify the characteristics of dry valleys (basins and drainage systems).However, although there is increasing the availability of DEM data from remote sensing sources, it remains difficult for users to select an appropriate DEM for a specific application researchers has found that DEM quality and resolution significantly affect the accuracy of any extracted hydrological features(Kenward et al., 2000, pp.432-444).Whereas the watershed parameters regard to three aspects of (1) area characteristics (size, shape, and slope of the area), (2) length of the stream, and (3) slope of the mainstream which was automatically extracted from DEMs is varying with using different resolution DEMs for the same area.

The estimation of runoff in dry wadi dependent on the availability of some hydromorphology parameters such as drainage basin area, slope and length of the main canal along with the calculation of drainage density and other parameters. On the other hand, needed to on the maximum daily rainfall data, the location of the stations and distribution within the basin and the calculation of the so-called intensity and depth of rain. An important question in hydrology is how much streamflow occurs in a wadi in response to a given amount of rainfall. To answer this question we need to know where the water goes when it rains, how long does water reside in a watershed, and what pathway does water take to the stream channel. Hence, certain physical properties of the watersheds significantly affected the characteristics of the runoff and, as such, are of great interest in hydrologic analyses. While rainfall input is a fixed for the same area but watersheds characteristic vary depending on the DEMs resolution which was derived the watershed and stream network from it for the same area.

For these reasons, the goal of the current study is to assessing the effect of DEM resolution on watershed network delineation and the performance of rainfall-runoff models where it is very necessary to check and compare the performances of results based on different DEMs resolution. the quantify the changes in morphometric characteristics and hydrologic processes will be done based on comparing between all features derived from DEMs 90, 30 and 12.5 meters. Which focuses on implications of DEM the reliability of derived hydrologic derivatives and Influence factors on runoff and simulation results with different DEM resolution through conducting a hydrologic modeling on Wadi Uranah using of three DEMs that different in spatial resolution.

## 1.2 Objectives

The aim of this study is conducting a hydrologic modeling on Wadi Uranah using each of three DEM that different in spatial resolution (90, 30, and 12.5 meters) separately and comparing between results to determine the following:

What the difference in characteristics of morphometric parameters for drainage basins and Stream networks which had derived from different DEM resolution and the impact of different spatial resolutions of DEM on it?

What the effect of the difference of morphometric characteristics watershed and stream network on the estimation of surface runoff?

## 1.3 Justification of the Study

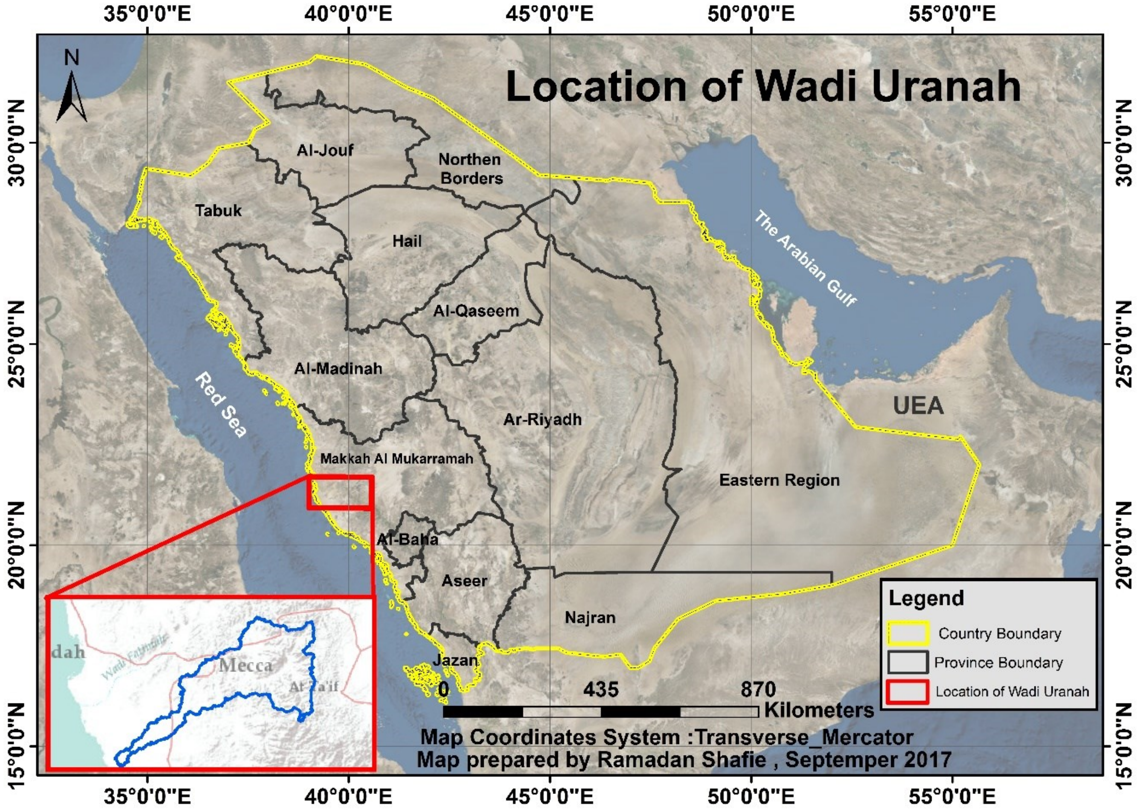
There are many studies that recommend not relying on Low-resolution DEMs due to the lack of credibility of their results which showed that the Root-Mean-Square Error (RMSE) increases with increasing the cell size and thus the lack of spatial resolution, which often use the Low-resolution DEMs (cell size dimensions greater than 15 meters) for general data such as knowing the general shape of the study area in terms of elevation, topography of surface, slope and etc. of data that can be derived to determine the characterized of area topography conversely DEMs with medium or high spatial resolution (cell size dimensions less than 15 meters) which useful in identifying accurate data used to represent the accurate surface it can be reliable to derive the accurate data on the hydrological characteristics of networks and drainage basins in the study area and estimating the amount of rainfall on each wadi accurately and the quantity of water discharged and discharge time. Therefore, we can identify the areas affected by runoff and produce accurate maps, also we can rely on the results of their analysis in estimating the losses caused by flash flood. In view of this, it was motivated to conduct a study to highlight the differences of analysis results for the same area using different spatial resolution DEMs.

## 1.4 Study Area

### 1.4.1 Location

The study area is located within the western province of Saudi Arabia between geographic coordinates: 39° 12′ 00" E; 40° 18′00" E and 21° 01′ 30"N; 21° 35′ 30"N presented in Map1.1. Wadi Uranah one of the major five watersheds in the central part of the Tihamah-Hijaz (middle part of the Arabian Shield) region. Wadi Uranah area is about 2303 km2 and the total length of Wadi Uranah about 119 km while the parameters of the wadi have 601 km. Wadi Uranah extends longitudinally from east to west with an area about 2303 km2, the maximum height of Wadi Uranah is 2611 meters at the upper basins and the height reaches below at the exit of the wadi near the red sea coast. The basin is exposed to frequent flash floods, whose gravity latent be due to its location inside the holy city of

Makkah which are visited more than 2 million Muslims annually during the pilgrimage season and the month of Ramadan.



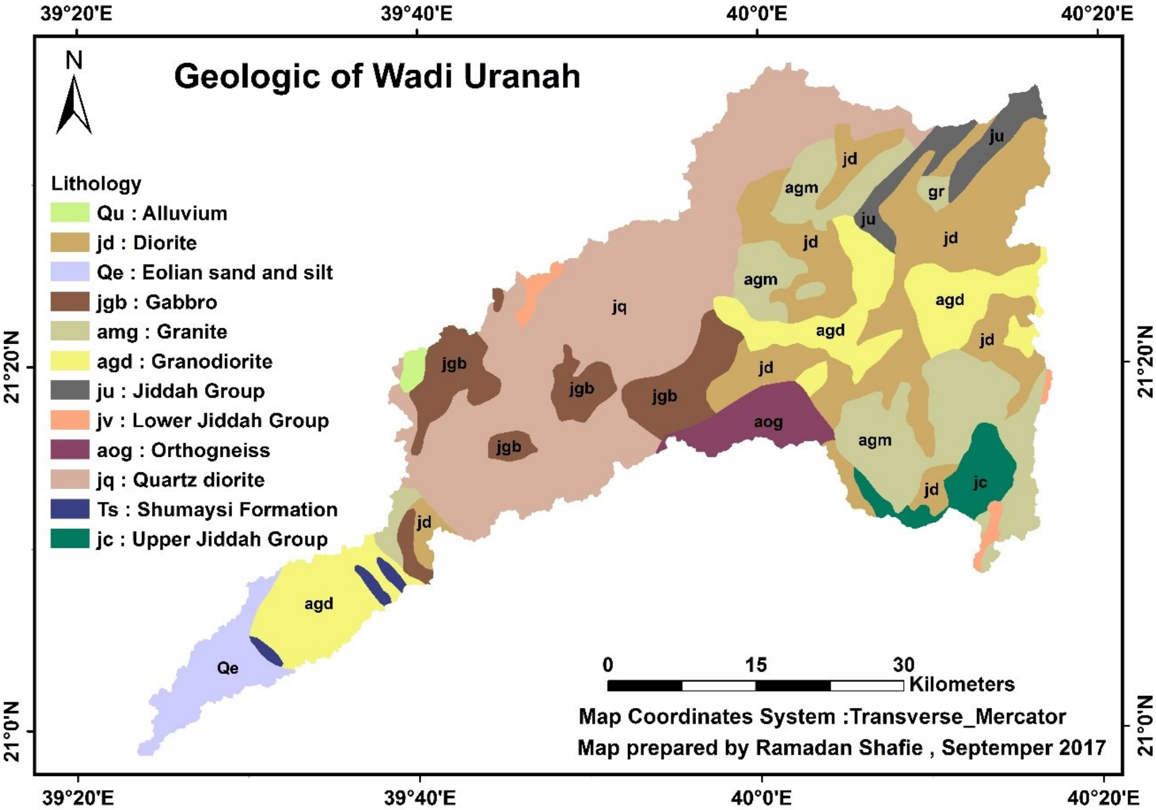

**Map 1.1:** Location of Wadi Uranah

### 1.4.2 Geology

The study area lies within the western region of the Arabian Peninsula and known geologically as the Arab shield, which its rocks belong mostly to the Pre-Cambrian era. It's covered by different types of igneous, metamorphic and sedimentary rocks of Precambrian and lower Paleozoic era. In addition, there are subordinate sedimentary rocks and basaltic lava flow of Tertiary and Quaternary age. Map 1.2.Some detailed was got on the geology of Wadi Uranah within the Geologic map of the Makkah Quadrangle(Moore and Al-Rehaili, 1989, pp.62). According to Geology of the Arabian Peninsula; shield area of western Saudi Arabia(Brown et al., 1989, pp.1-199).

### 1.4.3 Climate

The climate in the study area is a desert climate. Temperatures are high throughout the year and the average annual temperature is 30.0 °C in the study area. In a year, the minimum value of monthly mean temperature is 16-24 °C. The prevailing wind is of north-west-east direction most of the year and the northwest wind is dry in summer and humidity in winter. The rainfall varies from year to year and it often occurs as thunderstorms of very high intensity during a local storm followed by dry periods. Because of the high rainfall and high intensity, flash floods frequently take place, were the average annual rainfall is about 89 mm in Makkah al Mukaramah station, while the average annual rainfall is about 72.6 mm in Al Taif station.



**Map 1.2:** Geologic of Wadi Uranah

<u>A summary of this chapter</u>: This chapter presented the motivation for this research work and the research objectives, it also provided a comprehensive overview of the study site geography and geology and climate. Which highlighted the importance and sensitivity the site of study area which requires selection the most accurate data when conducting hydrological analysis.

# Chapter-2: Literature Review

## 2.1 Introduction

This chapter delivers information related to the effect of DEM resolution on hydrology modeling, where the literature review contains four major sections that document several sides relevance to the study topic which deals with the effect of digital elevation models on hydrological modeling and methods of extraction watershed and definition of hydrological modeling, as well as modeling and process of estimating amount of surface runoff.

### 2.2 Effect of DEM Resolution on hydrology Modeling

Different DEM resolutions can cause different spatial patterns which further affects quantification of hydrologic connectivity and simulation of hydrologic processes. **(Teegavarapu et al., 2006, pp.1-8)** used two DEM resolutions, 10m and 90m, to define the watershed boundaries and other hydrologic parameters that are used for simulation of daily streamflow using HSPF model (Hydrologic Simulation Program Fortran)in Kentucky State by comparing the hydrographs in each simulation that have found that the boundaries of the delineated watersheds are different based on 10m and 90m DEM therefore, increase in the watershed area which resulted in increase in the total flow volume.

**(Sharma et al., 2011, pp.573-582)** Used five different resolutions of DEMs 30, 45, 60, 75, and 90 m using TOPOGRID algorithm to determining an optimum cell size for DEM in prior to hydrologic modelling. That have found the surface area of sink was observed to increase exponentially with increasing cell size. For 30 m DEM the surface area of sink covers only 0.14% of total area, while for the 90 m DEM the sink surface area is about 0.56% of the total area and the Spatial variability of interpolated DEM surfaces was increased from 30 to 90 m resolution DEM while the random noise content decreased from fine to coarse resolution DEM over the same resolutions. The results indicated that a

DEM of 90 m cell size is sufficient for capturing the terrain variability of the study area and for subsequent hydrologic modelling.

**(Hanuphab et al., 2012, pp.712-718)** In this study, addressed assess how different sources and resolution of DEM data may affect the outcomes of hydrological model and the investigated the effects of DEMs resolution on driving topographic and hydrological attributes based on generating stream network and watershed area in Phuket Province, Thailand using four resolutions including 5m, 10m, 20m, and 30m and conduct comparing stream networks and watershed boundaries from all datasets to evaluate the effects of data spatial resolution and data source, the results shown that DEMs generated from coarsely sampled elevation points may have severe limitations in their use for hydrological analysis. That shows the impact of grid cell size on stream network and watershed boundary as reported by other authors.

**(Azizian and Shokoohi, 2014, pp.64-78)** The study aimed to investigate the effect of DEM resolution and the assigned threshold for river network delineation the results of rainfall-runoff models in the Kasilian watershed, a small part of the Caspian Sea watershed, The results showed that the decreasing the DEM resolution (increasing DEM cell size) led to decrease in the slope and the number of streams and the area of sub basins and the mean length of the overland flow increase, According to the results one can deduce that DEM resolution and stream delineation threshold have significant effects on the performance of GIUH-based models, and researchers should be careful in using DEMs with different cell sizes.

**(Wang et al., 2015, pp.1505-1521)** This study focused on examining the impacts of the spatial resolution of rainfall inputs through compared the outputs based on16 DEM spatial resolutions, from 30 to 480 m, that showed as the DEM resolution decreased, total computed watershed area, average watershed slope, total stream length, and channel slope drop also decreased. also in DEM resolution 90 m watershed area was larger than that simulated using the 30 m resolution DEM, and the total stream length was larger than for the 60 m DEM and similar to the value for the 30 m DEM, which can in turn affect the uncertainty in simulated flow and nutrient loads. finally, this study suggested that every effort must be made to collect higher resolution input data to minimize uncertainty in model simulations.

### 2.3 Watershed and Stream Network Delineation

Delineation is part of the process known as watershed segmentation to analyze watershed behavior, delineation of watersheds and stream channel networks are essential step in the hydrologic analysis the delineation is based on a variety of algorithms and the quality of DEMs influences the derived stream network .One of the is a most commonly used methods the Eight Direction (or D8) method, the flow direction for each cell is determined according to the steepest descent to one of its 8 neighboring cells according to the Figure 2.1

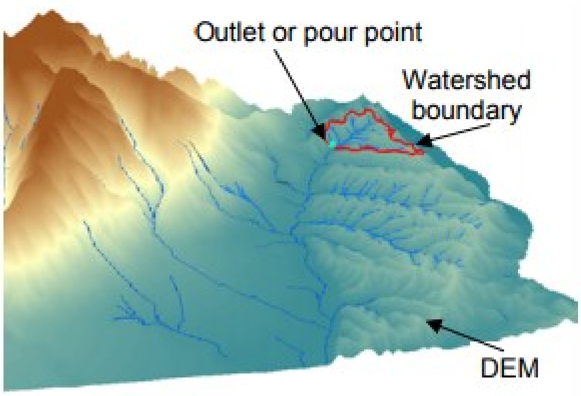



**Figure 2.1:** Representation of a DEM, a pour point and the watershed boundary

**(Wilson et al., 2008, pp.213-236)** Reviews the nine flow routing algorithms that simulate the distribution and flow of water across landscapes and the experiments that have been conducted to evaluate their performance over the past 15 years are discussed.
The comparisons showed that the D8 and Rho8 SFD algorithms initiated flow from 30–40% of the cells and produced much higher proportions of cells with small upslope contributing areas compared to the FD8 and DEMON MFD algorithms.

Although the D8 method is a most commonly used for flow tracing but has drawbacks were the elimination of the unimodal link between the flow directions and the complications in defining the watersheds boundary due to the multiple flow direction from a cell.

**(Jana et al., 2007, pp.717-727)** This study highlighted of an improved algorithm for flow tracing in residual undulating terrains using a low-resolution spatial database the method, named as CBRGM,is an improved approach for extracting the distributed drainage network of a watershed to avoid the formation of spurious pits and flat areas and thus generates a more detailed DEM. This method is based on the D8 algorithm that takes a larger window for analysis and tries to capture the topography and assign the flow direction accordingly window size, is gradually increased from the nearest neighborhood (d ¼ 3, i.e., 3 3 cells) to a larger area until a unique direction.

**(M. Rahman et al., 2010, pp.49-58)** conducted a study to undertake to evaluate the performance of 90m SRTM DEM in delineation of drainage network in the flat terrain of Bangladesh through selected of Twelve watersheds from the five hydrological zones of Bangladesh the results indicated that, in flat terrains having a slope flatter than 1:2,850, delineation of drainage network must be carried out carefully using the hydrology tool of ArcGIS software that uses the D8 method for delineation of drainage pattern and watersheds. It is also recommended that other techniques excluding D8 method as implemented in ArcGIS, should be experimented before a general conclusion about the use of SRTM data in flat terrains could be drawn.

### 2.4 Hydrologic Modeling

**(K. Rahman et al., 2013, pp.35)** Hydrological modelling is a powerful technique in the planning and development of an integrated approach for management of water resources. Hydrologic models simulate the precipitation and runoff processes of a watershed. In the model, a physical representation of a watershed is made up of hydrologic elements connected in a network. The models allow selection of methods for transforming excess rainfall to runoff, base flow representation, and hydrologic routing.

**(Devendran and Lakshmanan, 2014, pp.171-178)** A hydrologic simulation model is composed of three basic elements, which are equations that govern the hydrologic processes, maps that define the study area and database tables that numerically describe the study area and model parameters.

**(Zema et al., 2016, pp.294-308)** HEC-HMS It is a hydrologic modeling software developed by US Army Corps of Engineers Hydrologic Engineering Center. HMS HEC is widely used as it generally gives good simulations in urban areas where it would give better results since impermeability is better known and losses can be well estimated as it provides user-friendly graphical interfaces. It also has a wide range of methods to set up and control variables for simulating a rainfall-runoff. HEC-HMS performance of the 'SCS-CN', 'Green-Ampt' and 'Initial and Constant' infiltration methods in predicting runoff volume and peak flow were evaluated at the outlet of the Mésima torrent, Calabria, Southern Italy. A good accuracy in predicting runoff volume was achieved using the 'SCS-CN' method after calibration of the initial curve numbers. Peak flow was better estimated using the 'Initial and Constant' method.

**(Weiler and Beven, 2015, pp.7777-7784)** Many hydrological models have been developed and used for decades for both research and operational hydrology and many of those models are similar in structure However, new model structures are still being developed to incorporate new conceptual understanding of specific watersheds processes and place. So this study was motivated to ask the question, how would focus on the development a community hydrological Model for used rather than wasting time and effort in developing another model again, and leave as an open question whether such a community model could be programmed in a way that is agile enough to be used as an effective learning tool.

### 2.5 Rainfall-runoff processes and modelling

Estimating streamflow that response to a given amount of rainfall is The most important part of the hydrological cycle to answer it must be known where the water goes when it rains, how long does water reside in a watershed, and what pathway does water take to the stream channel (runoff processes).

**(Reddy, 2005, pp.322-323)** Rate and volume of runoff from an area mainly influenced by two factors Climatic factors and Physiographic Factors. Where Climate factors it is associated with characteristics of (Rainfall Intensity, Duration and frequency of Rainfall, Rainfall Distribution, Direction of Prevailing Wind, annual rainfall etc.) While Physiographic Factors it is associated with characteristics of (Size of Watershed, Shape of Watershed, Slope of Watershed, Orientation of Watershed, Land Use, Soil moisture, Soil type, Topographic characteristics, Drainage Density).

**(Satheeshkumar et al., 2017, pp.24-32)**The most common method of calculating the amount of rainfall converted to runoff is the SCS Curve Number (CN) Method that developed by the United States Department of Agriculture and Soil Conservation Service (USDA -SCS). The basis of the curve number method is the empirical relationship between the rainfall not converted into runoff and runoff properties of the watershed and the rainfall, the requirements for this method is rainfall amount and curve number,. The general equation for the SCS curve number method is as follows: $Q= (P-Ia)\ 2/P-Ia+S$

This method has limitation is the marked sensitivity to curve number (CN) values, fixing the initial abstraction ratio, and lack of clear guidance on how to vary Antecedent Moisture Conditions (AMC).

A summary of this chapter: This chapter Included a brief literature review where dealing with the Information on watershed delineation and hydrologic process modeling with some basic background and how the different DEM resolution affects portions of the modeling process, which has shown that DEMs with different resolutions can generate varied watershed shapes and structures which can in turn, result in a significantly different on runoff estimation.

# Chapter-3: Materials and Methodology

## 3.1 Data Used in the Study

This study will be based on a set of data that consists of three different DEMs resolution which will be used to extract the watersheds and compared the hydrological modeling adopted of each model. This model also required the assembly of all relevant data for surface water processes, to provide a very rich database of watershed information. Relevant information includes surface information such as topography, land use and soils distribution and subsurface information such as geology this data and resources will be listed as follows.

### 3.1.1 Digital elevation Model (DEM)

Several global digital elevation models (DEMs) are freely available on the web. This study will use three different DEMs resolution (90m, 30m And 12.5 m) their sources are as follows:

A) Shuttle Radar Topography Mission (SRTM)

SRTM data sets result from a collaborative effort by the National Aeronautics and Space Administration (NASA) and the National Geospatial-Intelligence Agency conducted in 2000 to obtain elevation data for most of the world. We will used two types of SRTM DEM:

- SRTM DEM as 3 arc second resolution (approx. 90m resolution)
- SRTM DEM as 1-arc second resolution (approx. 30m resolution)

B) High Resolution DEM (ALOS PALSAR DEM 12.5 m)

Obtained this data set through a project of the Alaska Satellite Facility that makes SAR data accessible to a broader community of users. ALOS PALSAR RTC products commenced October 2014 and was completed a year later the project corrects synthetic aperture radar (SAR) geometry and radiometry, and presents the data in the GIS-friendly GeoTIFF format.

### 3.1.2 Topographic Maps

Topographic maps provide a detailed representing of the natural and manmade features of the earth's surface, in this study used topographic maps scale 1:250000 to identify and show the names of natural features including mountains, valleys, plains, lakes, rivers, and vegetation. They also identify the principal works of man, such as roads, boundaries, transmission lines, and major buildings. The study area is located in 3 map sheet it is (NF37-11_MAKKAH AL MUKARRAMAH, NF37-12_TURUBAH and NF37-15_AL LITH).

### 3.1.3 Geology map

Geological map for the study area to prepare a database of subsurface structures to identify the subsurface geological structures of the rocks

### 3.1.4 Soil map

The soil map of the Kingdom of Saudi Arabia was obtained by the Ministry of Agriculture, which is classified the soil of the Kingdom based on the US classification used in the classification of the soil of the United States of America since 1975, The soil type and his ability to let water infiltrate has a similar effect to the dominant rock type in a drainage basin.

### 3.1.5 Land use Map

Land use very important layer for hydrologic characteristics of soil and water management in a watersheds which, in turn, influence the behavior of water flow on terrain surfaces.

### 3.1.6 Rainfall Data

Locations of rainfall measurement stations were obtained which are located within or near the study area also Meteorology data and rainfall information for those stations for a period of 1966–2011 was obtained from each of the Ministry of Water and Electricity and The General Authority of Meteorology and Environmental Protection.

## 3.2 Software used in the Study

- Watershed Modeling System (WMS 10.1): The Watershed Modeling System supports several industry-standard, numerical models to compute peak flow, hydrographs, water quality, etc.
- ArcGIS 10.2: to manipulate and analyze spatial data, and make maps.
- Global Mapper15.6: used to convert a set of elevation samples into a fully gridded data set.
- HEC-HMS 4.1: one of the Hydrologic Modeling System developed for the U.S. Army Corps of Engineers it is designed to simulate the complete hydrologic processes of dendritic watershed systems.

## 3.3 Methodology

### 3.3.1 Methodology overview

This chapter will describe the data sources and methodology Figure 3.1 to answer the two research objectives specified in the first chapter. Where firstly will be listed all available data which are useful in order to do the work about the area, then expatiate on the methods employed which can be summarized in several In a few steps starting from download DEM data and then conduct pre-processing of DEM data including only the filling of pits and depressions, then flow direction and flow accumulation for Stream networks and watershed were derived from the DEM resolution based on a contributing area one threshold for all DEM and the morphometric characteristics of the basins derived from different DEM resolution will be compared. To completing a process of hydrologically modeling and estimate runoff and infiltration resulting from precipitation the rainfall data, soil type data, and land-use data were all three used in the creation of the SCS curve number grid. Once the computation of this process the results could be compared.

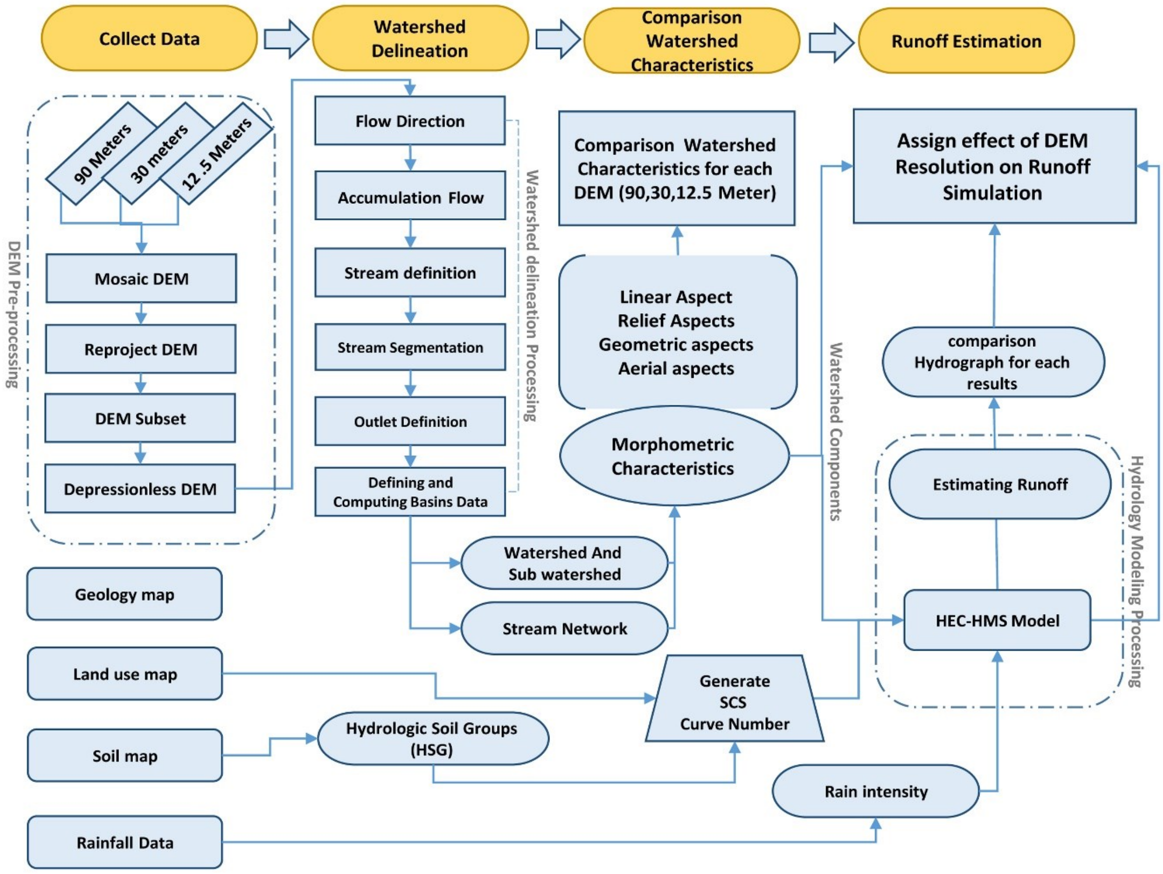



**Figure 3.1:** Methodological flow chart for study

### 3.3.2 Data Preparation

DEM requiring more pre-processing before the watersheds delineation. There are generally levels of pre-processing of DEM to making it more suitable for subsequent analysis, which is illustrated below:

<u>Mosaic DEM tiles</u>

When starting preview the digital elevation models for the study area through the data sources for download we find that they are available in more tiles therefore, we must select the tiles that covered the study area then download it as an individual tile as in Figure 3.2 .So it is of utmost importance we must merge the DEMs into a single new DEM and export it as (.dem) format.

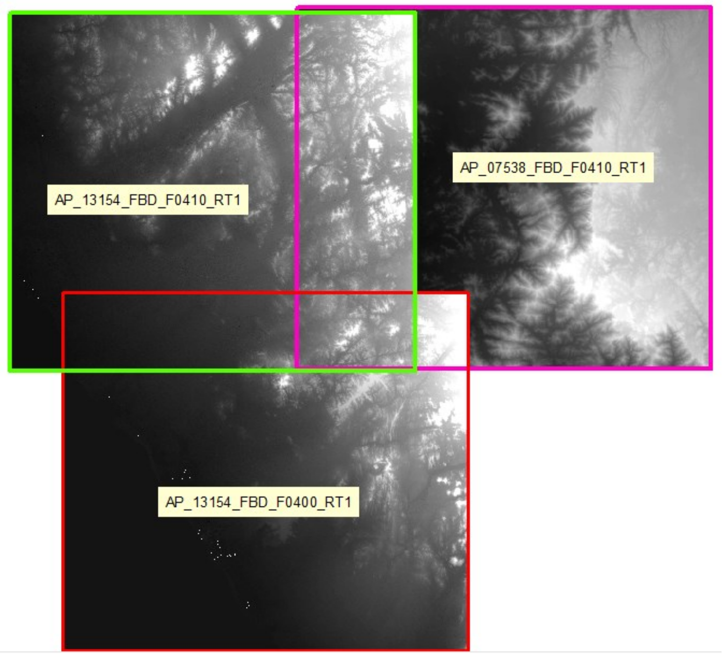



**Figure 3.2:** DEM Tiles (12.5 meters) that covered the study area

<u>Reproject DEM</u>

Global datasets are usually downloaded a DEM in (Geographic Coordinate System, Lat/Lon) for correct calculation of DEM derivatives, the DEM should be reprojected to a Universal Transverse Mercator (UTM) projection "UTM_Zone_37N" this can be done most easily with the " Projections " tools in the Arc Toolbox.

<u>DEM Subset</u>

After re-projected the digital elevation models we will make subset of DEM consistent with the boundaries of the study area.

<u>Depressionless DEMs</u>

DEM (Digital Elevation Model) set of regularly or irregularly spaced grid of elevation points, (DEMs) are the most convenient means for representing the earth's surface. There are several main sources of DEM data represented in ground survey techniques, existing topographic maps, aerial photographs or satellite imageries using the photogrammetric techniques and recently radar interferometric techniques and Laser, Where DEM that derived from stereo satellite images is a wide source which uses of many applications

However, DEMs have shortcomings and limitations that must be understood before using the data in hydrological modeling, the most important of these problems it is that contains many data voids, mostly in mountainous terrain.

So the DEM need to refinement for hydrologic modeling by the filling of these depressions and pits in the DEM as in Figure 3.3 and removing abnormal data values which have lower or higher values than those of neighboring cells by fill bad values in digital elevation models (DEMs) with values calculated using a surface fitting technique. Usually, this is a recommended procedure commonly used before performing any hydrological analysis with DEM data due that  the existence of depressions in DEMs can substantially influence the overland flow estimation (Zhu et al., 2013, pp.495-505).

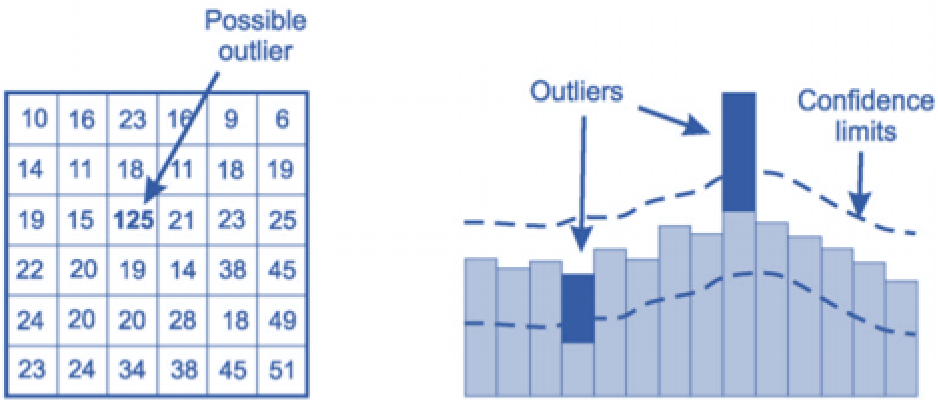



**Figure 3.3:** Filling of depressions and pits in the DEM

There are numerous methods and algorithms can be used to create the depression less DEM, which is usually achieved by filling depressions or pits(Doan, 2000, pp.113-143). While There are two of most widely used pit filling algorithms (Jenson and Domingue, 1988 and Planchon,2001) are compared in terms of their performance and ability to extract topographical parameters (Senevirathne and Willgoose, 2013, pp.1624-1630) The depression-filling algorithm presented by Planchon and Darboux works very quickly compared to other published methods that has been implemented in widely used commercial geographic information system (GIS) software package that uses a different approach through in first inundates the surface with a thick layer of water and then removes the excess water, working inwards from the edges as in Figure 3.4.

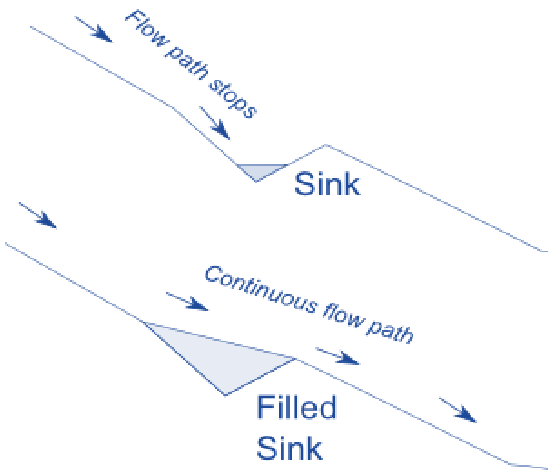



**Figure 3.4:** Preprocessing – Sink Fill

One of the Digital Elevation Models that will be relied upon in this study that derived from Shuttle Radar Topography Mission (SRTM) the 'finished' grade version of this data still contains data voids (some 836,000 km2 6 ) and other anomalies that prevent immediate use in many applications (Reuter et al., 2007, pp.983-1008).To derive an initial research-quality DEM, the raw SRTM data has been processed standard GIS procedures have been developed to remove sinks an automated process.

### 3.3.3 Watershed and Stream Network Delineation

A watershed is defined as an area of land in which all of the incoming precipitation drains to the same place – toward the same body of water or the same topographic low area as a result of its topography(Edwards et al., 2015, pp.3-20). Watershed delineation based on digital elevation models (DEMs) is the key step and priority for hydrologic analysis and provides a visualization and analyzing capabilities to understand the scenarios of various parameters in the watershed. A watershed has five components: watershed boundary, Sub basin, Drainage divides, Stream network, Outlets (pour points) as in Figure 3.5.

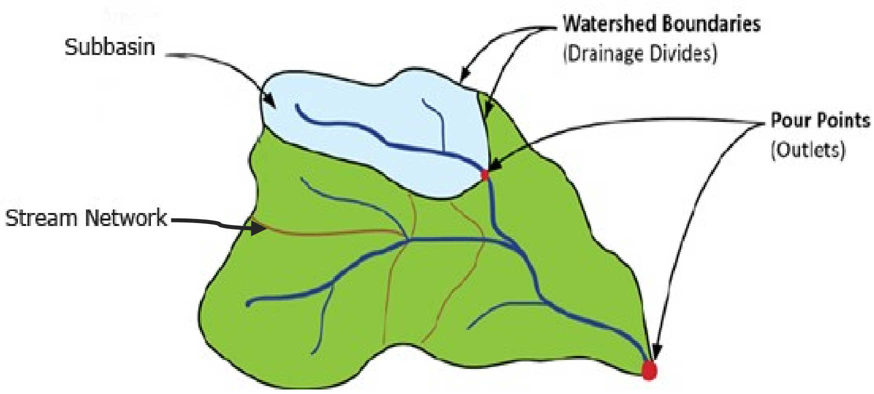



**Figure 3.5:** Components of Watershed

In this section, we will be using different DEMs resolution to derive several data sets that collectivity describes the drainage patterns of the watersheds. Raster analysis is performed to generate data on flow direction, flow accumulation, stream definition, stream segmentation, and watershed delineation to conduct a comparison between Characteristics of all watershed that derived from each DEMs and discuss the effect of cell size in that. There is a set of procedures that must be followed to Watershed and Stream Network delineation from different digital elevation models which is made by following a series of steps which we will have made with each DEM this steps will be discussed in the following elements:

3.3.3.1 Flow Direction

Determined the flow direction from every cell is a crucial step in hydrological modeling that assigns a value to each cell to indicate the direction that water will flow from that particular cell based on the underlying topography of the landscape which in turn will determine the ultimate destination of the water flowing across the surface of the land.

The D8 algorithm is a Simple and widely used method for determining flow direction that is calculated by comparing the distance weighted drop of neighboring cells where the main idea behind assigning a flow direction is to determine which of the eight neighboring cells has a lower elevation In order to be each cell have a flow direction before any hydrologic analysis, If a cell is lower than its 8 neighbors it is assigned a value of 0 meaning it is an outlet or sink. When running this model in a GIS, the flow direction tool gives you the following values: 1, 2, 4, 8, 16, 32, 64 and 128 each number indicates a direction, as shown by Figure 3.6.

- (1) East
- (128) Northeast
- (64) North
- (32) Northwest
- (16) West
- (8) Southwest
- (4) South
- (2) Southeast

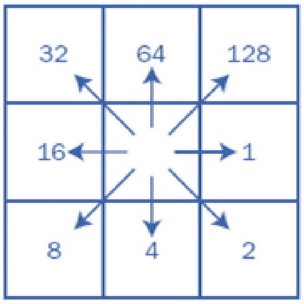
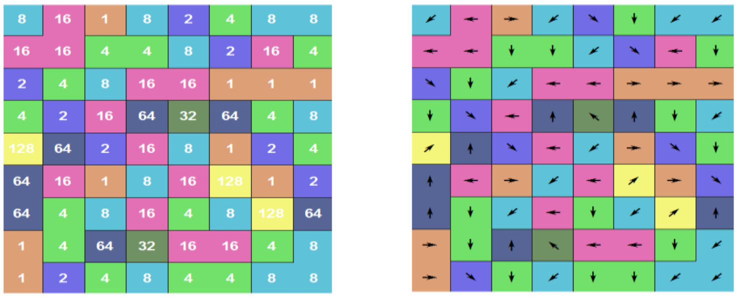



**Figure 3.6:** D8 Flow Direction Coding



(a) Flow direction grid values, (b) Symbolic representation of flow directions.

The dominant flow direction of streams is of great hydrologic importance. Even though, in Wadi Uranah there is more than one prevailing dominant flow direction because Wadi Uranah is a large-scale drainage system through the Table 3.1showing the number of cells in each direction the principal flow directions that reflecting the drainage of water also shows that the most of the direction among cells in the west direction in each of the DEMs.

| Directions | Number of Cell | | |
|---|---|---|---|
| | DEM 90 m | DEM 30 m | DEM 12.5 m |
| East | 28,400 | 263,446 | 1,462,479 |
| Southeast | 19,561 | 189,988 | 1,184,034 |
| South | 48,392 | 436,340 | 2,476,602 |
| Southwest | 37,938 | 320,026 | 1,781,785 |
| West | 66,295 | 553,000 | 3,094,724 |
| Northwest | 30,501 | 266,767 | 1,550,584 |
| North | 40,515 | 366,690 | 2,042,355 |
| Northeast | 16,365 | 181,602 | 1,153,827 |

**Table 3.1:** Number of cells in each direction derived from each DEM

3.3.3.2 Flow Accumulation

The intent of this function to simulate the flow path of water to form streams In other words to determine the ultimate flow path of every cell based on the direction of flow of each cell. The flow accumulation function creates a new grid that contains the accumulated number of cells that are draining to any particular cell in the DEM. Value of a cell is the number of upstream cells that flow to it. From the flow accumulation grid, stream networks can be created. The Cells that used to identify stream channel have substantially higher values than cells on hill slopes. Either which has a zero value used to identify the ridges Figure 3.7.

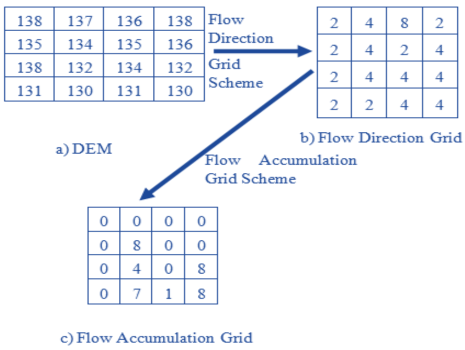



**Figure 3.7:** Flow Accumulation Grid

The resulting of this process is a raster depiction of the stream network showing the progressive accumulation of water values range from 0 to highs topographic value where streams have the value greater than of 0 that show in white and gray color and all other cells are 0 that show in black color as in Figure 3.8.

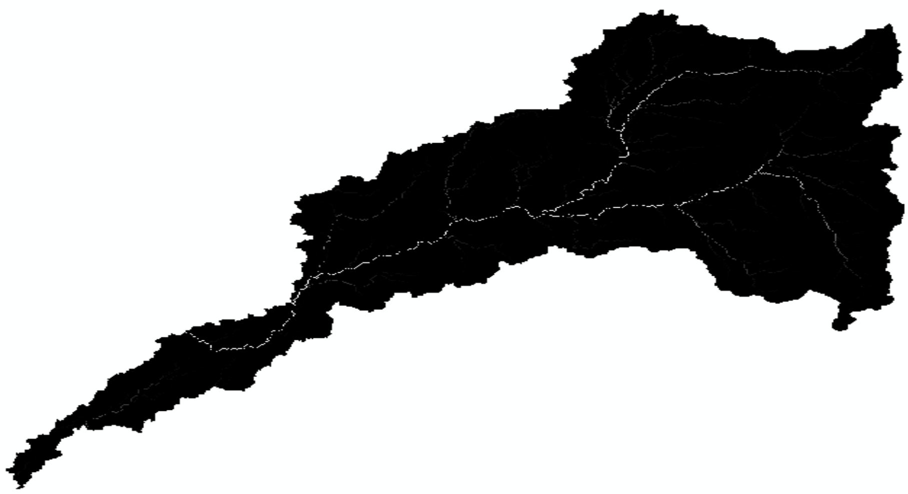


**Figure 3.8:** The resulting of flow Accumulation

3.3.3.3 Threshold definition (stream definition)

Through this function, streams may be defined through the use of a threshold flow accumulation value. The threshold value that will be selected will represent the minimum threshold for computes a stream grid all the cell have value greater than the threshold will contain a value of "1" while the cells that have less than this value will not be counted as a Streams within the Stream network will contain "No data".

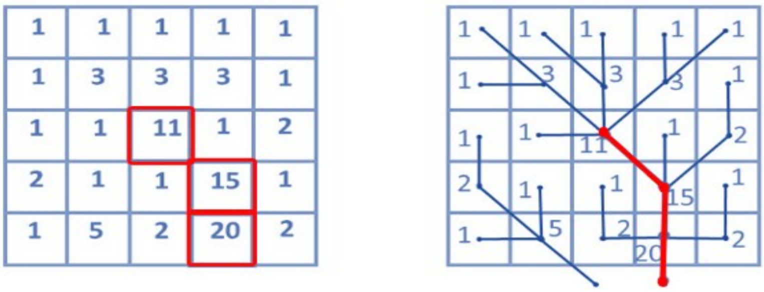



**Figure 3.9:** Threshold definition

A) Flow accumulation > 10 cell threshold B) Stream Network for >10 cell threshold drainage area

The Figure 3.9 shown in the A part the cells with accumulation greater than or equal to 10 thresholds which are considered stream cells and in B part Streams identified on the flow network a red color.

The selection of the threshold affects watershed delineation where a high number of streams generate when increasing the threshold area (a low threshold) and, on the contrary, a small number of streams generate when threshold area increases (a high threshold)(Azizian et al., 2014, pp.64-78) Figure 3.10.

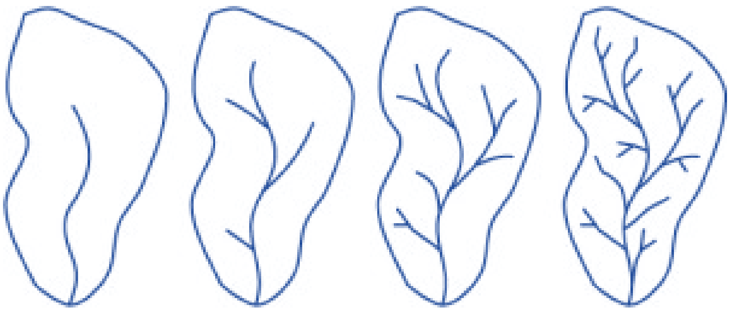


**Figure 3.10:** The effects of threshold variations on the simulated

The threshold of flow accumulation is a key factor in stream network extraction from DEMs and will strongly influence the results obtained(Lin et al., 2006, pp.289-306) and there is no consensus about how it should be chosen and Select the threshold depending on the desired performance a size of watershed and goals of analysis. We will determine the same value of sensitivity threshold for each DEM used in this study (30.90.12.5) in the watershed and stream network delineation.

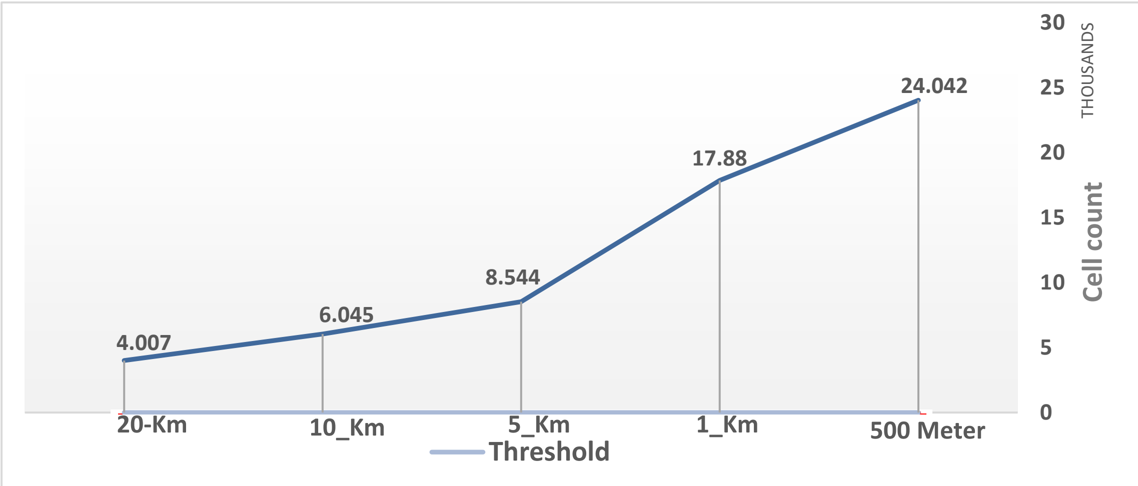



**Figure 3.11:** Results of tested a different thresholds

While tried tested a different threshold value on DEM 90 Meters which Figure 3.11 displays the effect of different threshold areas on the results of cell count with each threshold value that shown peak flow at the threshold area of 500 meters and shows a 71% difference with the simulated peak flow at the threshold area of 20 km.

### 3.3.3.4 Stream Segmentation

The Stream Segmentation function creates a grid of stream segments that have a unique identification to stream cells located within the same stream segment. Segments are defined as either head stream segments (the most upstream stream branch) or segments located between two segment junctions. All the cells in a particular segment have the same grid code that is specific to that segment as in Figure 3.12.

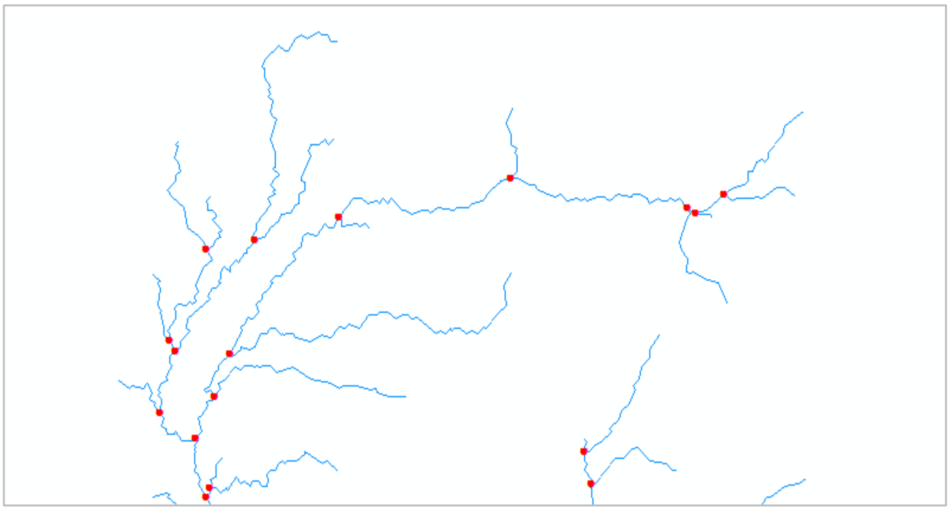


**Figure 3.12:** Stream Network Segmentation

3.3.3.5 Outlet Definition

Outlet point placement is an important step in the process of watershed delineation that should exist within an area of high flow accumulation because it is used to calculate the total contributing water flow to that given point. If the outlet point is not situated in cells of high flow accumulation then the resulting watersheds will be excessively small.

3.3.3.6 Defining and Computing Basins Data

The last step is the watersheds delineation process such an area is also referred to as a basin, watersheds. A watershed is an area of land draining into a stream at a given location, watershed delineation using the detailed stream network.

In the part of the define basins for each outlet point is created, a basin for each upstream feature arc is created for the hydrologic modeling tree.

In part of Computing Basins Data, all geometric parameters and attributes such as basin areas and slope and stream lengths and slopes can be computed.

The watershed delineation steps were then repeated for sub basin delineation for each stream network reach.

### 3.3.4 Comparison of morphometric Parameters

Study of the morphometric characteristics of basins helps shed light on basin hydrology and assessment of hydrological characteristics. One of many factors that influence watershed hydrology the morphometric parameters that have immense utility in the quantitative description of the geometry of the drainage basins and its network which helps in characterizing the drainage network. The morphometric analysis includes basin size, shape, the slope of drainage area, drainage density, size and length of the tributaries, etc.(Moussa, 2003, pp.33-58).

Several studies have delved into the accuracy assessment of individual DEM datasets, e.g. for SRTM data and have looked into their effect on the extracted features like drainage and terrain aspects and the difference in resolution may affect the resultant output DEM quality and the stream network information derived from it, So DEM usage always comes with some caveats(S. Das et al., 2016, pp.1544). These parameters have been used in various studies of geomorphology and surface-water hydrology, such as flood characteristics, sediment yield, and evolution of basin morphology(Breinlinger et al., 1993, pp.171-181). Furthermore, Morphometric analysis is used to determine the influence of drainage-network morphometry on flooding and to estimate the potential flood hazard in several works(Migiros et al., 2011, pp.215-228). All of the morphometric parameters, except the topographic parameters, have greater impacts on the hydrologic response of the wadi rainfall intensity increases.(Abdel-Fattah et al., 2017, pp.553). Usually, the analysis of basin morphometry is a prerequisite to the assessment of hydrological characteristics of the surface water basin. So we will compare the morphometric characteristics that derived from the three different DEMs resolution to study the effect of different resolutions on morphometric characteristics and to quantify differences in morphometric characteristics and to assess the scale effect going from a 90 m DEM to an 12.5 m DEM.

The description of morphometric parameters and their mathematical formulae which each morphological parameter is defined it has been classified into four categories (Linear

Aspect, Geometric Aspects, Arial Aspects and Relief Aspects) which will address in the follows:

3.3.4.1 Linear Aspect

Stream number (Nu)

Total number of streams (N) of a given order (U) within each basin boundary

Stream length (Lu)

Stream length one of the most important hydrological characteristics of the area as it gives information about surface runoff characteristics. Stream length is computed from the mouth to the drainage divide.

3.3.4.2 Geometric aspects

Drainage basin Area (AU)

The basin area is the total area projected upon a horizontal plane contributing to cumulate of all order of basins. The drainage area is probably the single most important watershed characteristic to hydrological design and reflects the volume of water that can be generated from rainfall (Pal and Debnath, 2012, pp.351-363) also, It is used to calculate many important parameters such as drainage density and the hypsometric Integral etc.

Drainage basin perimeter (P)

Basin perimeter is the outer boundary of the watershed that enclosed its area(Pareta and Pareta, 2011, pp.248-269) It is measured along the divides between watershed and may be used as an indicator of watershed size and shape. P = the total length of the drainage basin boundary (km).

Drainage basin length (Lb)

Basin length defined as the longest dimension of the basin parallel to the principal drainage line (Pareta et al., 2011, pp.248-269) Lb= The maximum length of the basin.

Form Factor (Rf)

Form factor defined as the ratio of drainage network area to square of the drainage length by Horton and expressed as: [ $Rf=Au / (Lb)^2$ ] Where, Au=Area of the Basin ($km^2$) and Lb=Maximum Basin length (km)(Ansari et al., 2013, pp.508-528).

Drainage Texture (Dt)

Drainage texture one of the important concept of geomorphology which shows the relative spacing of the drainage lines. Drainage texture is the total number of stream segments of all orders per perimeter of that area (A. Das et al., 2012, pp.995-1013) expressed by the following formula [ $Dt=\Sigma Nu/P$ ]where Nu=Total no. of streams of all orders and P=Perimeter (km).

Circularity Ratio (Rc)

Circularity Ratio is the ratio of the area of a basin to the area of a circle having the same circumference as the perimeter of the basin(Miller, 1953, pp.1-51) expressed by the following formula [ $Rc = 4\pi Au/ P^2$ ] Where, Au= Basin Area ($km^2$) P= Perimeter of the basin (km)(Ansari et al., 2013, pp.508-528).

Elongation ratio (Re)

The elongation ratio is defined as the ratio between the diameter of the circle of the same area as the drainage basin and the maximum length of the basin. Is an indicative of shape of the river network and expressed by the following formula [ $Re = 2 \sqrt{Au / \pi} / Lb$] Where Au is Area of the Basin ($km^2$) and Lb is Maximum Basin length (km) (Chadha and Neupane, 2011, pp.101).

3.3.4.3 Aerial aspects

Stream frequency (Fs)

Stream frequency is the total number of stream segments of all orders per unit area, which can be calculated as follows [ $Fs = N/Au$ ] where: N=Total number of streams and Au=Area of Basin $km^2$ (H. T. Basavarajappa et al., 2015, pp.97-112).

Drainage density (D)

Drainage density is the stream length per unit area in region of watershed(Goudie, 2004, pp.371) which is an important indicator of the linear scale of landform element in stream eroded topography represented by the following equation[ D=ΣLu/ Au ] where Lu=Total stream length of all orders and Au= Area of the Basin ($km^2$). Drainage density reflects the effectiveness of the overland flow as well as infiltration. Usually, a high drainage density is associated with a higher flood hazard.

<u>Infiltration Number (FN)</u>

Infiltration number of a drainage basin is the product of drainage density and stream frequency that expressed by the following formula [If = Fs * D] where D= Drainage density

<u>Length of overland flow (Lg)</u>

Length of overland flow defined as the length of flow path, projected to the horizontal, non-channel flow from point on the drainage divide to a point on the adjacent stream channel. And Horton noted that length of overland flow is one of the most important independent variable affecting both hydrologic and physiographic development of drainage basins (Horton, 1945, pp.275-370) expressed by the following formula [Lg = 0.5/D] where D=Drainage Area .

3.3.4.4 Relief Aspects

<u>Relief ratio (Rh)</u>

Relief ratio is the ratio of maximum watershed relief to the horizontal distance along the longest dimension of the watershed parallel to the principal drainage line, It is expressed as Rh = H/L Where H is the difference in height between the highest and lowest points in the basin and L is the maximum length of the basin parallel to the principal drainage line(Schumm and Alfred, 1956, pp.597–646).

<u>Relative Relief (Rhp)</u>

Relative Relief is the difference between highest and lowest points of the basin, which can calculated using the formula [Rhp = H x (100)/P] where, H = Maximum drainage relief and P = Perimeter of the drainage "Km" (H. T. Basavarajappa et al., 2015, pp.97-112).

Ruggedness number (Rn)

Ruggedness number derived from the product of maximum basin relief and drainage density within the drainage basin. And expressed as: [ $Rn = Dd \times (Bh/1000)$ ] where, Bh = Relief of the drainage network and Dd = Drainage density (H. T. Basavarajappa et al., 2015, pp.97-112).

### 3.3.5 Rainfall Data Analysis

Total of rainfall that received in a certain period at a location is highly variable from one year to another. The variability depends on the type of climate and the length of the considered period. The amount, intensity and areal distribution of precipitation are essential in many hydrological studies(Jain et al., 2007, pp.87-153) Rainfall intensity is the ratio of the total amount of rain (rainfall depth) falling during a given period to the duration of the period It is expressed in depth units per unit time, usually as mm per hour (mm/h). Data sets of highest monthly rainfall for the period (1966–2011) are used for evaluating the proper theoretical statistical distribution of extreme monthly rainfall in Wadi Uranah. The frequency analyses and most statistical test were done using a commercial version of HYFRAN (Hydrological Frequency Analyses) program to obtain the corresponding rainfall depth values of the probabilities for a different frequency.

There are various analysis that can be conducted to analyze the rainfall data before using the rainfall data in any hydrology analysis but the ranking of the rainfall data and estimates of rainfall depths or intensities that can be expected for a specific probability during a specific reference period is the first step in the frequency analysis.

Log Pearson type III distribution has found very wide use in hydrological sciences, especially in flood frequency analysis, especially since adoption from U.S. federal agencies(Kamal et al., 2017, pp.1979-1986).

In this study Log Pearson III distribution function selected for estimating and deriving the return period (XT) of rainfall.

### 3.3.6 Runoff estimation

Runoff is that portion of precipitation that does not evaporate or infiltrate and the Infiltration is the passage of water through macrospores from the surface to the subsurface and determines the amount of runoff that causes erosion (Mao et al., 2008, pp.49-58) The proportion of rainfall that eventually becomes runoff is dependent on the several factors :

- Factors associated with the morphometric characterizes of basins such as size, Shape, etc.
- Topography where Runoff volume generally increases with steepness of slope.
- Soil characteristics, particularly permeability and infiltration capacity where if the infiltration rate of the soil few this will increase the amount of runoff.
- Precipitation rainfall characteristics (Depth-duration, intensity, Frequency, etc.)

The Hydrological Engineering Center Hydrologic Modeling System (HEC-HMS) was selected for this study that provides a comprehensive modeling environment for simplifying the computation of hydrologic parameters.

Several methods are used to estimate runoff from a given watersheds.in this study, we will use one of these methods is the Soil Conservation Service (SCS) curve number method which was developed by the United States Department of Agriculture (USDA) Soil Conservation Service (SCS).

The basis of the curve number method is the empirical relationship between the retention (rainfall not converted into runoff) and runoff properties of the watershed and the rainfall. Thus, the variables used as inputs to the SCS model are the cumulative rainwater depth, the watersheds area and the time of concentration (Tc) and the runoff coefficient (CN). Figure 3.13.

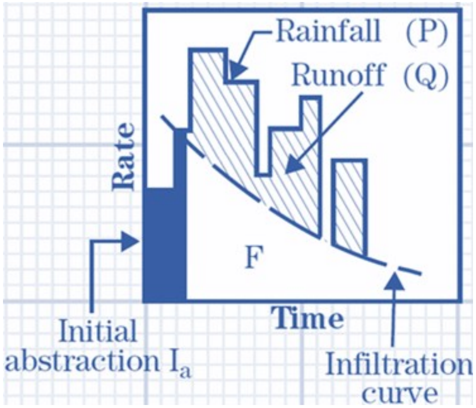



**Figure 3.13:** Components of SCS Runoff equation

The equation for the excess precipitation is given as:

$$Q = \frac{(P - I_a)^2}{(P - I_a + S)}$$

Where Q is the gathered runoff in mm, P is the rainfall depth in mm, $I_a$ is the initial abstraction in mm ($I_a$ = 0.2 S) and S is the potential maximum retention after the runoff begins in mm.

The maximum retention S is further related to the soil and cover conditions of the analyzed watershed through the CN by The retention parameter which defined as:

$$S = \frac{25400}{CN} - 254$$

Where CN is the curve number. CN = curve number < 100

Curve Number method may be used to estimate the total time of concentration Use Equation:

$$Tc = \frac{L^{0.8}\left[\left(\frac{1000}{CN}\right) - 9\right]^{0.7}}{\left[4407\left(S_g\right)^{0.5}\right]}$$

Where: Tc = time of concentration (hrs), and L = longest flow length (m), and Sg = average watershed gradient in m/m, % and CN = runoff curve number (Muhammad and Khan, 2015, pp.1-3).

The SCS has classified all soils into four major hydrologic soil groups denoted as A, B, C and D according to their infiltration rate which is obtained for bare soil after prolonged wetting. The four groups are summarized in Table 3.2.

| SCS | Soil Textural class | Runoff Potential and Infiltration Rate |
|---|---|---|
| A | Sand, Loamy sand and Sandy loam | Low runoff potential and high infiltration rate |
| B | Silt loam and loam | Moderate infiltration rates |
| C | Sandy clay loam | Low infiltration potential |
| D | Clay loam, sandy clay, silty clay loam, silty clay and clay | High runoff potential and very low infiltration rates |

**Table 3.2:** Soil Conservation Service Hydrologic Soil Groups (HSG)

The values of CN for various land uses on these soil types are given in the table No.
For a watershed made up of several soil types and land uses a composite average CN is customarily used, despite the nonlinearity of (71) and (70)(Şen, 2017, pp.180).

<u>A summary of this chapter:</u> This chapter covered the detail about the data and software used also the methods used in the study that has been answered which way to stream and watershed delineation? Which has consisted of several steps from Processes for data preparation with a pre-processed DEM to watershed delineation using the watershed modeling system (WMS 10.1) through calculation flow direction to computes the flow direction for a given grid, then calculation of flow accumulation which used to generate a stream network, based on the direction of flow of each cell and streams definition then defining and computing basins data and determined the formulas that used to calculate all characteristics of watershed and stream network. Also, determined the hydrologic modeling process based on HEC-HMS model in runoff prediction, the method used in the model was the SCS Unit Hydrograph for the Transform Method.

# Chapter-4: Process and Results

## 4.1 Introduction

This chapter discusses comparing the results of morphometric parameters and hydrology modeling for the study area that derived from different DEM resolution to assessing the effects of the spatial resolution of DEMs on hydrological modelling. Where this chapter contains six major sections that documented includes the specific steps taken to test the proposed hypotheses. Concurrent with analysis steps, comments have also been made on the nature of analysis results.

### 4.2 Comparing of Topographic attributes from different DEM resolution

Topography is an important land-surface characteristic that affects most aspects of the water balance in watersheds including the generation of surface and sub-surface runoff. Digital Elevation Model (DEM) is one of the methodologies to represent the surface which is widely used but ignore the impact of DEM resolution on the accuracy of topographic representation. The primary topographic parameters associated with a DEM are Elevation, slope and aspect are among the most important data in many natural resource spatial databases. DEM resolution has crucial importance because the topographic features which derived from a DEM are affected by the DEM resolution

It is thus imperative to understand the relationship between DEM resolution and the accuracy to which a topographic is represented to examine the impact of DEM resolution and how spatial resolution affects the accuracy of slope and aspect through comparison between the results from the resolutions of 90m, 30m, 12.5m of DEM.

### 4.2.1 Elevation

The overall Statistics of elevation for study area such as the minimum, maximum, mean and standard deviation of elevation values obtained to examine differences in elevation in-different DEM It's results much clearer in Table 4.1.

| DEM Resolution/m | Summary statistics for elevation | | | |
|---|---|---|---|---|
| | **Maximum** | **Minimum** | **Mean** | **Std dev.** |
| **12.5** | 2611 | 3 | 550 | 432 |
| **30** | 2603 | 4 | 542 | 432 |
| **90** | 2584 | 7 | 544 | 434 |

**Table 4.1:** Summary statistics for elevation

As indicated in Table 4 and Figure 4.1, there is little change in the computed statistics for elevation where the percentage change around 0.35 % between the highest and lowest value for the maximum elevation where Maximum elevation values exhibited 2611 meter computed from the 12.5 meters DEM, and 2584 meters computed from the 90 meters DEM.This indicates that with the digital elevation models that have largest cell size the maximum elevation becomes slightly underestimated. Also mean elevation tend to decrease slightly with resolution reduction with a reduction rate of 0.48 m/m. Additionally, there is little-observed variation in the standard deviation across cell sizes as values ranging from 434 meter for cell size 90 Meter, to a lower value of 432 meter at a cell size 30 meter.

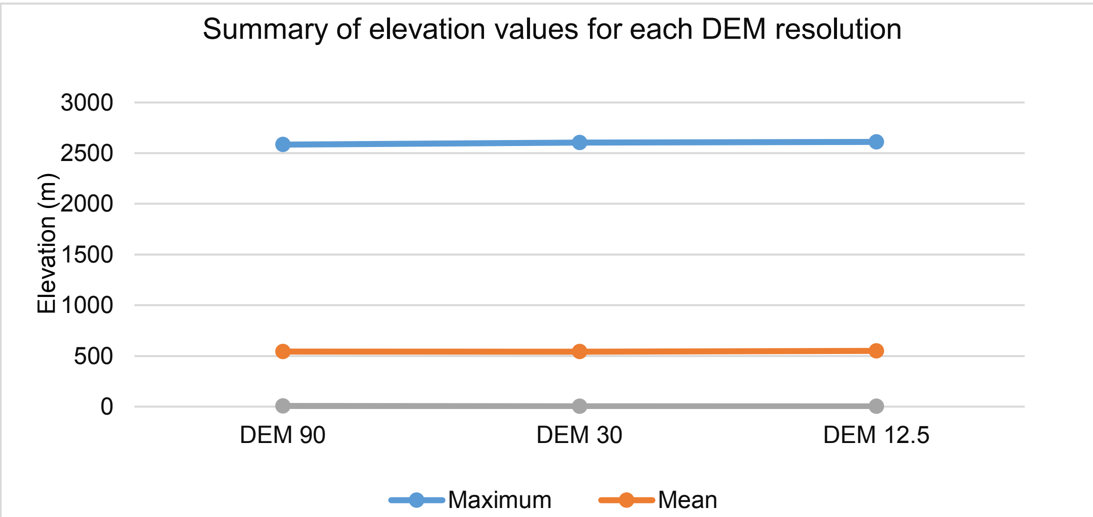
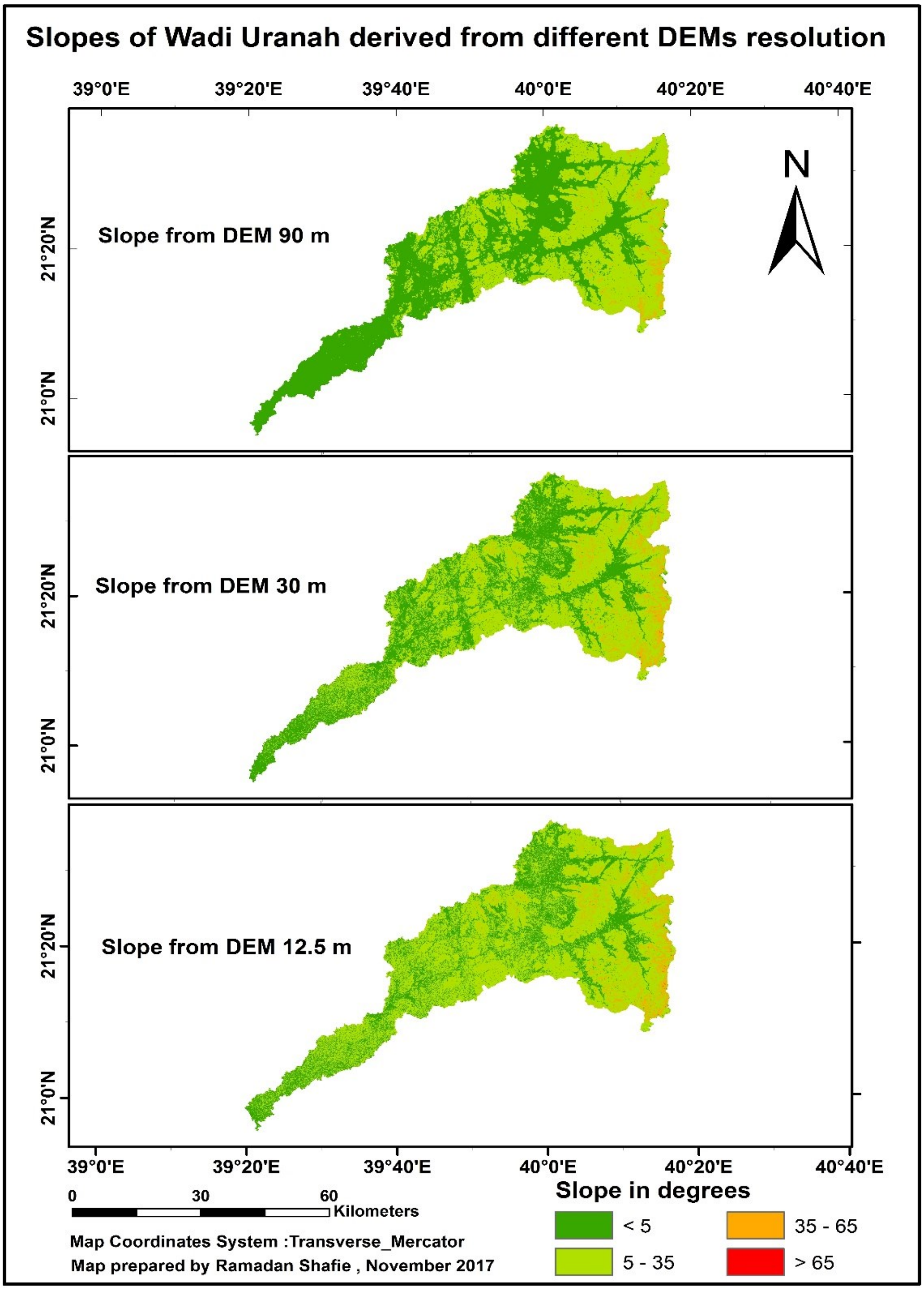



**Figure 4.1:** Summary of elevation values for each DEM resolution

## 4.2.2 Slope

Slope is the degree of incline of a surface and the slope for a particular location is computed as the maximum rate of change of elevation between that location and its surroundings. The slope can be expressed either in degrees or as a percentage Slope can be calculated as percent slope or degree of slope. The slope of Wadi Uranah it has been extracted from the different three DEMs as shown in Map 4.1.




**Map 4.1:** Slope of Wadi Uranah derived from different DEMs Resolution

Through the summary of statistics Slope, the results show slope seems to be largely influenced by resolution and that the differences of slopes are more extreme than for elevation. Which maybe will influence geomorphometric procedures and applications. The effect of DEM resolution on slope is very substantial as shown in Table 4.2 and Figure 4.2. That indicated that slope decreases when computed from a DEM with a large resolution where maximum computed values of slope range from a high of 82 degrees when computed from a 12.5 meter DEM to a low of 65 degrees for the 90 meter DEM. also, Mean values fall from a high of 13.55 degrees and 12.49 degrees to 10 degrees respectively.

| DEM Resolution/m | Summary of statistics Slope (Values in degrees) | | | |
|---|---|---|---|---|
| | **Maximum** | **Minimum** | **Mean** | **Std dev.** |
| **12.5** | 82 | 0 | 13.55 | 11.14 |
| **30** | 74.51 | 0 | 12.49 | 11.17 |
| **90** | 65.17 | 0 | 10 | 10.42 |

**Table 4.2:** Summary statistics for slope

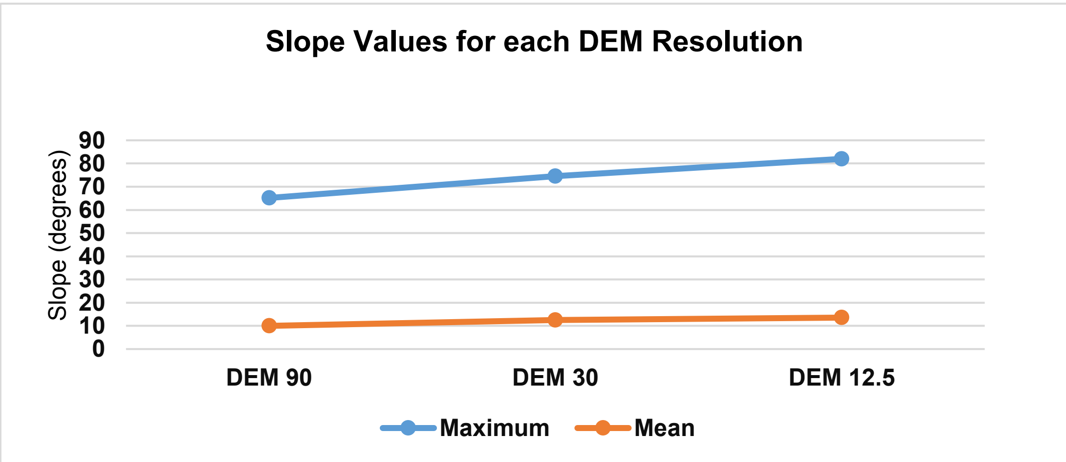
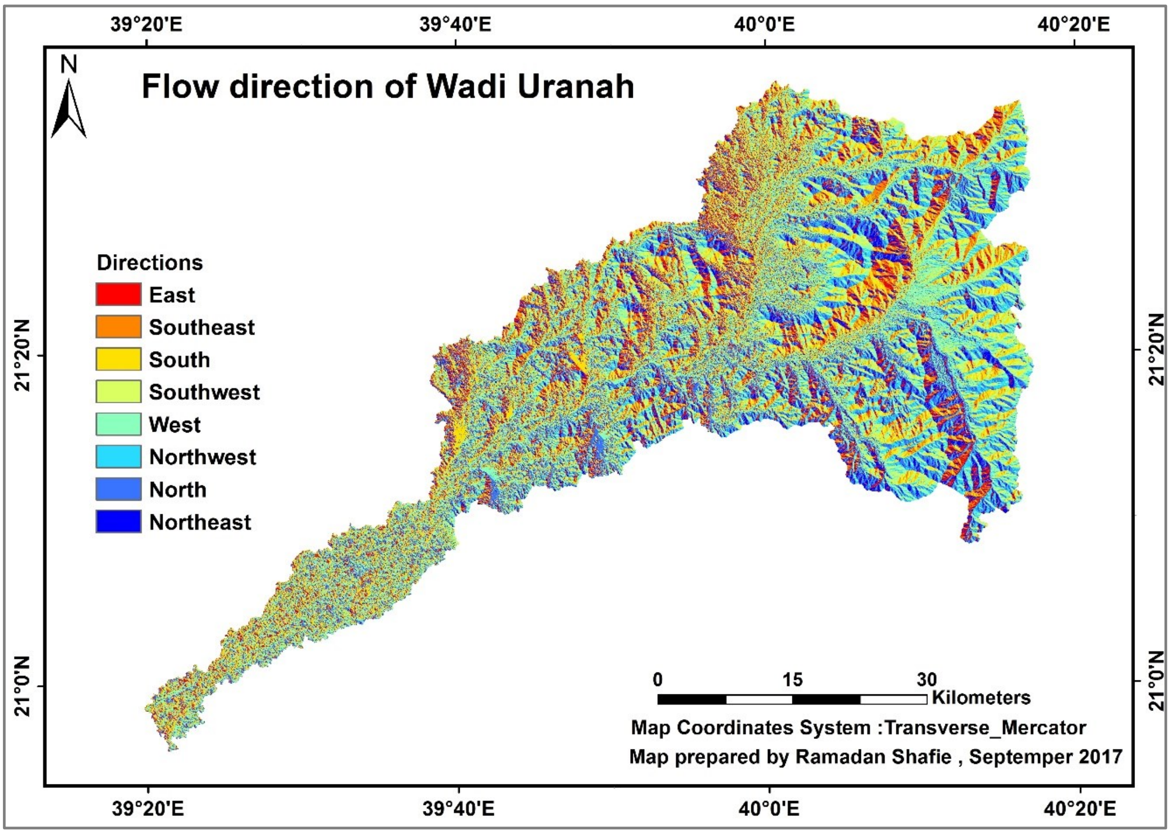



**Figure 4.2:** Slope values for each DEM resolution

Regardless of the algorithms of slope that require knowledge of a cell's neighbors, this means that all of these algorithms experience problems at the edges of a DEM but remain the most significant outcome is that slope varies inversely with the different DEM resolution.

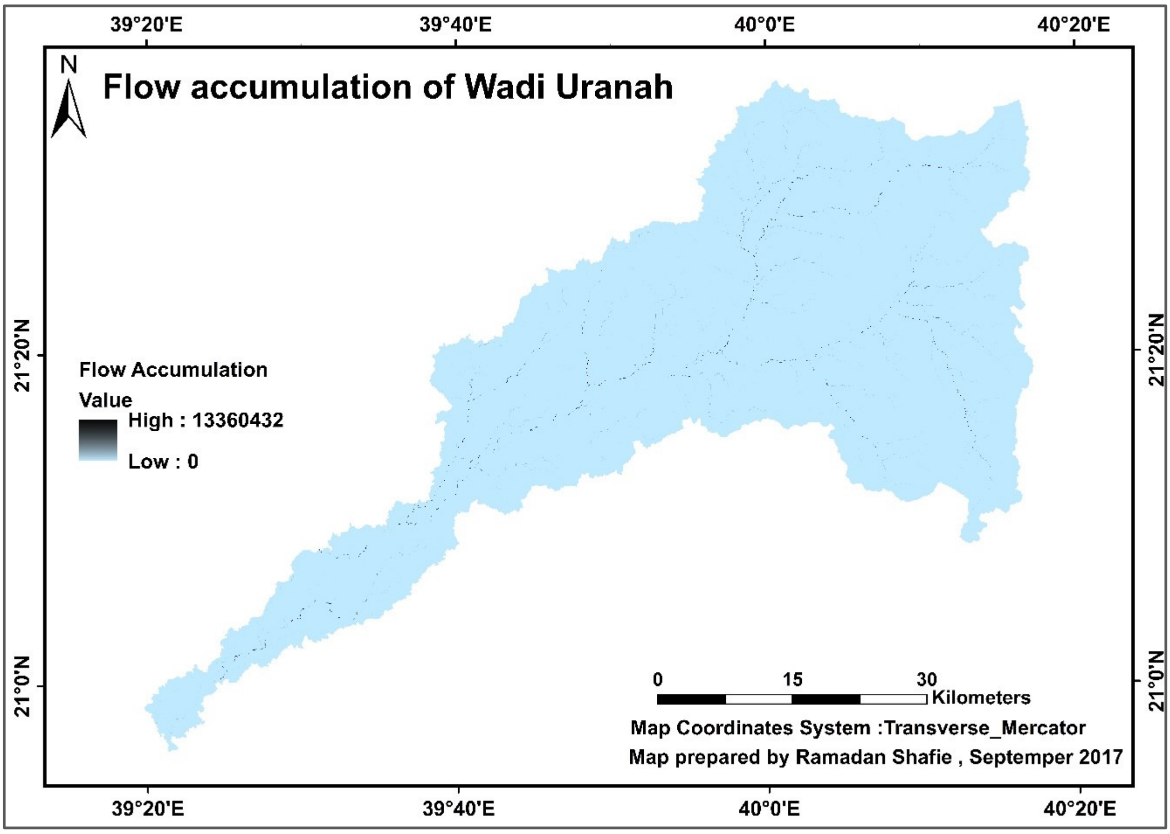
## 4.3 Watershed and stream network delineation using different DEM resolution

Watershed and stream network were delineated from different digital elevation models in the resolution which this study is based on which is one of the critical steps for many hydrology-related applications, in total, 3 watersheds were derived respectively from the 90 meter, 30 meter, and 12.5 meters DEMs In preparation to compare the watersheds to one another. The main steps include sink filling, identification of flow direction, calculation of flow accumulation and stream definition. The flow direction was calculated based on the most widely used D8 algorithm and defines the direction of slope for each cell. A grid of flow accumulation where created by determining the number of upstream cells draining to a given cell as in Map 4.2 and Map 4.3.




**Map 4.2:** Flow direction of Wadi Uranah

The results of flow accumulation used to create a stream network by applying a threshold value. A range of threshold values has experimented when extracted the streams networks from the DEMs as shown in Figure 4.3 using 10 km$^2$, 5 km$^2$, 2 km$^2$ and 0.2 km$^2$ threshold.




**Map 4.3:** Flow accumulation in Wadi Uranah

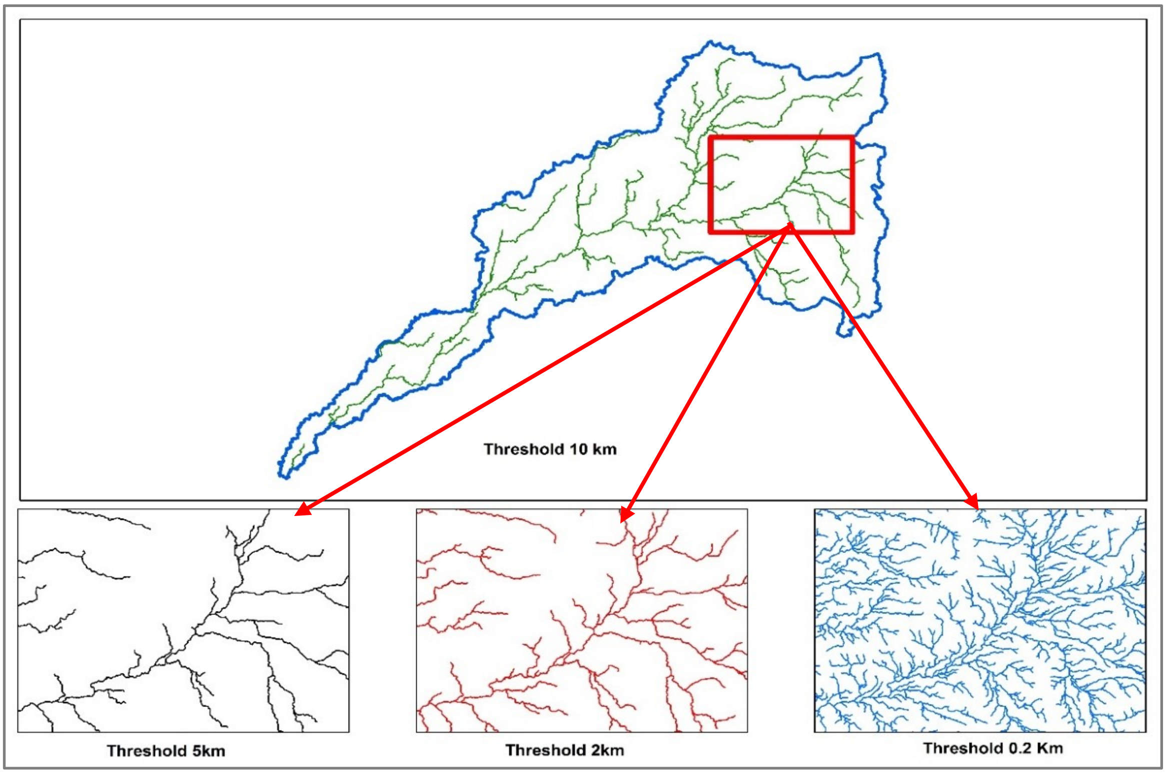
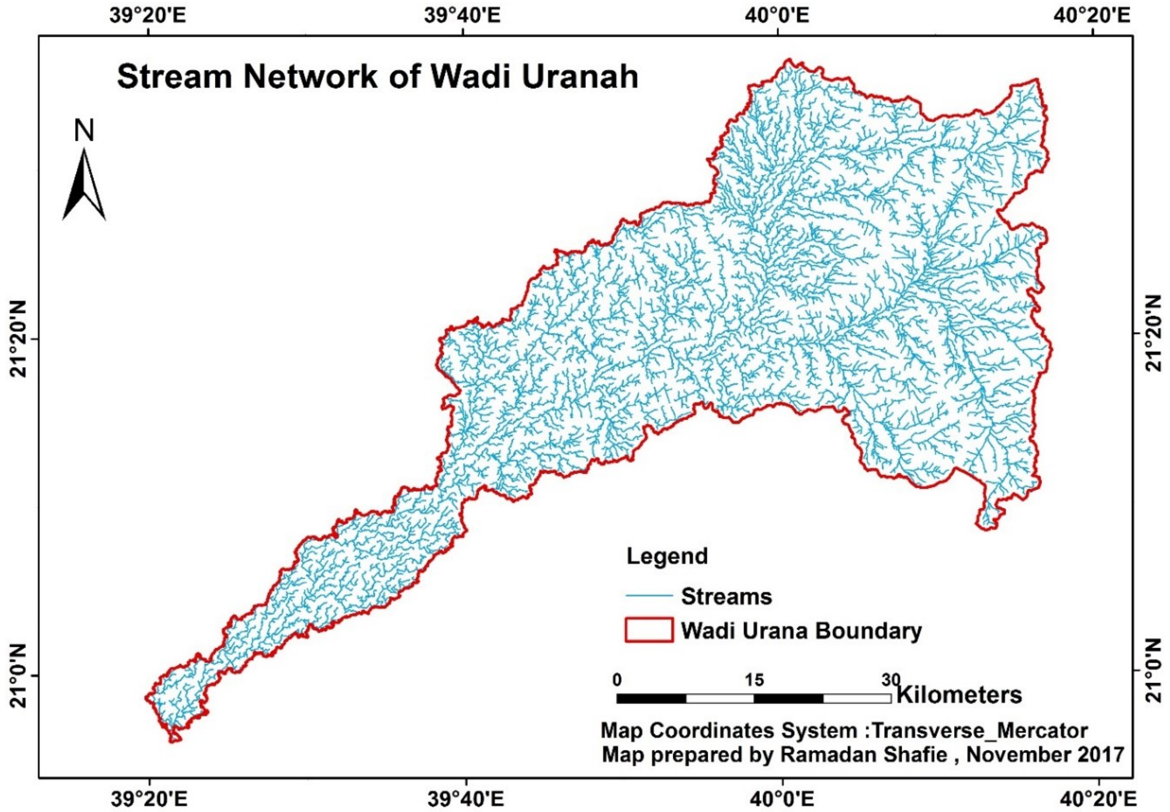


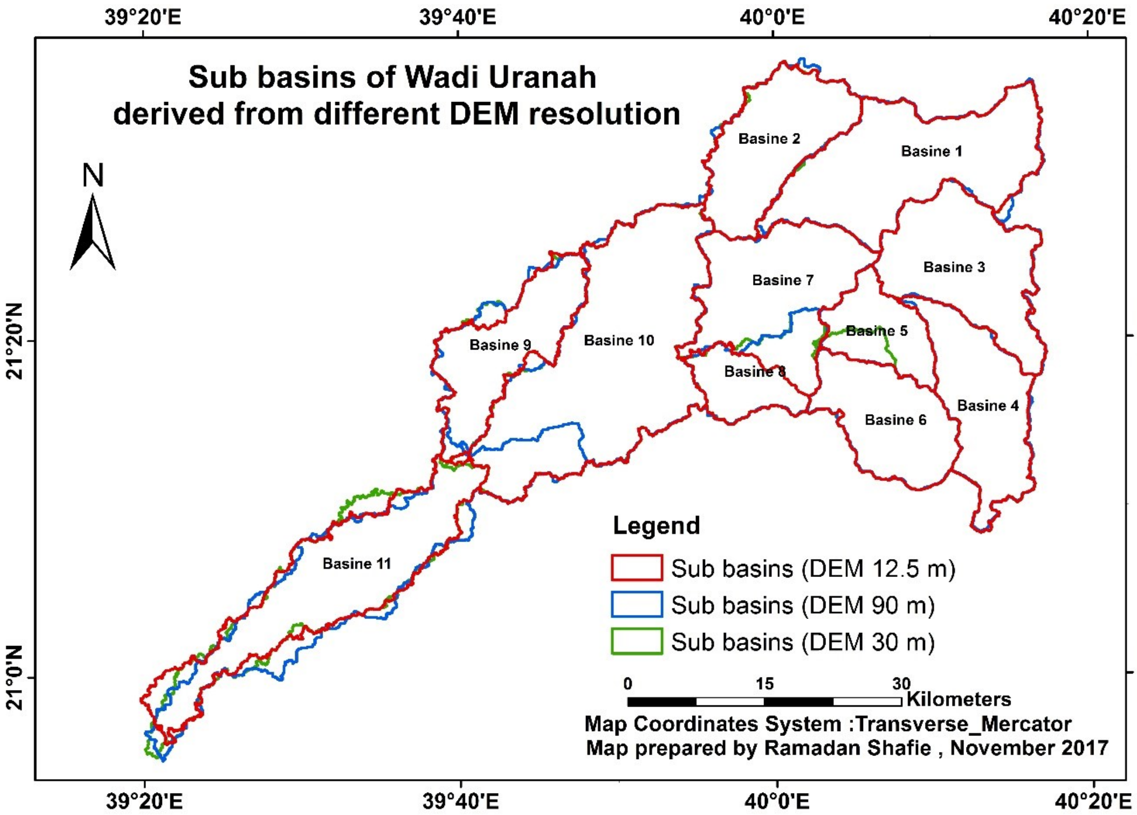

**Figure 4.3:**Experiment of determining the threshold for stream network delineation

Through experimenting with a range of threshold values 0.2 km2 threshold was found that chosen when determining the contributing area threshold to use to initiate a stream network and produce a more detailed delineation of the drainage network. Upon successful completion of the process, the stream grid is added to the map that contains all the cells in the input flow accumulation grid that have a value greater than the given threshold (0.2 km2).Watersheds delineated process needs three grid layers pour points, flow accumulation, and flow direction then watersheds are delineated as shown in Map 4.4.




**Map 4.4:** Stream Network of Wadi Uranah

The second round of watershed delineations was sub basins created, where the watershed of Wadi Uranah was subdivided into eleven sub basins as shown in the Map 4.5 which divided based on the hierarchy of the stream network from a different three DEM resolution.




**Map 4.5:** Sub basins of Wadi Uranah derived from different DEMs Resolution.

The results indicated the sub basins is affected by changing the resolution where there are differences in the sub basins areas that delineation from different DEM resolution. While the largest difference values appear in basins no 11, 10, 9, 5 and 7. While the other sub basins have very slight variations, which are clearly visible in sub basins No 4,3,1,2, which have a ruggedness surface. As well as a visual comparison for steam network some detail is lost in the stream network when streams are derived from DEMs of coarser cell sizes as shown in Figure 4.4. That appearing when seeing the streams network which derived from DEM 30 and 12.5 meters.

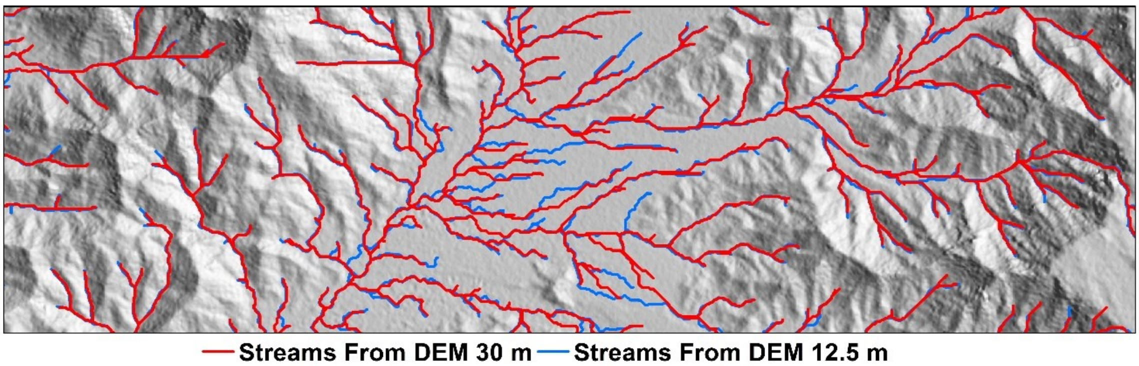
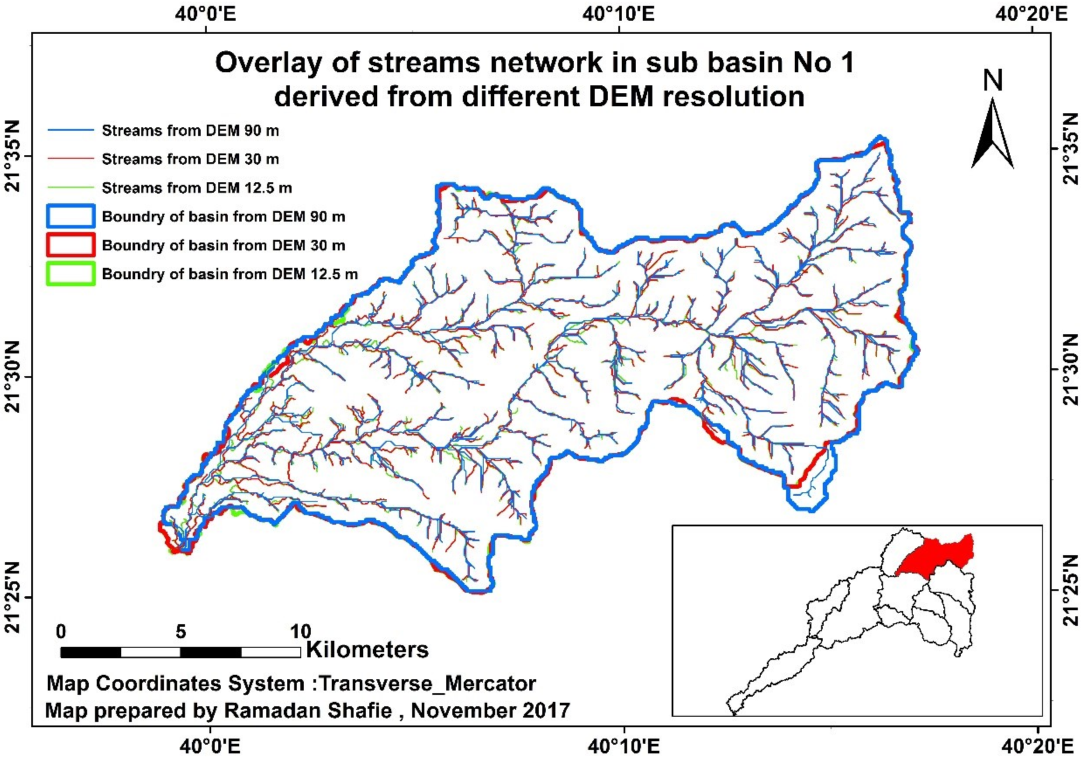
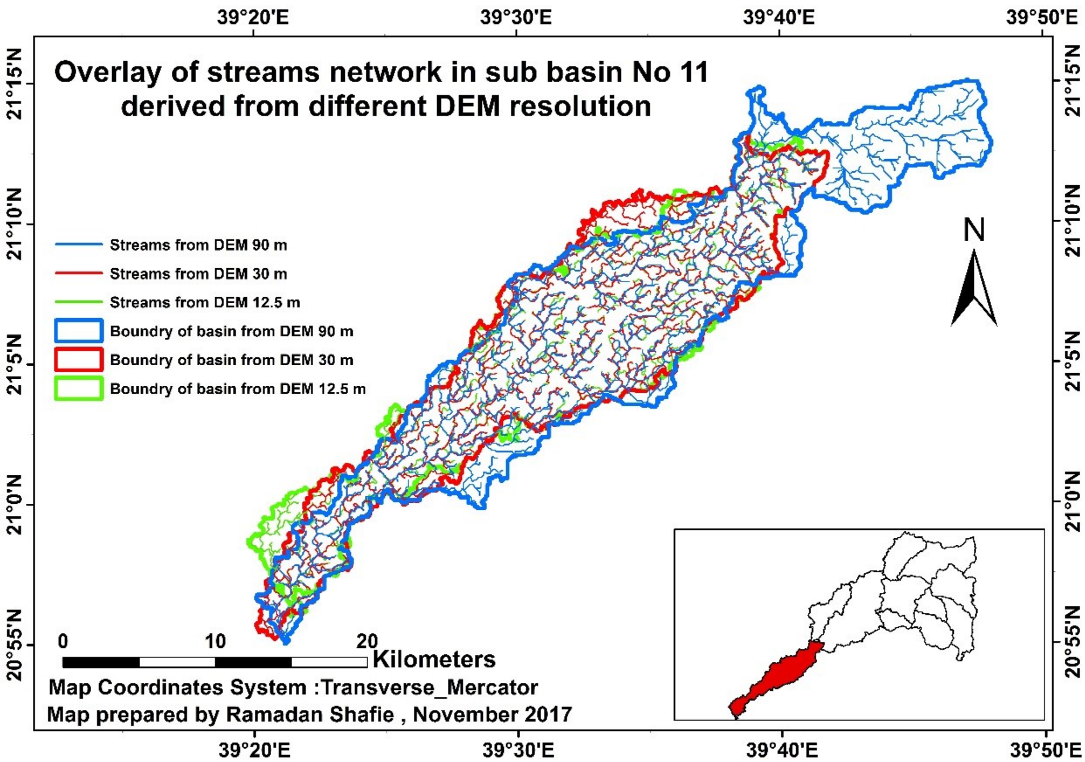



**Figure 4.4:** visual comparison for steam network

It is obvious from Maps 4.6 and 4.7 that there is much difference between each of the derived networks in flat areas on the contrary in the relief areas this differences in the networks increase as the cell size from which they are derived does.




**Map 4.6:** Overlay of streams network in sub basin No 1




**Map 4.7:** Overlay of streams network in sub basin No 11

In flat areas, Streams network changes their structures and patterns with the increase of DEM grid size and we can clearly see that the networks are not identical. The main reason for this phenomenon can be reasoned that aspect errors happening in the flat area will cause the error of flow direction, and hence get erroneous drainage networks. This kind of error is most apparent in the sub basin No 11 which are shown in the strong difference between the streams that derived from different DEM resolution as well as the boundaries of the basin also, on the contrary in the sub basin No 1 have been greatly limited of the obvious error in the flat areas because of the less aspect error where this basin is characterized by a hilly terrain. Although of apparent some difference in the stream networks when viewed at a small scale, however, the comparison of the morphometric parameters is necessary to observe the effect of DEM resolution upon the derivation of stream networks from DEMs.

## 4.4 Comparing of morphometric parameter from different DEM resolution

Morphometric parameters of the basin were estimated based on the stream network and different DEM resolution and comparative this parameters that obtained through analysis of extracted drainage from different DEM resolution (DEM 90 meters, DEM 30 meters, and DEM 12.5 meters) to give an overview of the performance of the different DEM and impact in the characteristics of basins. In the present study, morphometric attributes divided to four category parameter (Linear, Geometry, Arial aspects and relief aspects)
The main objective of the present work is analyzing and comparing the morphometric characteristics of Wadi Uranah that derived from different DEM resolution. To know and assess the impact of change DEM resolution on the morphometric characteristics
The different morphometric parameters have been determined as shown in Table 4.3 which shown the results of the morphometric analysis of Wadi Uranah using drainage network and different DEM resolution and discuss the results in the following sections to

understand the variability of different morphometric attributes derived from different DEM resolution.

| # | Morphometric Parameter | | Value | | |
|---|---|---|---|---|---|
| | | | **DEM 90** | **DEM 30** | **DEM 12.5** |
| **1** | **Linear** | Total Stream length (Lu) km | 3563.06 | 3926.35 | 4047.24 |
| **2** | | Total Stream Number (Nu) | 5717 | 6126 | 6203 |
| **3** | **Geometry** | Basin Area ( Au ) $Km^2$ | 2332.36 | 2319.91 | 2303.71 |
| **4** | | Perimeter (P) Km | 532.62 | 577.16 | 601.94 |
| **5** | | Basin Length(Lb) Km | 120.87 | 121.23 | 119.43 |
| **6** | | Relative perimeter (Pr) | 4.38 | 4.02 | 3.83 |
| **7** | | Form Factor (Rf ) | 0.16 | 0.16 | 0.16 |
| **8** | | Drainage texture (Dt) | 10.73 | 10.61 | 10.30 |
| **9** | | Circulatory ratio (Rc) | 0.41 | 0.35 | 0.32 |
| **10** | | Elongation Ratio (Re) | 0.45 | 0.45 | 0.45 |
| **11** | Aerial | Stream frequency (Fs ) $km^{-2}$ | 2.45 | 2.64 | 2.69 |
| **12** | | Drainage density(Dd) ($Km/Km^2$ ) | 1.53 | 1.69 | 1.76 |
| **13** | | Drainage Intensity (Di) | 1.60 | 1.56 | 1.53 |
| **14** | | Constant of Channel Maintainace $km^{-2}.km^{-1}$ | 0.65 | 0.59 | 0.57 |
| **15** | | Infiltration Number (FN) $km^{-2}$ | 3.74 | 4.47 | 4.73 |
| **16** | | Length of overland flow (Lg ) (Km) | 0.33 | 0.30 | 0.28 |
| **17** | **Relief** | Basin Relief (H) | 2593.95 | 2606 | 2610 |
| **18** | | Relief Ratio (Rh ) | 21.46 | 21.50 | 21.85 |
| **19** | | Relative Relief (Rhp) | 487.02 | 451.52 | 433.60 |
| **20** | | Ruggedness number (Rn) | 4.16 | 4.07 | 4.00 |

**Table 4.3:** Morphometric parameter results

### 4.4.1 Linear Aspects

The linear aspects include Total stream length, Total stream number and. The stream order has overlooked because it is not important for hydrologic modeling**.** The results of the analysis are given in Table 4.3 and discussed below:

Total Stream Length

The analysis of extracted stream network expound that the total length of streams derived from DEM 90 meter (3563.06 km) is closely followed by DEM 30 meter (3926.35 km), while ALOS PALSAR DEM 12.5 m has a relatively higher value (4047.24 km) hence streams length appears to increase with increasing the DEM resolution. Where the difference rate between the lowest lengths streams the highest length up to 4.20 %. This ratio is different when compared the lengths of streams network within the eleven sub basins Figure 4.5 where this difference is less to 2.23% among the stream length of the basin number 3 in three DEM, while the rate of difference increases to 10.94%,10.65% in Basin Number 7 and basin Number 10 respectively. This large difference in stream length among the basin no 10, 7 is mainly attributed to the variability in basin area Figure 4.6.

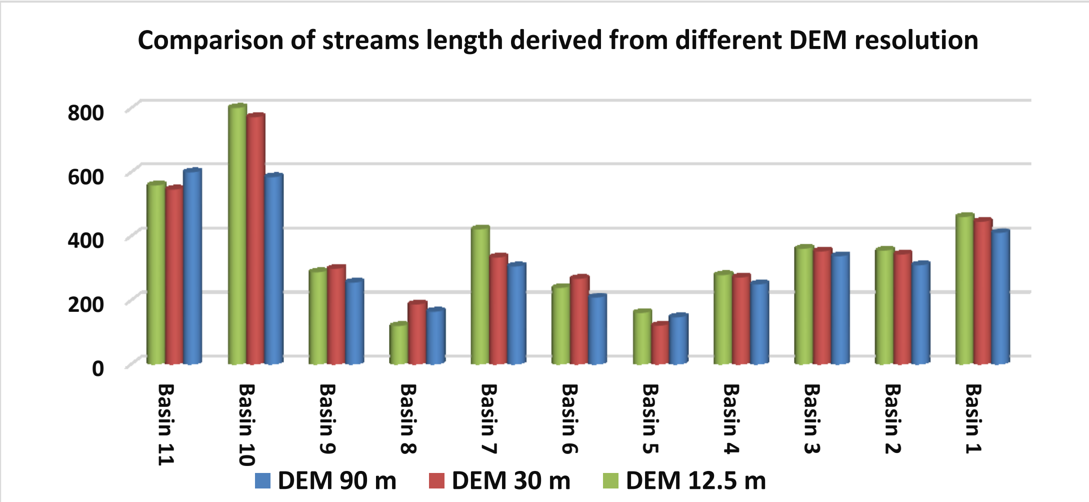



**Figure 4.5:** Comparison of stream length derived from different DEM resolution

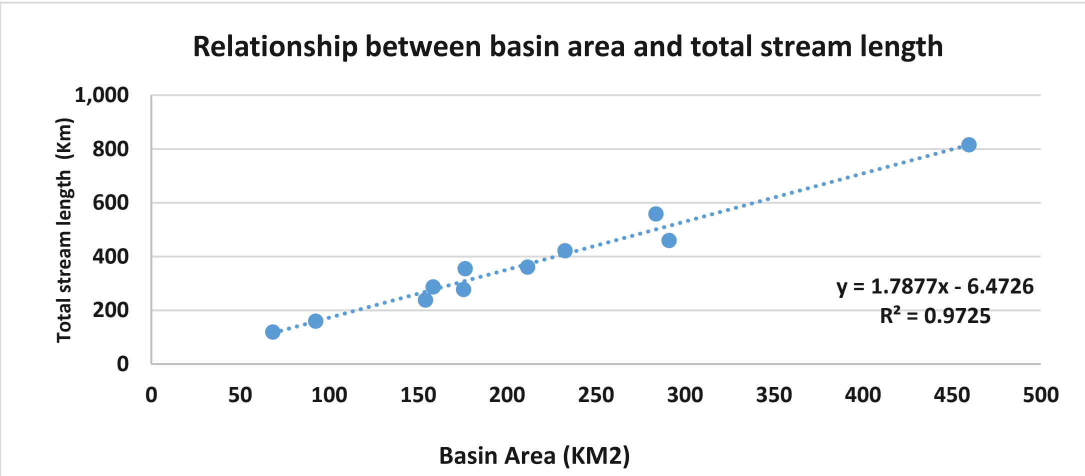



**Figure 4.6:** Relationship between basin area and total stream length

Total Stream Number

Table 4.3 and examination of drainage network extracted from different DEM resolution shows that the total number of streams are even more in DEM resolution 12.5 meters when compare to the lowest resolution datasets Figure 4.7 The largest basin have large streams number are the basin no 10 where the stream number ranges from 954 to 1,271 from DEM 90 meters to DEM 12.5 meters respectively as this basin is the largest area between the watershed basins Figure 4.8.

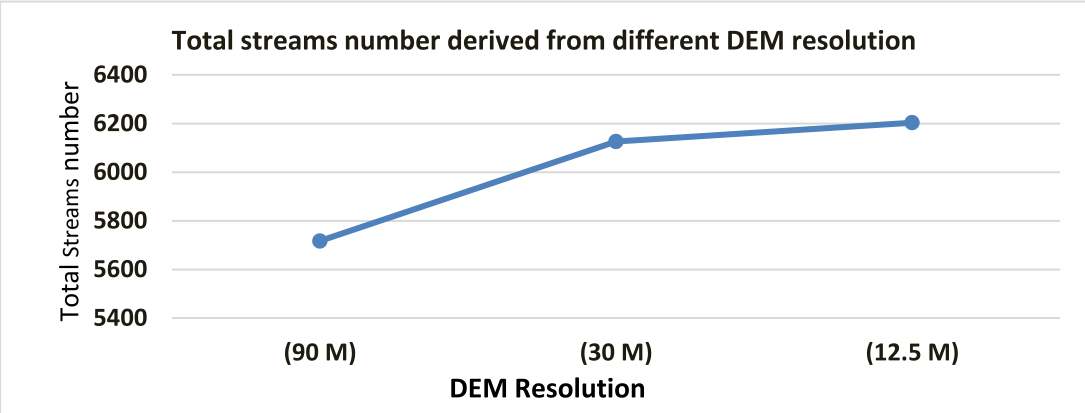



**Figure 4.7:** Total streams number derived from different DEM resolution

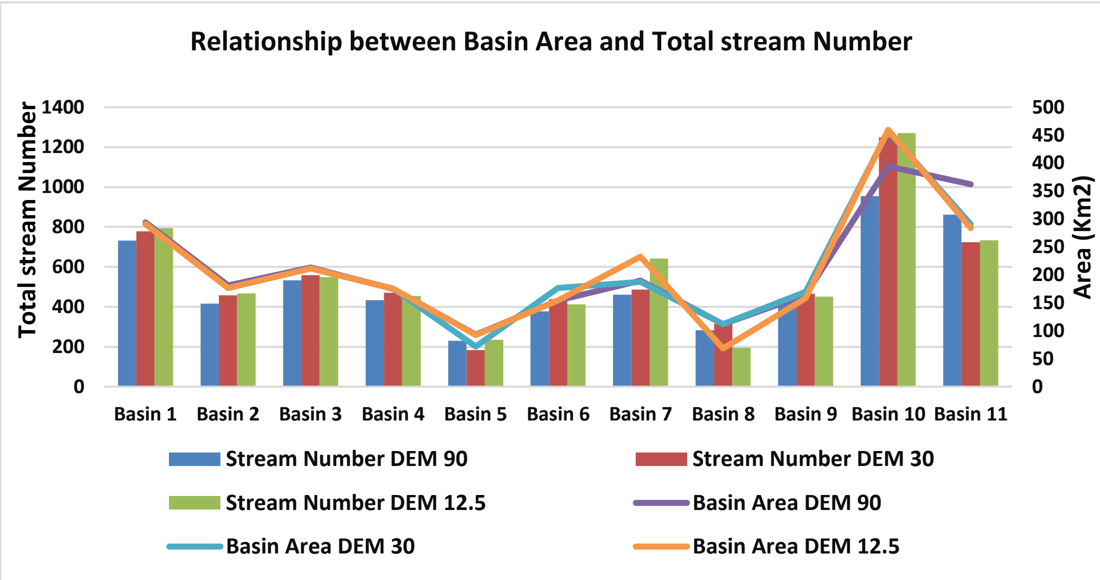


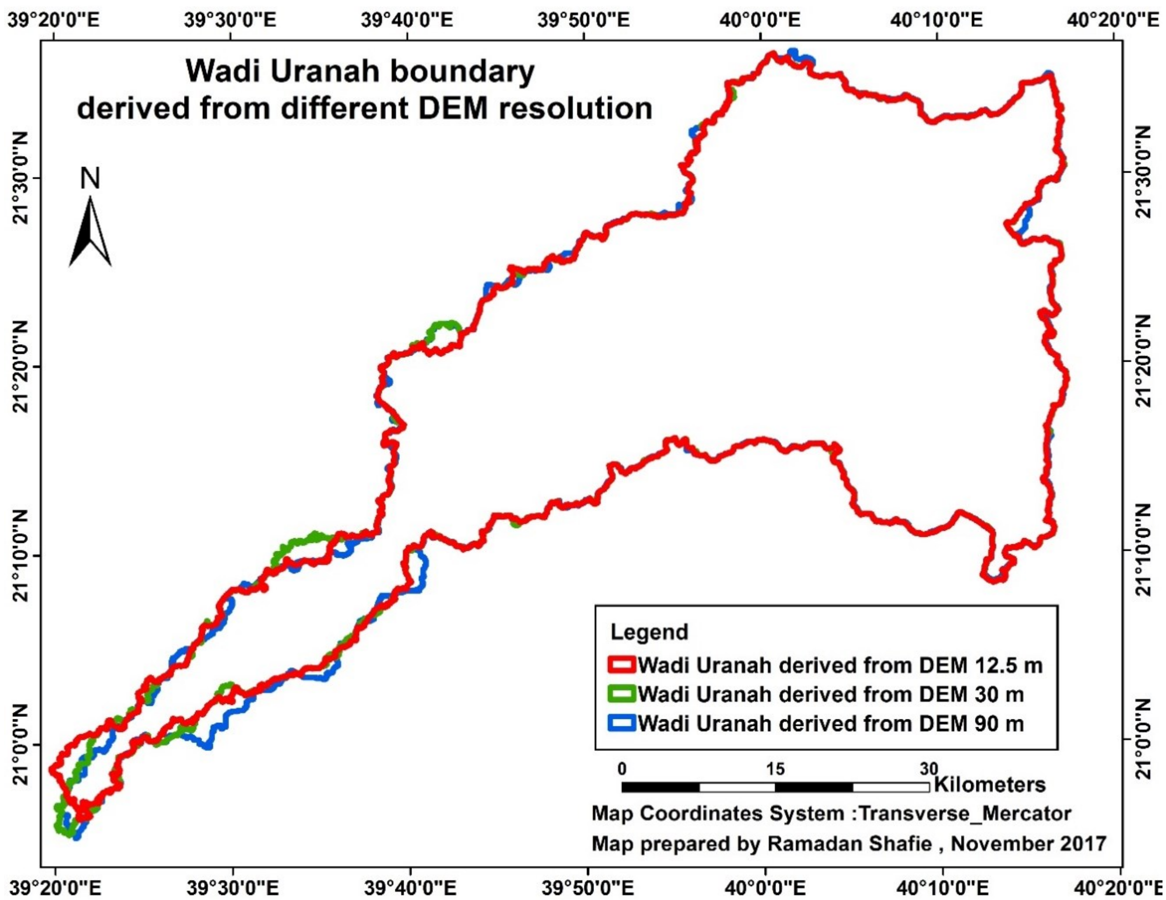

**Figure 4.8:** Relationship between basin area and total stream number

### 4.4.2 Geometric aspects

The basin geometry characterized by various factors such as (basin area; basin perimeter; basin length) have greater significance on the basin hydrology as these control the shape of hydrograph and magnitude of peak run-off, e.g. the maximum flood discharge per unit area is inversely related to basin size (Chorley et al., 1957, pp.138-141). Comparison between values of geometric aspects from different DEM resolution for Wadi Uranah are given in Table 4.3 and the results of the analysis and discussed below:

<u>Basin Area (Au)</u>

In a comparative among area of the Wadi Uranah based on different DEM resolutions, we can see the difference up to 4.19 % where the basin area is 2332.36 $km^2$ according to DEM 90 meters while the area is 3926.35 $km^2$, 4047.24 $km^2$ from DEM 30 meters and DEM 12.5 meters respectively. When seeing the parts that have very different in the area we can clearly see that the boundary of the basin is not identical in flat areas, in contrast in high mountain areas, we found the boundary of the basin is matching by far in three different DEM resolution as shown in Map 4.8.




**Map 4.8:** Wadi Uranah boundary derived from different DEM resolution

This difference in the area reinforces when comparing the areas among sub basin of Wadi Uranah as in Figure 4.9 where we found that the largest sub basins which can be seeing a clear difference in the areas show in basin number 10 and number 11 which are located in the flat area and lowest elevations.

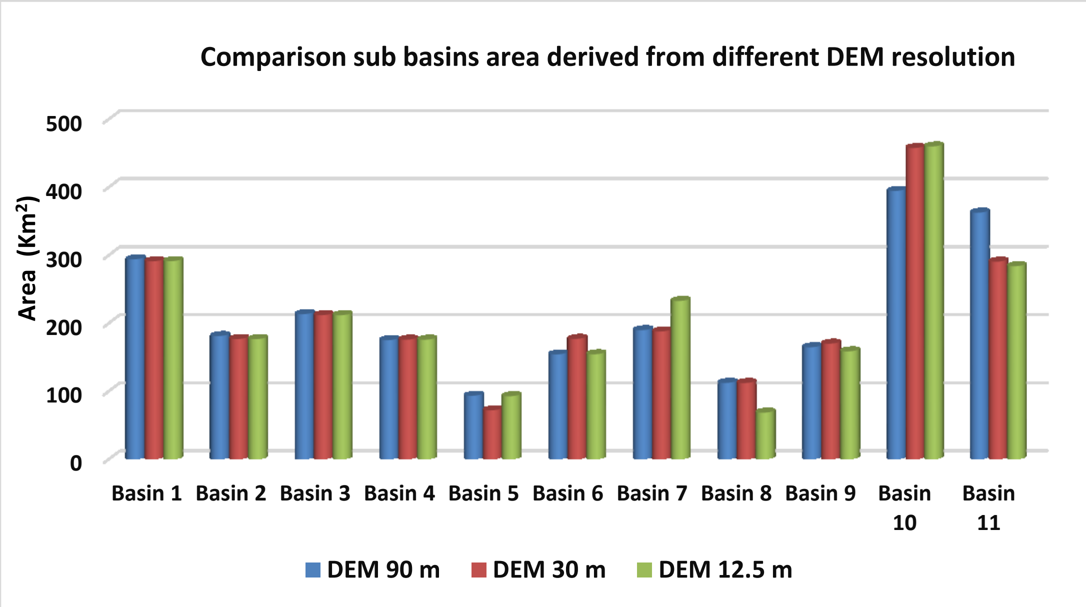



**Figure 4.9:** Comparison of sub basin area derived from different DEM resolution

Perimeter (P)

Perimeter like the area is depending on the number of segments, length of the segments and attitude. And may be used as an indicator of watershed size and shape.

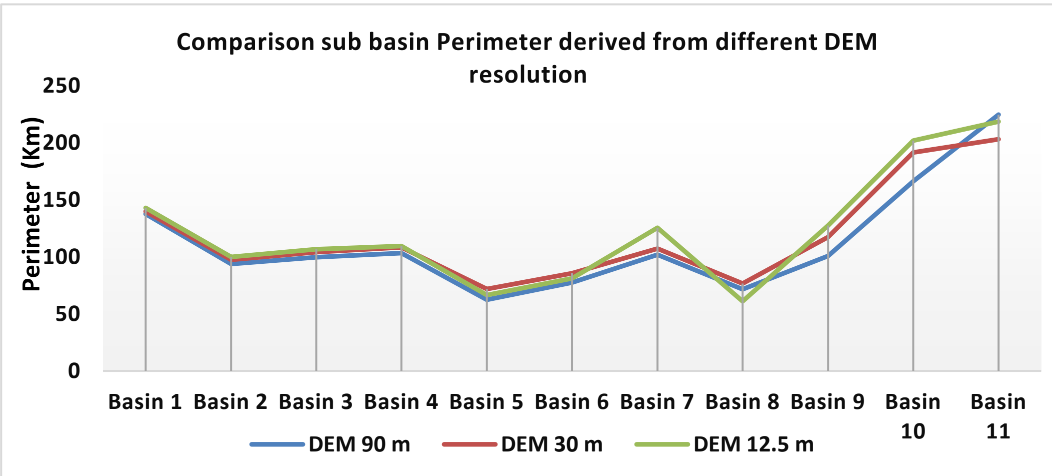



**Figure 4.10:** Comparison sub basin Perimeter derived from different DEM resolution

The perimeter of the watersheds varies from 532.62 to 601.94 Km. the low perimeter is noticed in the hilly terrain at Wadi Uranah, while high perimeter is in the flat area of Wadi Uranah as in Figure 4.10. And on the other the relative perimeter (P) of Wadi Uranah is about 4.38, 4.02 and3.83 Km respectively from DEM 90, 30 and 12.5 meters.

Basin Length (Lb)

The total length of Wadi Uranah is about 120.87, 121.23 km and 119.43 km, respectively from DEM 90, 30 and 12.5 meters. Through comparing the lengths of the sub basins don't found a significant difference only in the sub basin Number 11 and 10 as shown in Figure 4.11.

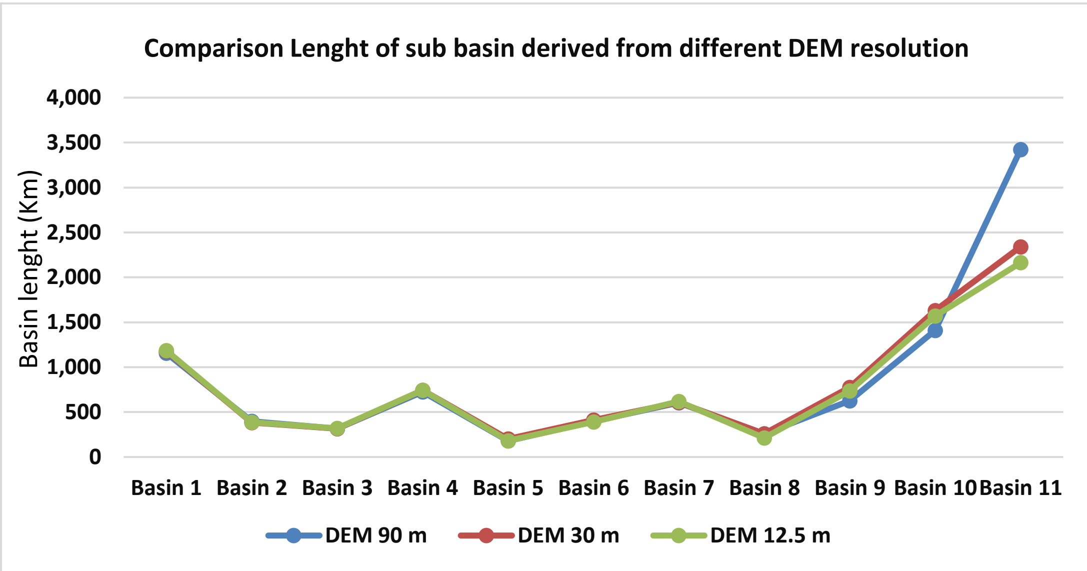



**Figure 4.11:** Comparison length of sub basin derived from different DEM resolution

Form Factor (Rf)

The value of form factor would always be less than 0.754, the form factor of the Wadi Uranah is 0.16 and the sub basins values range between 0.11- 0.67 Table 4.3. The basin number 3, 5, and 8 show high values of form factor, 0.67, 0.52 and 0.44 are circular type basins that means it has high peak flows of shorter duration. Whereas the smaller value of form factor is mean the basin will have an elongated form and flow for a longer duration as in the sub basins number 11, 10 and number 9 that tends to have less flood hazard compared to circular basin because of longer flow duration.

| Form Factor (Rf) | | | |
|---|---|---|---|
| **Sub basin** | **DEM 90 m** | **DEM 30 m** | **DEM 12.5 m** |
| Sub basin 1 | 0.25 | 0.25 | 0.25 |
| Sub basin 2 | 0.45 | 0.46 | 0.46 |
| Sub basin 3 | 0.67 | 0.67 | 0.66 |
| Sub basin 4 | 0.24 | 0.24 | 0.24 |
| Sub basin 5 | 0.52 | 0.36 | 0.51 |
| Sub basin 6 | 0.39 | 0.43 | 0.40 |
| Sub basin 7 | 0.31 | 0.31 | 0.38 |
| Sub basin 8 | 0.43 | 0.44 | 0.32 |
| Sub basin 9 | 0.26 | 0.22 | 0.22 |
| Sub basin 10 | 0.28 | 0.28 | 0.29 |
| Sub basin 11 | 0.11 | 0.12 | 0.13 |

**Table 4.4:** Form Factor of sub basins in Wadi Uranah

Through comparing the values of form factor among sub basin that derived from different DEM resolution the effect of resolution is shown in the sub basin number 5 and number 8 whereby the above Table 4.4 and Figure 4.12 we can be noted change the value in Basin No. 5 from 0.36 to 0.51 where the highest values were derived from DEM 12.5 meters. On the contrary, the lowest value in the second largest change value between the sub basins was in DEM 12.5 meters with its value up to 0.32 opposite 0.44 in DEM 30 meters due to the difference in area in both the extracted basins.

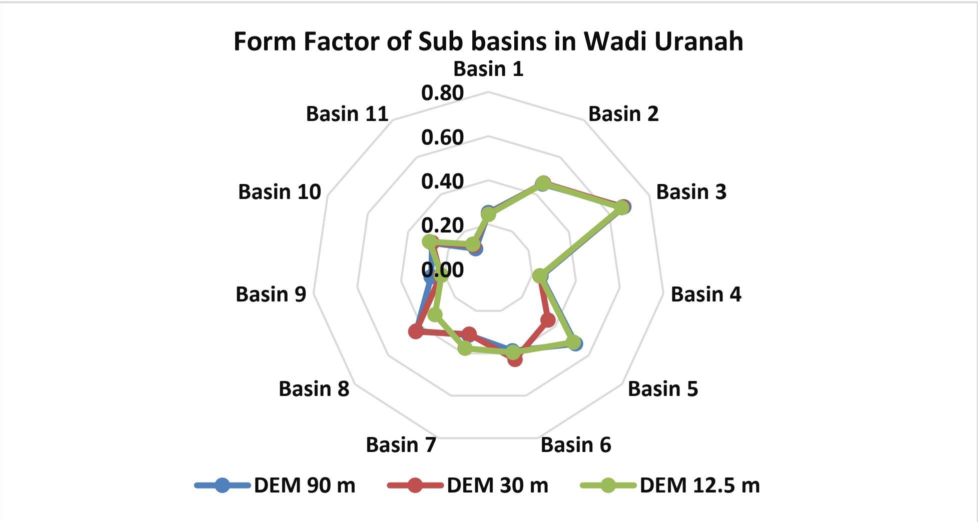



**Figure 4.12:** Form Factor of sub basins in Wadi Uranah

Drainage texture (Dt)

Drainage texture shows the relative spacing of drainage lines and it has a strong correlation with drainage density and stream frequency. Smith (1950) classified drainage texture as follows: very coarse (<2), coarse (2 to 4), moderate (4 to 6), fine (6 to 8) and very fine (>8) the drainage texture of Wadi Uranah are ranging from 10.30 – 10.73 according DEM 12.5 meters and DEM 90 meters respectively It indicates that category is very fine drainage texture this indicates the impermeable surface material and mountainous relief. In eleven sub basins of Wadi Uranah the drainage texture varies between moderate textures (2.56) to fine textures (6.53) Figure 4.13 Low density represents course drainage texture; while high drainage density represents fine drainage texture(H. Basavarajappa, 2013, pp.24-26).

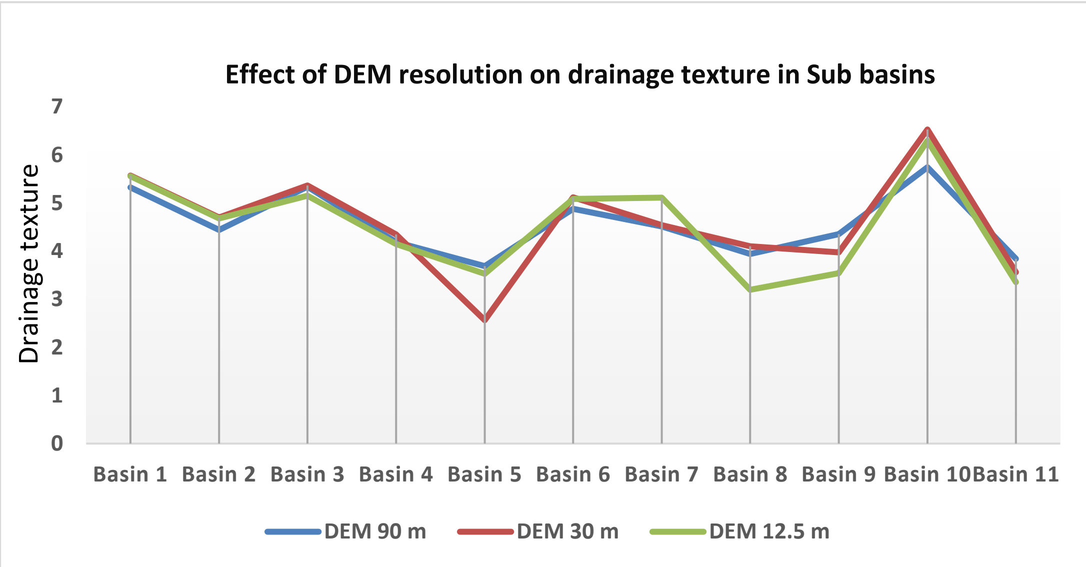



**Figure 4.13:** Effect of DEM resolution on drainage texture in sub basins

Circulatory ratio (Rc)

The circularity ratio value (0.41, 0.35, and 0.32) of the watershed according to DEM 90.30.12.5 meters respectively. But these values have different at the level of the sub-basins which ranging from 0.7 in basin No 11 according to DEM 12.5 meters, to 0.32 in basin No 6 according to DEM 90 meters as in Table 4.5.

| Circulatory ratio (Rc) | | | |
|---|---|---|---|
| **Sub basin** | **DEM 90 m** | **DEM 30 m** | **DEM 12.5 m** |
| Sub basin 1 | 0.20 | 0.19 | 0.18 |
| Sub basin 2 | 0.26 | 0.23 | 0.22 |
| Sub basin 3 | 0.27 | 0.25 | 0.23 |
| Sub basin 4 | 0.21 | 0.19 | 0.18 |
| Sub basin 5 | 0.30 | 0.18 | 0.26 |
| Sub basin 6 | 0.32 | 0.30 | 0.29 |
| Sub basin 7 | 0.23 | 0.21 | 0.19 |
| Sub basin 8 | 0.28 | 0.24 | 0.23 |
| Sub basin 9 | 0.20 | 0.16 | 0.12 |
| Sub basin 10 | 0.18 | 0.16 | 0.14 |
| Sub basin 11 | 0.09 | 0.09 | 0.07 |

**Table 4.5:** Circulatory ratio of sub basins in Wadi Uranah

Elongation Ratio (Re)

The elongation ratio has important hydrological consequences where this ratio helps to give an idea about the hydrological character of a drainage basin. The value of elongation ratio in Wadi Uranah was found to be 0.45 in all DEM dataset indicating relatively moderate relief of the terrain and elongated shape of the drainage basin.

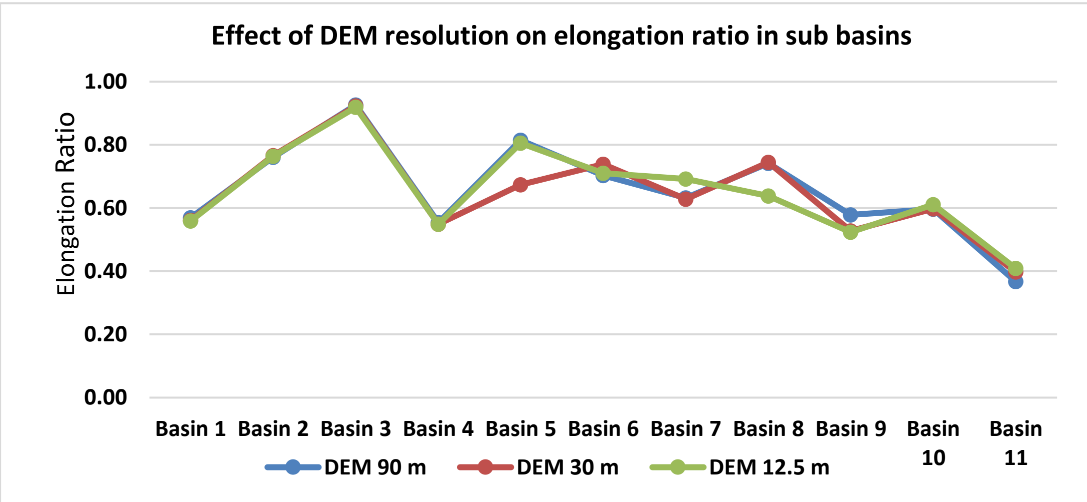



**Figure 4.14:** Effect of DEM resolution on elongation ratio in sub basins

The Figure 4.14 and Table 4.6 shows the effect of DEM resolution on the change the elongation ratio value among the sub basins where the ratio varies from 0.37 to 0.77 in sub basins of Wadi Uranah table no 5 where typical values are close to 1.0 for regions of very low relief and are between 0.6 and 0.8 for regions of strong relief and steep ground slope(Kumar, 2011, pp.257-257).

| **Elongation Ratio (Re)** | | | |
|---|---|---|---|
| **Sub basin** | **DEM 90 m** | **DEM 30 m** | **DEM 12.5 m** |
| Sub basin 1 | 0.57 | 0.56 | 0.56 |
| Sub basin 2 | 0.76 | 0.77 | 0.76 |
| Sub basin 3 | 0.93 | 0.92 | 0.92 |
| Sub basin 4 | 0.55 | 0.55 | 0.55 |
| Sub basin 5 | 0.81 | 0.67 | 0.81 |
| Sub basin 6 | 0.70 | 0.74 | 0.71 |
| Sub basin 7 | 0.63 | 0.63 | 0.69 |
| Sub basin 8 | 0.74 | 0.74 | 0.64 |
| Sub basin 9 | 0.58 | 0.53 | 0.52 |
| Sub basin 10 | 0.60 | 0.60 | 0.61 |
| Sub basin 11 | 0.37 | 0.40 | 0.41 |

**Table 4.6:** Elongation Ratio of sub basins in Wadi Uranah

### 4.4.3 Aerial aspects

The aerial aspects include stream frequency (Fs), drainage density (Dd), infiltration no (If) and Length of overland flow (Lg)

Stream frequency (Fs )

Stream frequency value provides additional information concerning the response of drainage basin to runoff process(Selvan et al., 2011, pp.22-27) The smaller stream frequency values might be attributed to relatively lower relief and higher infiltration capacity. The value of stream frequency for Wadi Uranah entire ranging between from 2.45 to 2.69 km-2 according DEM 90, DEM12.5 meter respectively. Table 4.7 reflects the stream frequency of the sub basin which ranges from 2.38 – 2.85 km-2.

| Stream frequency (Fs ) $km^{-2}$ | | | |
|---|---|---|---|
| **Sub basin** | **DEM 90 m** | **DEM 30 m** | **DEM 12.5 m** |
| Sub basin 1 | 2.49 | 2.68 | 2.73 |
| Sub basin 2 | 2.30 | 2.59 | 2.65 |
| Sub basin 3 | 2.50 | 2.64 | 2.59 |
| Sub basin 4 | 2.48 | 2.68 | 2.59 |
| Sub basin 5 | 2.47 | 2.56 | 2.54 |
| Sub basin 6 | 2.45 | 2.48 | 2.67 |
| Sub basin 7 | 2.43 | 2.60 | 2.76 |
| Sub basin 8 | 2.52 | 2.81 | 2.85 |
| Sub basin 9 | 2.67 | 2.75 | 2.85 |
| Sub basin 10 | 2.42 | 2.73 | 2.77 |
| Sub basin 11 | 2.38 | 2.49 | 2.58 |

**Table 4.7:** Stream Frequency of sub basins in Wadi Uranah

The sub basins number 1, 2, 8 and 4 that have structural hills have higher stream frequency, drainage density while the basins of the flat area have a minimum stream frequency like sub basin number 11 Which record the lowest frequency (2.38 km-2).Through the comparison between the values of the sub basins, we found the effect of changing the DEM resolution show on the sub basins that characterized by hilly terrain which is clearly observed in sub basin number1, 2 and 8 of Wadi Uranah Figure 4.15.

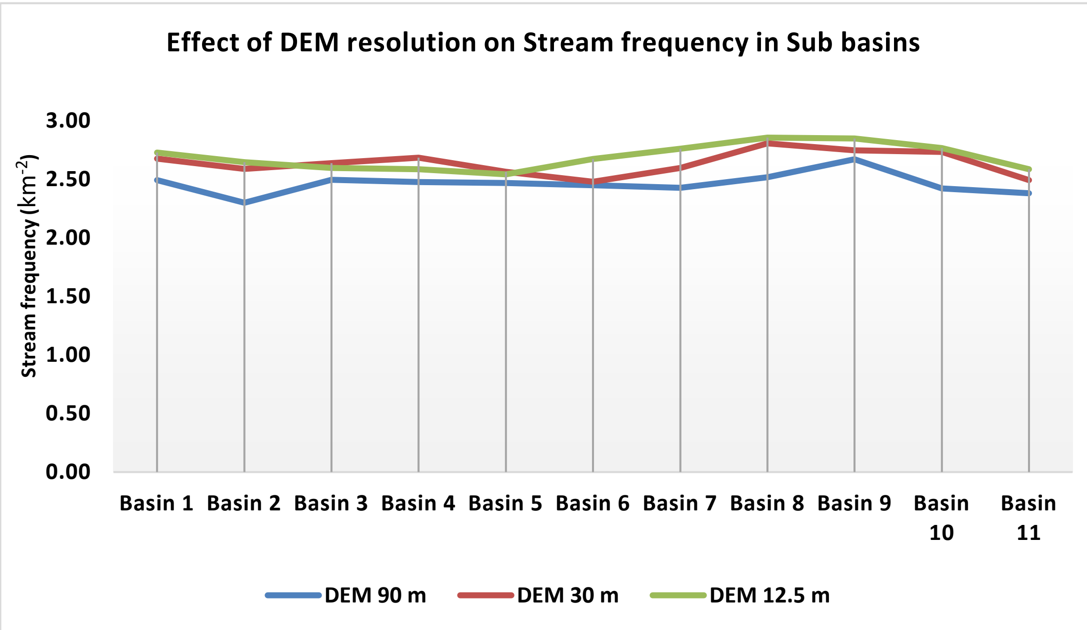



**Figure 4.15:** Effect of DEM resolution stream frequency in sub basins

Drainage density (Dd)

Drainage density is one of the important morphometric and hydrology parameters and has significant values in practical water management, drainage density relates to the number of streams in a particular drainage basin and the total area of a drainage basin. The most important factors effecting drainage density are the type of soil where drainage densities are higher on impermeable surfaces because there is less infiltration. Also, drainage densities are usually higher on steep land because there is less infiltration all of this related to high precipitation in the area.

Wadi Uranah has drainage density of 1.53 km km−2 in SRTM 90 meter, while that of SRTM 30 meter and ALOS PALSAR 12.5 meters is 1.69 and 1.76 km km−2, respectively Table 4.3 while the drainage density in the sub basins of study area varies between 1.35 and 2.01 km/ km2. Sub basin number 6 depicts minimum drainage density value obtained from DEM 90 meters and second minimum value also from DEM 90 in sub basin number 1. While that the maximum drainage density value has obtained from DEM 12.5 meters in sub basin number 2 suggesting that number 2 is more susceptible to floods. Table 4.8 shows the different values of drainage density for each sub basin according to change the DEM resolution.

| Drainage density (Dd) km $km^{-2}$ | | | |
|---|---|---|---|
| **Sub basin** | **DEM 90 m** | **DEM 30 m** | **DEM 12.5 m** |
| Sub basin 1 | 1.39 | 1.53 | 1.58 |
| Sub basin 2 | 1.70 | 1.94 | 2.01 |
| Sub basin 3 | 1.58 | 1.66 | 1.70 |
| Sub basin 4 | 1.42 | 1.54 | 1.58 |
| Sub basin 5 | 1.57 | 1.67 | 1.73 |
| Sub basin 6 | 1.35 | 1.50 | 1.54 |
| Sub basin 7 | 1.61 | 1.77 | 1.81 |
| Sub basin 8 | 1.46 | 1.66 | 1.74 |
| Sub basin 9 | 1.55 | 1.75 | 1.81 |
| Sub basin 10 | 1.48 | 1.69 | 1.77 |
| Sub basin 11 | 1.65 | 1.88 | 1.97 |

**Table 4.8:** Drainage density of sub basins in Wadi Uranah

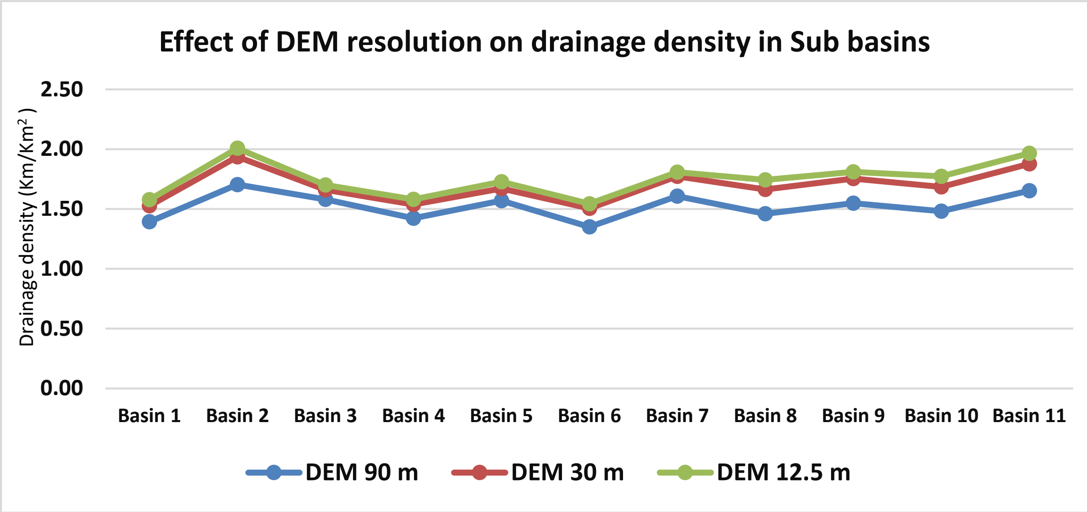



**Figure 4.16:** Effect of DEM resolution on drainage density in Sub basins

Figure 4.16 illustrates the effect of changing the resolution of the digital elevation model where the discharge density increases with increasing spatial resolution of the digital elevation models used. Also, Figure 4.17 shows the relation between drainage density and stream frequency which shows a positive linear correlation where the increase of drainage frequency with drainage density.

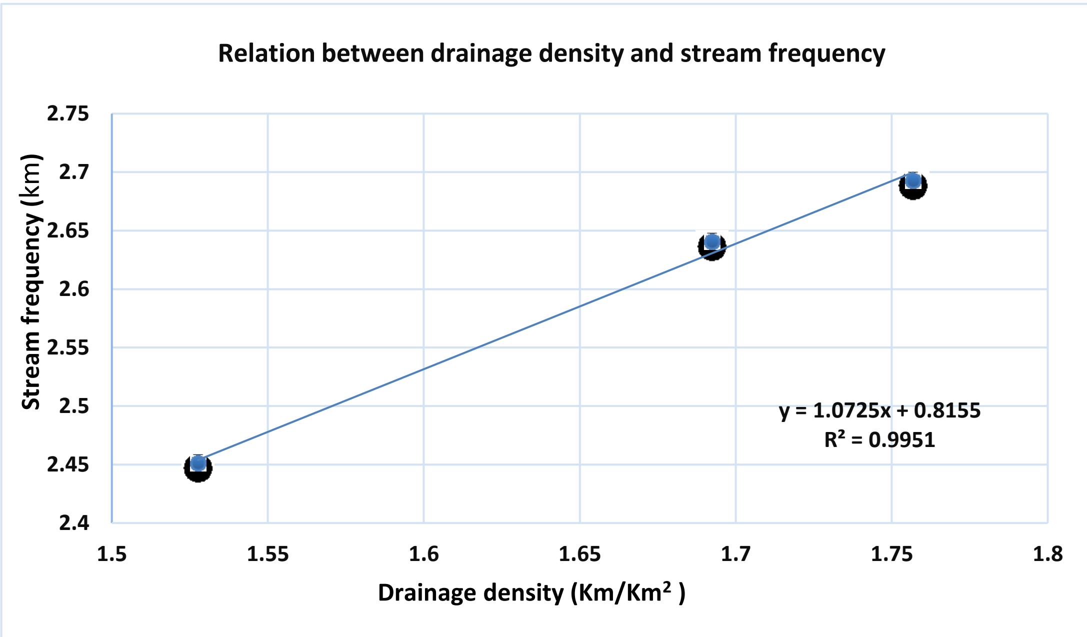



**Figure 4.17:** Relation between drainage density and stream frequency

Infiltration Number (FN)

The infiltration number gave an idea about the infiltration characteristics of the basin where the higher values of the infiltration number in a basin clearly indicate low infiltration and high runoff (Pareta et al., 2011, pp.248-269). Wadi Uranah has the low infiltration ranging from 3.47 to 4.73 according DEM 90 and 12.5 meters respectively, Table 4.9 show all the infiltration numbers for all sub basins which shows the rate of change in numbers for each sub basin when the difference in resolution of DEM.

| Infiltration Number | | | |
|---|---|---|---|
| **Sub basin** | **DEM 90 m** | **DEM 30 m** | **DEM 12.5 m** |
| Sub basin 1 | 3.48 | 4.09 | 4.30 |
| Sub basin 2 | 3.92 | 5.01 | 5.31 |
| Sub basin 3 | 3.94 | 4.38 | 4.41 |
| Sub basin 4 | 3.52 | 4.13 | 4.09 |
| Sub basin 5 | 3.87 | 4.29 | 4.39 |
| Sub basin 6 | 3.31 | 3.73 | 4.13 |
| Sub basin 7 | 3.90 | 4.60 | 4.99 |
| Sub basin 8 | 3.68 | 4.67 | 4.97 |
| Sub basin 9 | 4.13 | 4.82 | 5.15 |
| Sub basin 10 | 3.58 | 4.61 | 4.90 |
| Sub basin 11 | 3.93 | 4.68 | 5.08 |

**Table 4.9:** Infiltration Number of sub basins in Wadi Uranah

Length of overland flow (Lg )

The length of overland flow is one of the most important independent variable affecting both hydrologic and physiographic development of drainage basins. This factor basically relates inversely to the average slope of the channel. Wadi Uranah has the length of overland flow (lg) estimated from SRTM 90 meter, SRTM 30 meter and ALOS PALSAR 12.5 meters is 0.33, 0.30 and 0.28 respectively Table 4.3. while Table 4.10 shows the Lg values between 0.25 and 0.37 km $km^{-2}$ is observed in the eleven sub basins of Wadi Uranah, indicating the presence of moderate ground slopes, where the run-off and infiltration are moderate.

| Length of overland flow (Lg ) (Km) | | | |
|---|---|---|---|
| **Sub basin** | **DEM 90 m** | **DEM 30 m** | **DEM 12.5 m** |
| Sub basin 1 | 0.36 | 0.33 | 0.32 |
| Sub basin 2 | 0.29 | 0.26 | 0.25 |
| Sub basin 3 | 0.32 | 0.30 | 0.29 |
| Sub basin 4 | 0.35 | 0.32 | 0.32 |
| Sub basin 5 | 0.32 | 0.30 | 0.29 |
| Sub basin 6 | 0.37 | 0.33 | 0.32 |
| Sub basin 7 | 0.31 | 0.28 | 0.28 |
| Sub basin 8 | 0.34 | 0.30 | 0.29 |
| Sub basin 9 | 0.32 | 0.29 | 0.28 |
| Sub basin 10 | 0.34 | 0.30 | 0.28 |
| Sub basin 11 | 0.30 | 0.27 | 0.25 |

**Table 4.10:** Length of overland flow of sub basins in Wadi Uranah

It is noted when comparing the results obtained from the DEM resolution increase the rate of value with roughness resolution and when resolution increased the rate of length of overland flow is decreased. This is shown in Figure 4.18 we found in the results of DEM 30 and 12.5-meter approximate values while Dem 90 is different values.

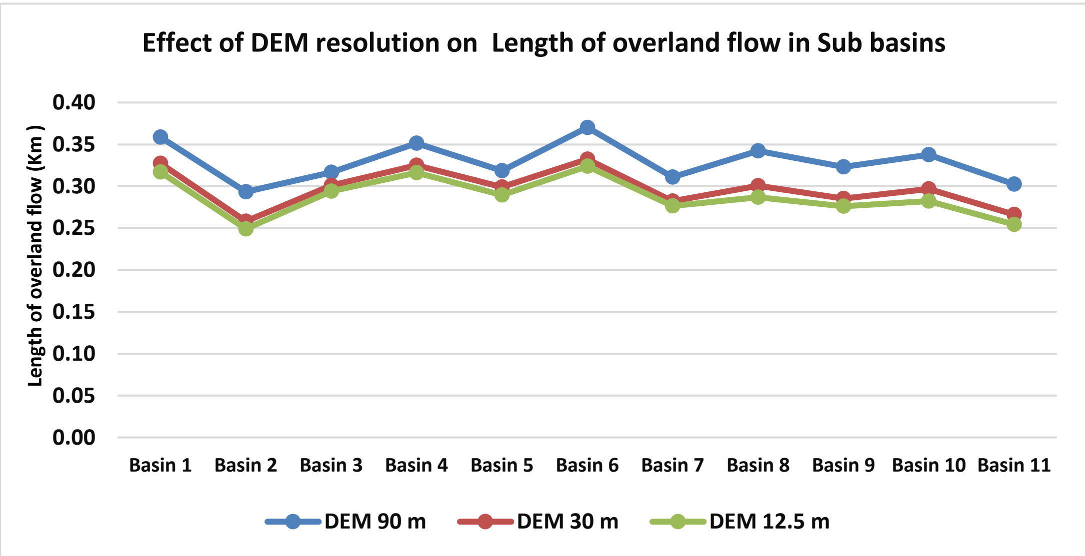



**Figure 4.18:** Effect of DEM resolution on Length of overland flow in Sub basins

### 4.4.4 Relief Aspects

The relief aspects include basin relief, relief ratio, relative relief and ruggedness number. The results of the analysis are given and discussed below.

Basin Relief (H)

Basin relief is an important factor in understanding the geomorphic processes and determines the stream gradient and influences flood pattern and volume of sediment that can be transported. The total basin relief of Wadi Uranah is 2593, 2606 and 2610 meters from DEM 90, 30 and 12.5 meters respectively.

When comparing the values of basin relief that obtained from the different DEM resolution we found that the values in all almost sub basins were not affected with change the resolution except in the flat areas this is evident in sub basin number 11 where the basin relief from DEM 90 meter is 453 m while it was 303 m in DEM 12.5 meter by a difference of 14% while in relief areas the difference in values is less than 1% Figure 4.19.

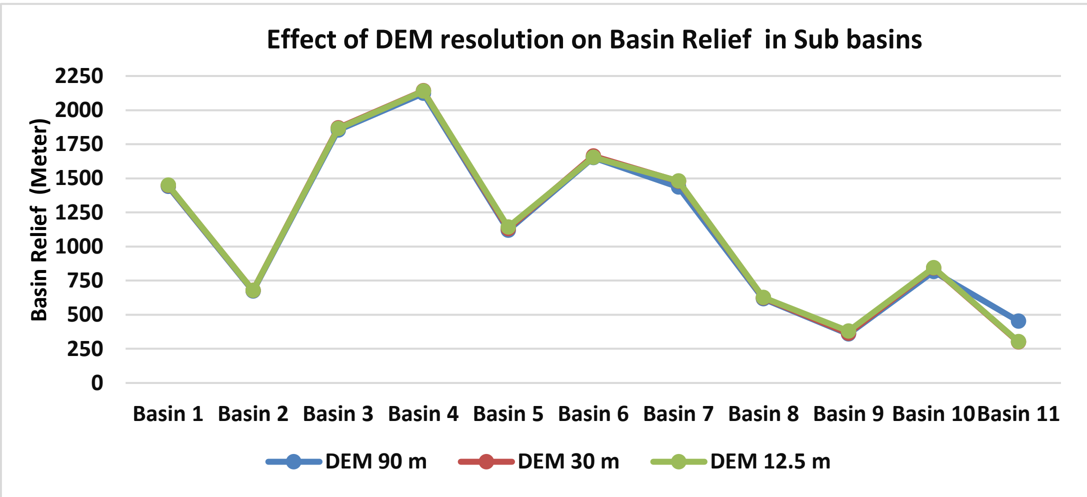



**Figure 4.19:** Effect of DEM resolution on basin relief in Sub basins

Relief Ratio (Rh)

It measures the overall steepness of basins and is an indicator of the intensity of erosion processes operating on slopes of the basins. Overall relief ratio for wadi Uranah is found to vary between 21.46, 21.50 and 21.85 from DEM 90, 30 and 12.5 meter respectively.

Relative Relief (Rhp)

Relative relief is the basin relief to the perimeter of the basin Overall Relative relief ratio for Wadi Uranah found to vary among 487,451,433 from DEM 90, 30 and 12.5 meter.

Ruggedness number (Rn)

The ruggedness number is a product of drainage density and relative relief per km. An extremely high a ruggedness number occurs when maximum basin relief and drainage density variables are large and the slope is not only steep but long as well.

The ruggedness number in Wadi Uranah is 4.16, 4.07and 4 which indicates the basin is less soil erosion prone and has inherent structural complexity in association with relief and drainage density. Figure 4.20.

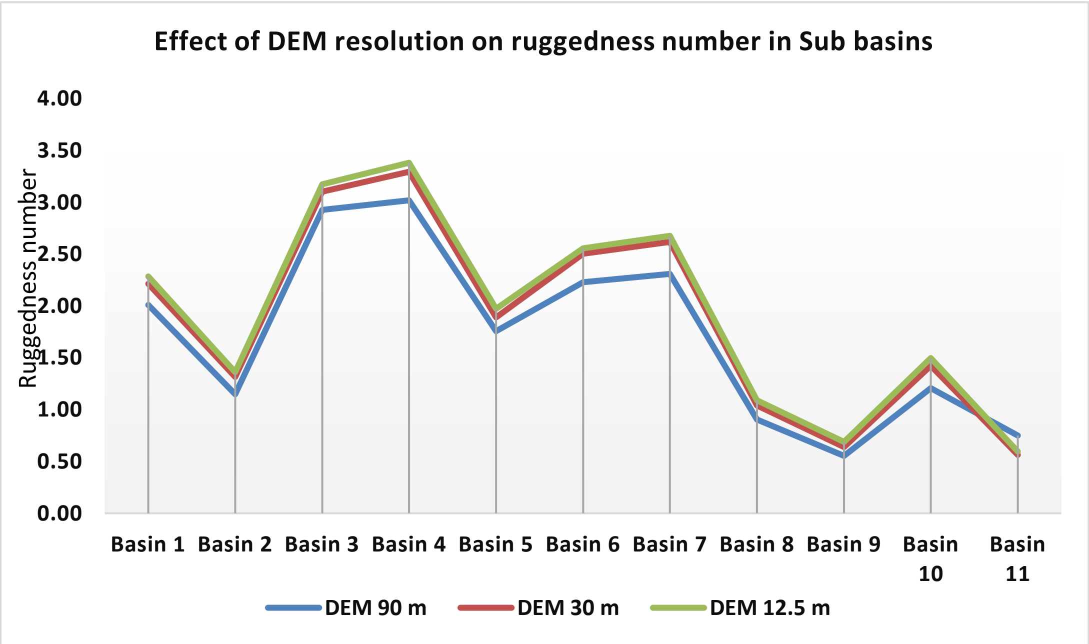


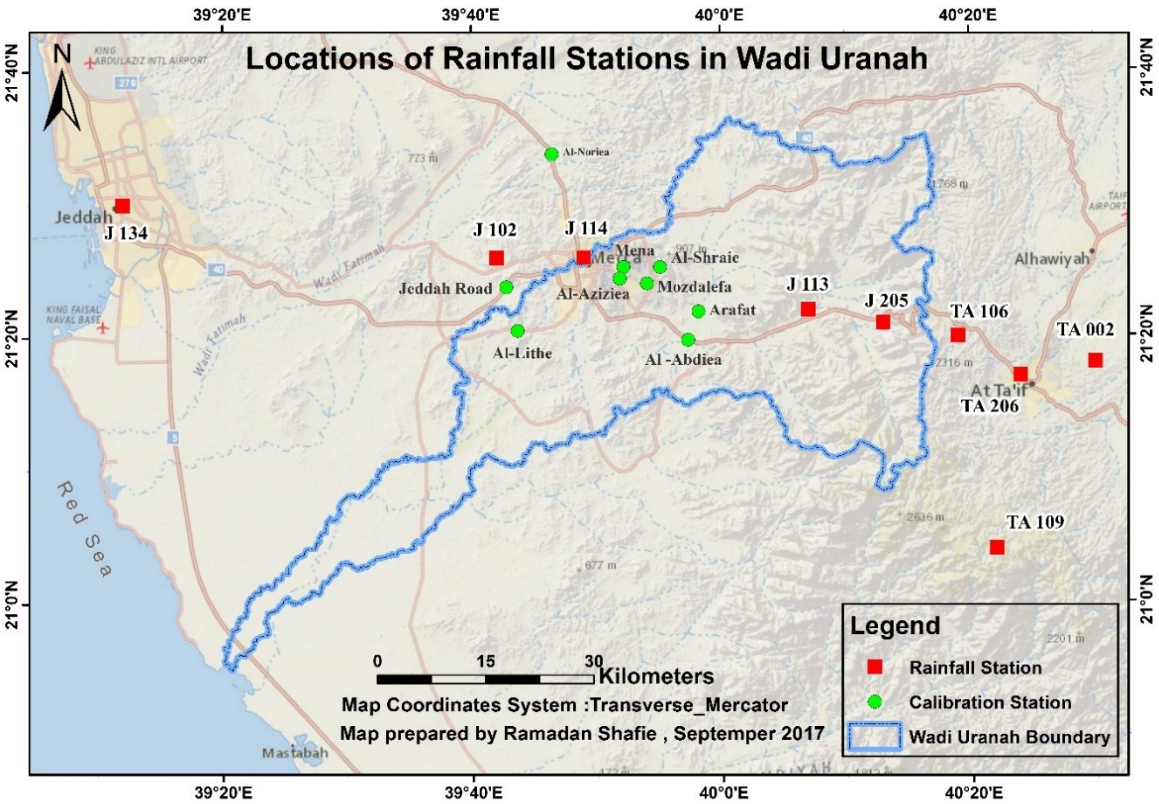

**Figure 4.20:** Effect of DEM resolution on ruggedness number in sub basins

## 4.5 Rainfall Analysis

Rainfall is a fundamental part of floods estimation for that the daily rainfall data was studied and analyzed in nine stations Table 4.11, Map 4.9 to establishing a probability distribution to represent the precipitation depth at various durations.

| No | Station Code | Station Name | Elevation(m) | Latitude | Longitude |
|---|---|---|---|---|---|
| 1 | TA 109 | Shifa | 2130 | 21.066667 | 40.366667 |
| 2 | TA 206 | Taif | 1680 | 21.283300 | 40.400000 |
| 3 | J 113 | Al-Furin | 520 | 21.366667 | 40.116667 |
| 4 | J 102 | New Bahrah | 116 | 21.433330 | 39.700000 |
| 5 | J 134 | Jeddah (Directorate) | 11 | 21.500000 | 39.20000 |
| 6 | J 205 | Mid-Hada | 910 | 21.350000 | 40.216667 |
| 7 | TA 002 | Hema sesd | 1500 | 21.300000 | 40.500000 |
| 8 | TA 106 | Wadi Muharram | 1870 | 21.333333 | 40.316667 |
| 9 | J114 | Makkah Al Mukaramah | 280 | 21.433333 | 39.816667 |

**Table 4.11:** Rainfall Stations in Wadi Uranah




**Map 4.9:** Locations of Rainfall Station in Wadi Uranah

The daily rainfall data of 45 years (1966-2011) have been collected from the nine-station, the data were then analyzed to identify the annual maximum rainfall received on one day, using and testing different fitting probability distributions such as gamma, Gumbel max, inverse Gaussian, lognormal, normal, log-Pearson type3, Weibull for evaluating the best-fitted probability distribution for rainfall as in Figure 4.21.

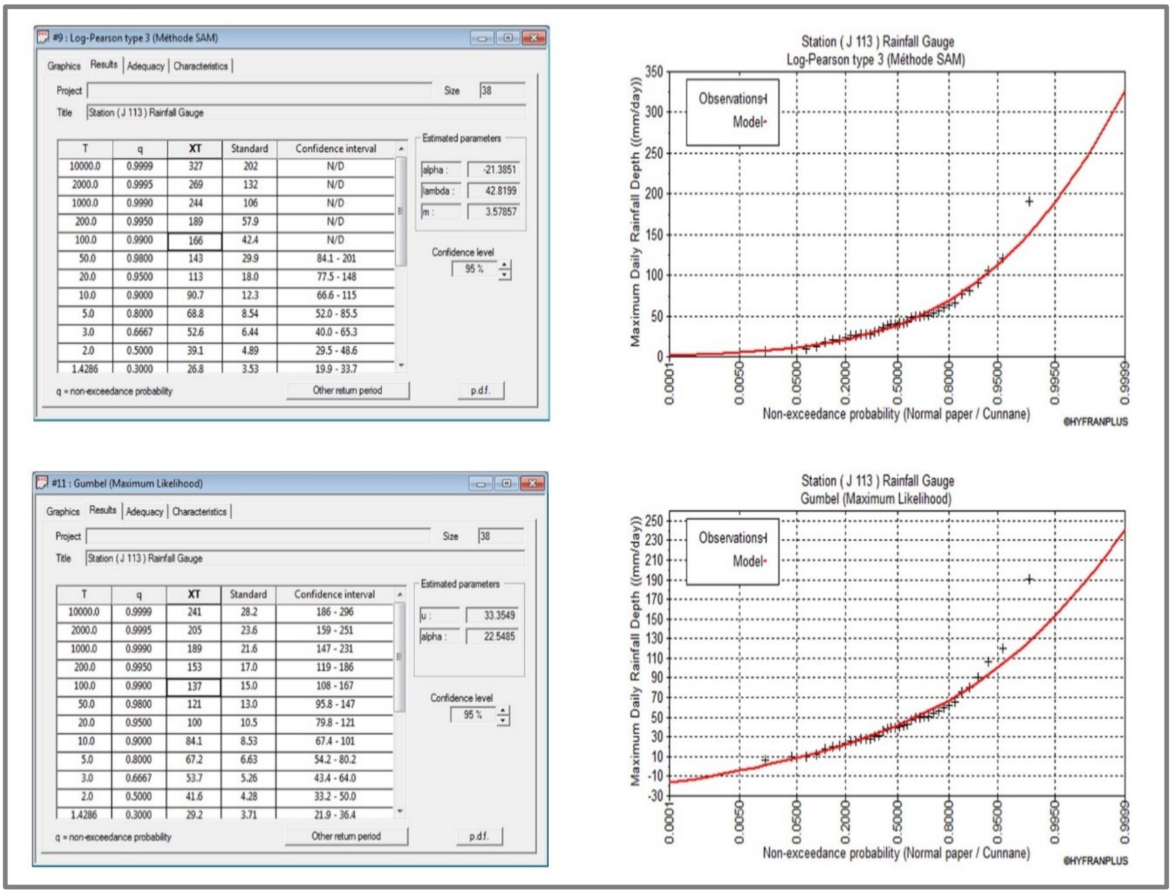



**Figure 4.21:** Testing a different fitting model of the probability distribution

The distributions were tested on data for all stations of the study area to choose between tested distributions it was found that the log- Pearson type 3 distribution is the one that best fits the data. Therefore selected to form the basis of the analysis. Annual maximum rainfall for the period 1966-2011 shows a high spatial variation with values ranging from 74.29 mm in the east to 27.76 mm in the west regions. As shown in Table 4.10 J 205 station which is located in the domain of the Wadi Uranah that affect the studied area, has the first highest reading comparing to the other stations for the return periods.

Table 4.10 shows the maximum daily rainfall amount for the 5, 10, 25, 50- and 100-year return periods obtained based on log- Pearson type 3

| Station_No | xT<br>5 Years | xT<br>10 Years | xT<br>25 Years | xT<br>50 Years | xT<br>100 Years |
|---|---|---|---|---|---|
| **TA 206** | 48.1 | 50.7 | 51.8 | 51.9 | 86.2 |
| **J 102** | 44.6 | 55.6 | 66.6 | 72.9 | 97.5 |
| **TA 002** | 47.2 | 61.9 | 79.9 | 92.6 | 105 |
| **J 134** | 48.7 | 66.3 | 87 | 101 | 113 |
| **TA 109** | 61.7 | 70.4 | 78.6 | 83.1 | 116 |
| **TA 106** | 59.6 | 73.3 | 90 | 102 | 113 |
| **J 114** | 61.8 | 77.5 | 95.9 | 108 | 124 |
| **J 205** | 70.6 | 80.6 | 87.6 | 90.4 | 133 |
| **J 113** | 68.8 | 90.7 | 120 | 143 | 166 |

**Table 4.12:** Annual maximum daily rainfall different return periods in study area stations

To compute the average rainfall over a Wadi Uranah, rainfall is measured at a number of the station but when rainfall stations are few compared to the size of should be using Thiessen polygon method to compute the average rainfall(Tabios and Salas, 1985, pp.365-380). This is the weighted mean method where the rainfall varies in intensity and duration from place to place. Thus the rainfall recorded by each rain gauge station should be weighted according to the area.

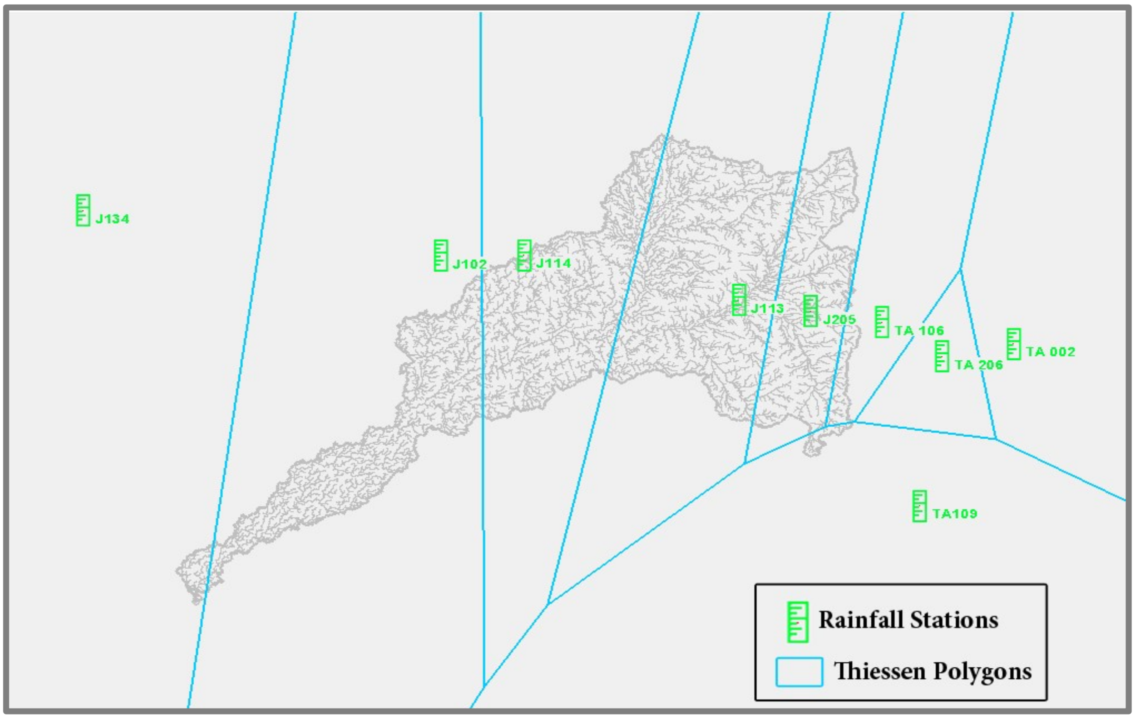



**Figure 4.22:** Thiessen polygon in Wadi Uranah

Then the average precipitation over the watershed will be computed by the total of station which is illustrated by the Figure 4.22 that there are 7 stations affect their values on Wadi Uranah according to Thiessen polygon method.

## 4.6 Computing CN values by SCS-Curve Number Method

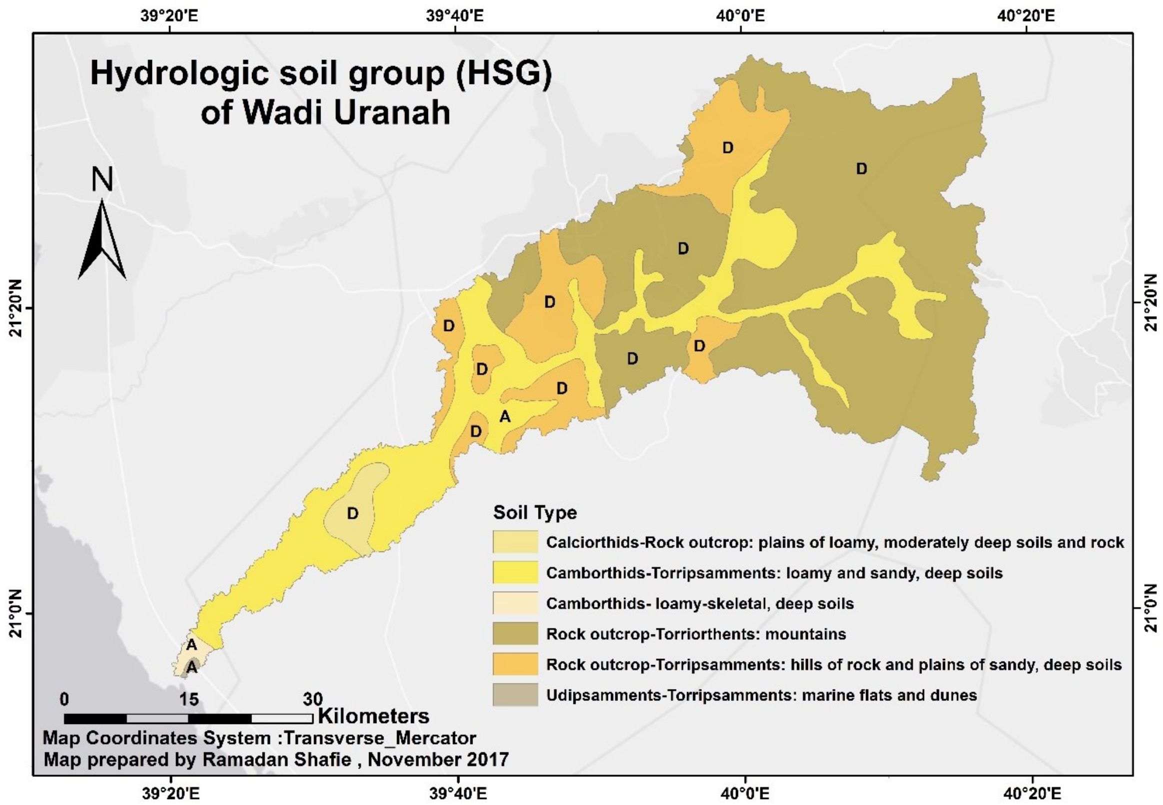
Hydrologic soil groups (HSG) and Land use are essential factors for water resource management analyses to classify land uses and (HSG) Where the Curve Number (CN) is determined based on hydrological soil group, land use in order to account for the water losses occurring due to infiltration and surface storage which occur prior to runoff.

### 4.6.1 Hydrology Soil Group (HSG)

Soil texture is important for hydrologic soil group determination, six types of soil texture are found in Wadi Uranah area that are rock outcrop plains of loamy, loamy and sandy deep soils, loamy-skeletal, mountains, hills of rock and plains of sandy deep soils and marine flats and dunes. Table 4.13 shows the characteristics and the areas of the major soil types in Wadi Uranah. These soil types are spatially distributed over the watersheds as illustrated in Map 4.10.

| Soil Type | General Characteristics | Area ($KM^2$) | Area (%) |
|---|---|---|---|
| Calciorthids-Rock outcrop | plains of loamy, moderately deep soils and rock | 44.88 | 1.94 |
| Camborthids-Torripsamments | loamy and sandy, deep soils, 0 to 5 percent slopes | 573.79 | 24.75 |
| Camborthids | loamy-skeletal, deep soils, 0 to 5 percent slopes | 11.74 | 0.51 |
| Rock outcrop-Torriorthents | mountains | 1,317.73 | 56.84 |
| Rock outcrop-Torripsamments | hills of rock and plains of sandy, deep soils | 367.32 | 15.84 |
| Udipsamments-Torripsamments | marine flats and dunes | 2.94 | 0.13 |

**Table 4.13:** Major soil types and characteristics in Wadi Uranah




**Map 4.10:** Hydrologic soil groups (HSG) of Wadi Uranah

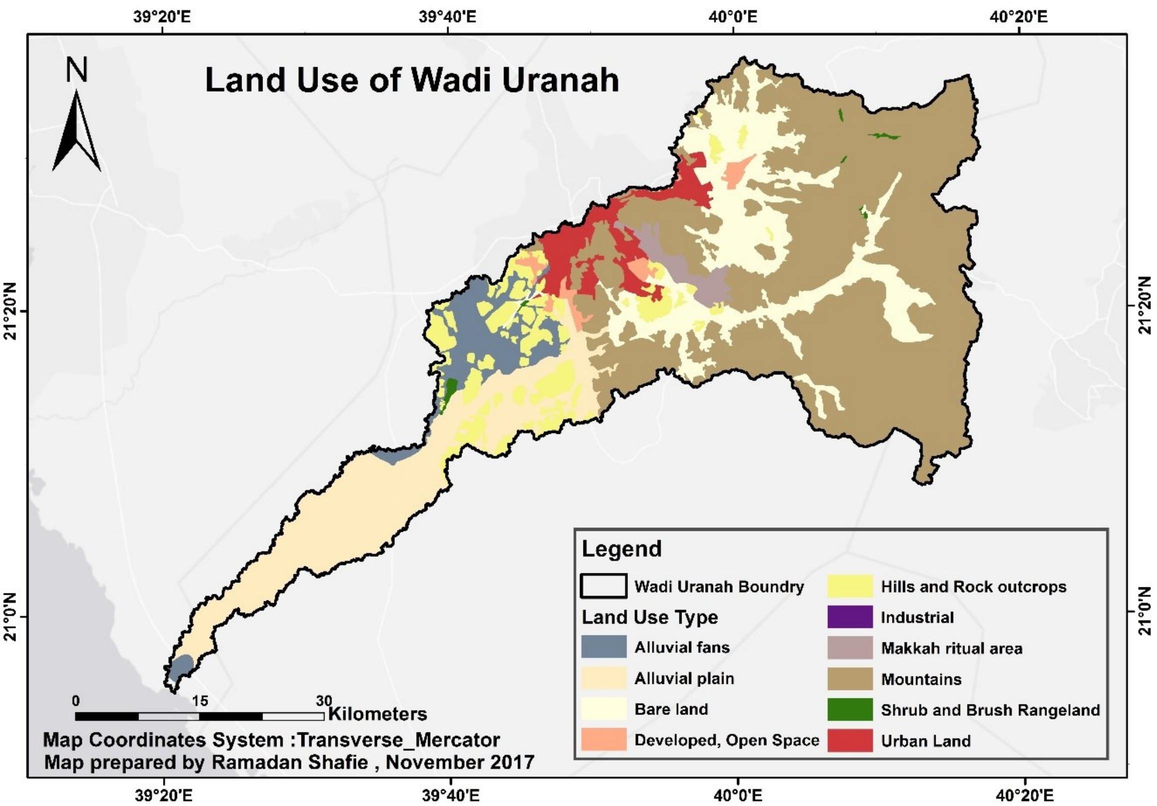
| HSG | Area $KM^2$ | Percentage % |
|---|---|---|
| **A** | 588.47 | 25.38 % |
| **D** | 1,729.93 | 74.62 % |
| **Total** | 2,318 | 100 |

**Table 4.14:** Hydrologic soil group (HSG) of Wadi Uranah

Each soil type is assigned a hydrologic soil group of A, B, C or D depending on its characteristics of infiltration. From Table 4.14, two HSG namely (D) and (A) were found to dominate the Wadi Uranah basin. The soils in the eastern part of the watershed were found to be of HSG (D) meaning they have highest runoff potential in the watershed where rocks and mountain dominate hence limiting infiltration and favoring runoff which constitutes most of the basin area about 74.62 % of the total area of the basin. The western parts of the watershed were found to be dominated by HSG (A) which has low runoff potential and having high infiltration rates this is majorly due to the presence of loamy and sandy in this section.

### 4.6.2 Land use Classification

There are different aspects covered the earth's surface, in turn, influence the behavior of water flow on terrain surfaces such as objects and sets of land uses and human activities, Therefore, a map was produced to show the different classes of land use in Wadi Uranah,




**Map 4.11:** land use of Wadi Uranah

After updated the land use and conduct accuracy assessment of the classified land use map through high-resolution satellite image for study area Map 4.11 is illustrated the land use classes in Wadi Uranah area.

Based on the generated land use map the total study area have five major Land use classes (Mountains, Bare land and developed open space, Hills and Rock outcrops, ritual area, and Urban Land) which show the majority land cover for the study area the mountains which covered about for 54% then the hills and Rock outcrops comes in the second with 31.25 % of total area while the urban area and developed open Space and the ritual area up to 10.78 %.

### 4.6.3 Determination of CN by SCS-Curve Number Method

Curve Number (CN) is a hydrologic parameter used for determining the approximate amount of runoff from a rainfall event in a drainage area. A spatial union between the land use and HSG datasets were created to calculate the CN-values and percentage area coverage of respective classes, the CN values may vary from 1 to 100. Higher values of CN indicate higher run-off. Hence, Table 4.15 presents the typical land use categories used for hydrologic analysis, along with corresponding curve numbers for each land use-(HSG).

| **Land use** | **Curve Number by Hydrologic Soil** | | | |
|---|---|---|---|---|
| | **A** | **B** | **C** | **D** |
| Alluvial fans | 65 | __ | __ | 84 |
| Alluvial plain | 65 | __ | __ | 85 |
| Bare land | 77 | __ | __ | 94 |
| Developed, Open Space | 77 | __ | __ | 94 |
| Hills and Rock outcrops | 81 | __ | __ | 93 |
| Industrial | __ | __ | __ | 93 |
| Makkah ritual area | 72 | __ | __ | 91 |
| Mountains | 98 | __ | __ | 98 |
| Shrub and Brush Rangeland | 49 | __ | __ | 84 |
| Urban Land | 89 | __ | __ | 95 |

**Table 4.15:** Land use categories and associated CN

The CN values which found by SCS CN method are presented in above tables that the lowest CN value was found to be 49 in Shrub and Brush Rangeland while the highest CN value was found to be 98 in a mountains areas.

Table 4.16 and Figure 4.23 shows the descriptive statistics of areas for each CN, where CN varying between 98 and 49 but the largest area accounted for 1,150.66 km2 which present about 49.63% of the total area of Wadi Uranah have 98 CN Value, that typically has lower infiltration rates and therefore higher runoff values. Furthermore, it can be observed that the 23.47 of the total area have less than 80 CN Value that has higher infiltration rates, and therefore lower curve numbers.

| CN | Area ($KM^2$) | Area (%) |
|---|---|---|
| **49** | 2.76 | 0.12 |
| **65** | 359.93 | 15.53 |
| **72** | 13.45 | 0.58 |
| **77** | 167.83 | 7.24 |
| **81** | 11.37 | 0.49 |
| **84** | 52.41 | 2.26 |
| **85** | 76.76 | 3.31 |
| **89** | 6.07 | 0.26 |
| **91** | 23.69 | 1.02 |
| **93** | 158.42 | 6.83 |
| **94** | 206.98 | 8.93 |
| **95** | 88.03 | 3.80 |
| **98** | 1,150.66 | 49.63 |

**Table 4.16:** Area of all of CN values in study area

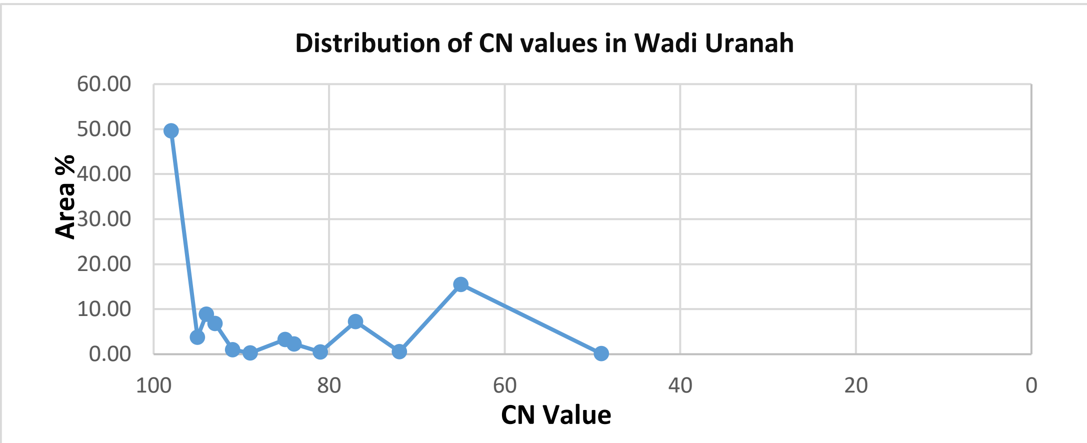



**Figure 4.23:** Distribution of CN values in Wadi Uranah

### 4.7 Hydrological Modeling processing

Hydrological modeling is important for watershed management as hydrology is the driving force behind many processes occurring in the watershed and the accurate prediction of runoff responses to rainfall still remaining(McColl and Aggett, 2007, pp.494-512)
Digital elevation model one of the key basis for hydrologic modeling and its resolution is a key factor in accurate prediction of runoff and various hydrological processes.

In this part, HEC-HMS model is used to simulate rainfall-runoff process in Wadi Uranah basin, to compute runoff volume, peak runoff rate. HEC-HMS is widely used as a rainfall runoff modeling tool, HEC-HMS uses separate sub models to represent each component of the runoff process, including models that compute rainfall losses, runoff generation, base flow, and channel routing (Du et al., 2012, pp.127-139).

### 4.7.1 Input Requirements of HEC-HMS

The HEC-HMS model requires different datasets including basin and sub basins, a stream network, rainfall data, soil type, and land use as in Figure 4.24 were the main components to runoff estimation can be divided into:

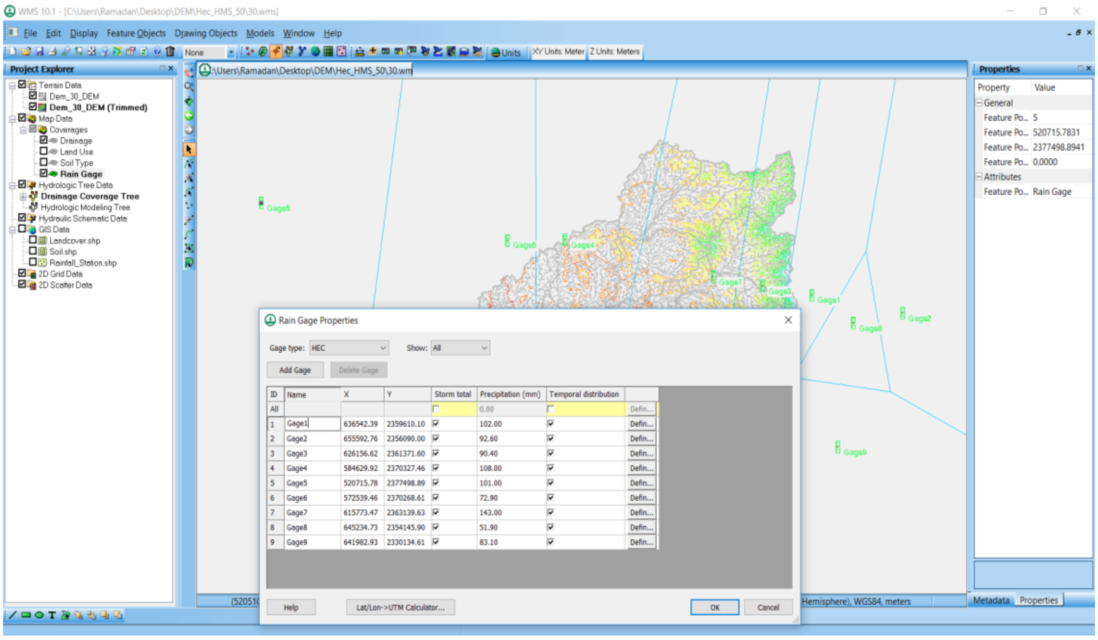



**Figure 4.24:** input requirement in HEC-HMS Model

<u>Specify the basin and Sub basin model:</u>

That includes the define the properties of your Sub basin such as Area (km2), SCS CN loss method CN prepared from land cover and soil surveys and Impervious area (%) that defines the percentage of the sub basin that are impervious.

<u>Specify the meteorological model:</u>

Using Gage Weights that automatically determine gage weights for each sub basin using the Thiessen polygon method Figure 4.25.

<u>Specify the Transform method</u>

Select SCS Transform method that allows specifying how to convert excess rainfall to direct runoff Figure 4.26.

<u>Control specifications manager</u>

Finally, to run HEC-HMS, we must create a control specification through Components Control Specifications Manager by defines the time period of the simulation and the time interval within that at which computations will be performed and 15 min was chosen as the intensity-duration.

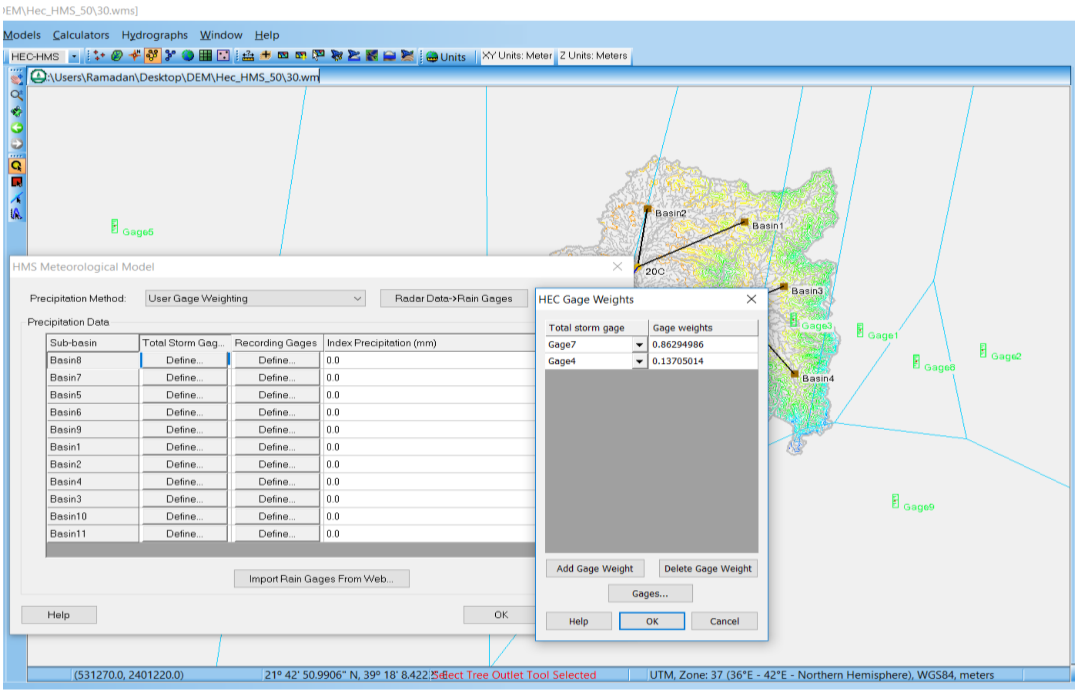
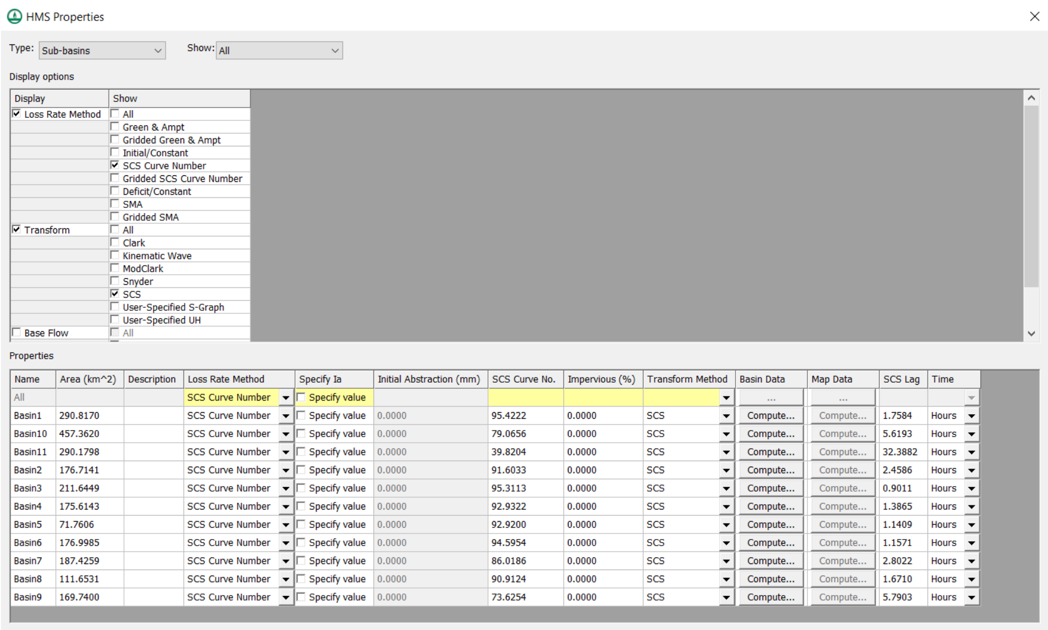



**Figure 4.25:** Determine gage weights for each sub basin




| Name | Area (km^2) | Description | Loss Rate Method | Specify Ia | Initial Abstraction (mm) | SCS Curve No. | Impervious (%) | Transform Method | Basin Data | Map Data | SCS Lag | Time |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| All | | | SCS Curve Number | Specify value | | | | | ... | ... | | |
| Basin1 | 290.8170 | | SCS Curve Number | Specify value | 0.0000 | 95.4222 | 0.0000 | SCS | Compute... | Compute... | 1.7584 | Hours |
| Basin10 | 457.3620 | | SCS Curve Number | Specify value | 0.0000 | 79.0656 | 0.0000 | SCS | Compute... | Compute... | 5.6193 | Hours |
| Basin11 | 290.1798 | | SCS Curve Number | Specify value | 0.0000 | 39.8204 | 0.0000 | SCS | Compute... | Compute... | 32.3882 | Hours |
| Basin2 | 176.7141 | | SCS Curve Number | Specify value | 0.0000 | 91.6033 | 0.0000 | SCS | Compute... | Compute... | 2.4586 | Hours |
| Basin3 | 211.6449 | | SCS Curve Number | Specify value | 0.0000 | 95.3113 | 0.0000 | SCS | Compute... | Compute... | 0.9011 | Hours |
| Basin4 | 175.6143 | | SCS Curve Number | Specify value | 0.0000 | 92.9322 | 0.0000 | SCS | Compute... | Compute... | 1.3865 | Hours |
| Basin5 | 71.7606 | | SCS Curve Number | Specify value | 0.0000 | 92.9200 | 0.0000 | SCS | Compute... | Compute... | 1.1409 | Hours |
| Basin6 | 176.9985 | | SCS Curve Number | Specify value | 0.0000 | 94.5954 | 0.0000 | SCS | Compute... | Compute... | 1.1571 | Hours |
| Basin7 | 187.4259 | | SCS Curve Number | Specify value | 0.0000 | 86.0186 | 0.0000 | SCS | Compute... | Compute... | 2.8022 | Hours |
| Basin8 | 111.6531 | | SCS Curve Number | Specify value | 0.0000 | 90.9124 | 0.0000 | SCS | Compute... | Compute... | 1.6710 | Hours |
| Basin9 | 169.7400 | | SCS Curve Number | Specify value | 0.0000 | 73.6254 | 0.0000 | SCS | Compute... | Compute... | 5.7903 | Hours |

**Figure 4.26:** Select SCS Transform method

After the completion of the basin model with WMS, the model was exported into HEC-HMS project file. Figure 4.27 shows the schematic representation of the basin model in HEC-HMS contains the hydrologic elements (sub basin, reach, and junction).

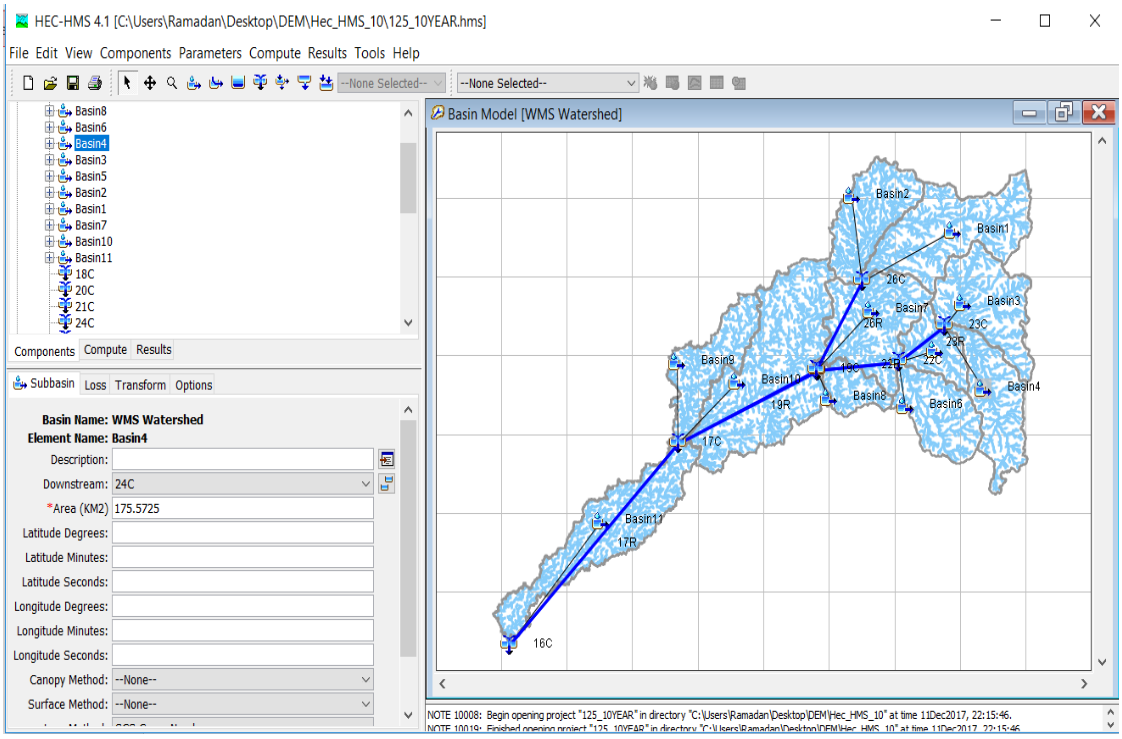


**Figure 4.27:** schematic representation of the basin model in HEC-HMS

### 4.7.2 Rainfall-Runoff Simulation

Hydrologic modeling was performed in order to create rainfall-runoff hydrographs resulting from storms with various statistical return periods we chose three return periods for 10, 25 and 50 years. In this part, the calibration hydrographs were conducted for all sub basins of Wadi Uranah that derived from different DEM resolution.

The first scenario is to consider Wadi Uranah as one basin which had been delineated by using different DEM resolution through a series of analysis procedures and using HEC-HMS model to simulate rainfall-runoff for, SCS Curve Number method was selected as an infiltration part of the model and direct runoff was transformed by US SCS unit hydrograph (UH) the SCS 24 hour rainfall and type II distribution were used to create rainfall hyetograph. That below table shown summarizes the peak discharge and time, the total volume of storm runoff and the drainage area for Wadi Uranah for return period 10 years. After steps of the calibration and validation, we can have the runoff generated by the model after creating simulation run and view the results in tabular or graphical form were that Table 4.16 shows a global results runoff simulation for 10 years return period for main basin.

| DEM resolution(m) | 10 Years Return Period | | | | | |
|---|---|---|---|---|---|---|
| | Drainage Area ($KM^2$) | Peak Discharge ($M^3/S$) | Time of Peak(hr) | loss Volume (MM) | Run off Volume (MM) | SCS Lag(hr) |
| 90 | 2332.3626 | 1465.4 | 24 | 39.62 | 32.79 | 10.752 |
| 30 | 2319.9102 | 1414.8 | 24 | 41.06 | 31.75 | 10.644 |
| 12.5 | 2303.7089 | 1521.4 | 23:15 | 39.95 | 33.701 | 10.066 |

**Table 4.17:** Summary of Runoff Simulation for 10 years return period for Main basin

The peak discharge of the 10 year-return-period flash-flood is 1465.4 m3/s for basin that derived based on DEM 90 meters, while up to 1404.8 m3/s with DEM 30meters and 1521.4 m3/s with DEM 12.5 meters with a change of up to 2.2% when DEMs resolution is changed as a comparison between the resulted hydrographs of the main basin of Wadi Uranah for peak discharges shows an increase in the different results for the main peak flow shown in Figure 4.28,4.29 and 4.30.

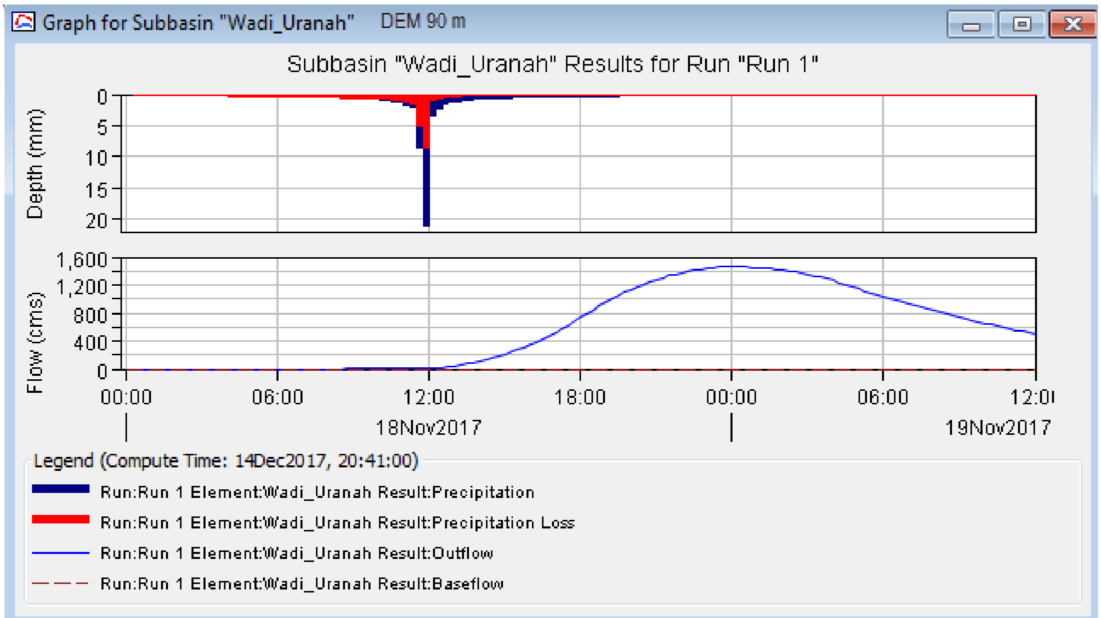



**Figure 4.28:** Hyetograph/Hydrograph of Wadi Uranah based on DEM 90 meter

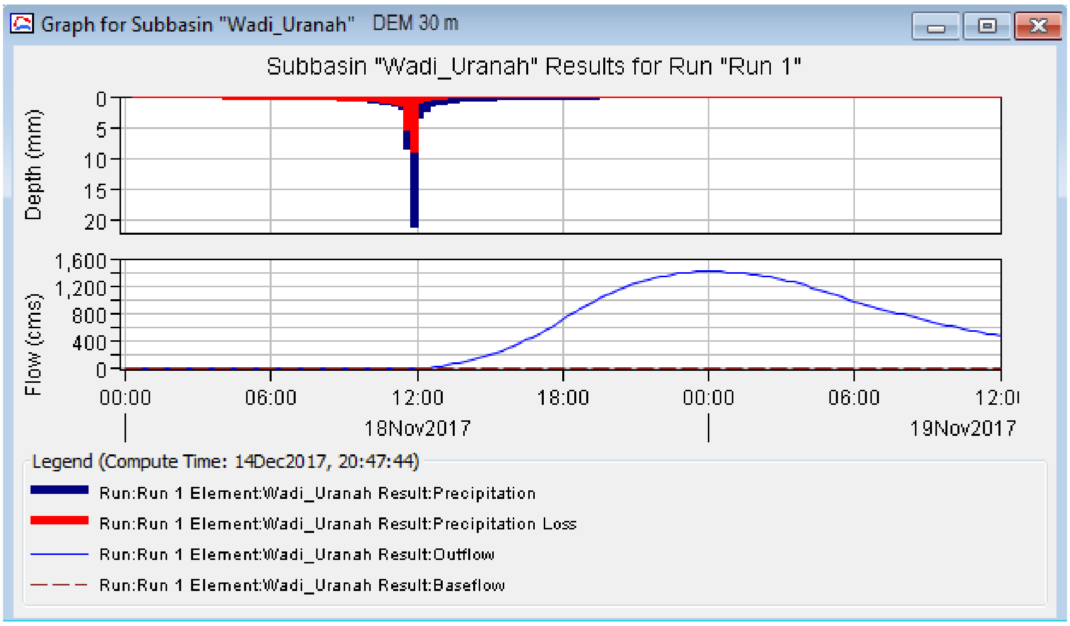



**Figure 4.29:** Hyetograph/Hydrograph of Wadi Uranah based on DEM 30 meter

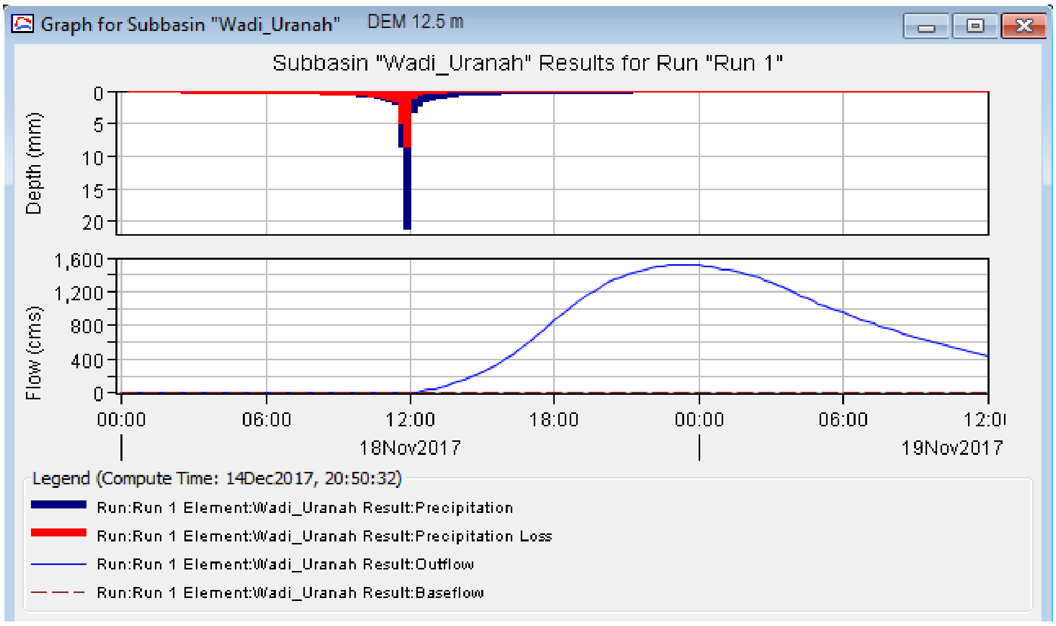



**Figure 4.30:** Hyetograph/Hydrograph of Wadi Uranah based on DEM 12.5 meter

In order to select discharge values, the second scenario the large basin should be divided into several sub basins to give more accurate results. The results of simulation in select return periods that depended on the basins that derived from different DEM resolution shown in Table 4.18, 19 and 4.2015 for return period 10, 25 and 50 years respectively.

| | DEM90 | | | |
|---|---|---|---|---|
| Sub basin | Drainage Area ($KM^2$) | Peak Discharge ($M^3/S$) | Time of Peak | Volume (MM) |
| Basin1 | 293.706 | 1430.8 | 13:45 | 74.75 |
| Basin2 | 180.9945 | 533.2 | 14:45 | 61.1 |
| Basin3 | 213.1434 | 1558.5 | 12:45 | 70.9 |
| Basin4 | 175.6809 | 778 | 13:30 | 58.17 |
| Basin5 | 92.4615 | 554.8 | 13:00 | 68.82 |
| Basin6 | 154.0377 | 1060.3 | 13:00 | 75.47 |
| Basin7 | 189.4914 | 459 | 15:00 | 51.25 |
| Basin8 | 112.0473 | 447.7 | 14:00 | 63.6 |
| Basin9 | 164.4381 | 51.7 | 19:45 | 13.56 |
| Basin10 | 394.1541 | 363.1 | 18:00 | 32.79 |
| Basin11 | 362.2077 | 0 | 00:00 | 0 |
| | DEM 30 | | | |
| Sub basin | Drainage Area ($KM^2$) | Peak Discharge (M3/S) | Time of Peak | Volume (MM) |
| Basin1 | 290.817 | 1421.5 | 13:45 | 74.51 |
| Basin2 | 176.7141 | 568.1 | 14:30 | 61.05 |
| Basin3 | 211.6449 | 1545 | 12:45 | 70.23 |
| Basin4 | 175.6143 | 831.9 | 13:15 | 59.87 |
| Basin5 | 71.7606 | 453.4 | 13:00 | 70.11 |
| Basin6 | 176.9985 | 1137.1 | 13:00 | 72.73 |
| Basin7 | 187.4259 | 459.9 | 15:00 | 51.66 |
| Basin8 | 111.6531 | 498.5 | 13:30 | 64.32 |
| Basin9 | 169.74 | 55.4 | 19:00 | 13.18 |
| Basin10 | 457.362 | 344.6 | 18:15 | 27.89 |
| Basin11 | 290.1798 | 0 | 00:00 | 0 |
| | DEM 12.5 | | | |
| Sub basin | Drainage Area ($KM^2$) | Peak Discharge ($M^3/S$) | Time of Peak | Volume (MM) |
| Basin1 | 291.143 | 1394.3 | 13:45 | 74.35 |
| Basin2 | 176.4781 | 567.3 | 14:30 | 60.98 |
| Basin3 | 211.5642 | 1480.9 | 12:45 | 69.81 |
| Basin4 | 175.5725 | 783 | 13:30 | 58.76 |
| Basin5 | 92.4642 | 524.1 | 13:15 | 68.08 |
| Basin6 | 154.125 | 1109.9 | 13:00 | 76.53 |
| Basin7 | 232.457 | 645.3 | 14:30 | 54.34 |
| Basin8 | 68.3189 | 299.6 | 13:45 | 63.91 |
| Basin9 | 158.4158 | 61.1 | 18:00 | 14.23 |
| Basin10 | 459.5961 | 372 | 18:00 | 29.29 |
| Basin11 | 283.5741 | 0 | 00:00 | 0 |

**Table 4.18:** Summary of runoff simulation for 10 years return period for all sub basin

| | DEM90 | | | |
|---|---|---|---|---|
| **Sub basin** | **Drainage Area (KM$^2$)** | **Peak Discharge (M$^3$/S)** | **Time of Peak** | **Volume (MM)** |
| Basin1 | 293.706 | 1834.3 | 13:45 | 96.78 |
| Basin2 | 180.9945 | 727.2 | 14:45 | 83.66 |
| Basin3 | 213.1434 | 1865.4 | 12:45 | 85.51 |
| Basin4 | 175.6809 | 896.3 | 13:15 | 67.22 |
| Basin5 | 92.4615 | 764.4 | 13:00 | 95.62 |
| Basin6 | 154.0377 | 1358.3 | 13:00 | 97.74 |
| Basin7 | 189.4914 | 673.7 | 15:00 | 74.92 |
| Basin8 | 112.0473 | 630.4 | 13:45 | 90.06 |
| Basin9 | 164.4381 | 81.3 | 19:30 | 20.81 |
| Basin10 | 394.1541 | 524.4 | 18:00 | 46.72 |
| Basin11 | 362.2077 | 0.1 | 12:00 | 0.01 |
| | **DEM 30** | | | |
| **Sub basin** | **Drainage Area (KM$^2$)** | **Peak Discharge (M$^3$/S)** | **Time of Peak** | **Volume (MM)** |
| Basin1 | 290.817 | 1827.1 | 13:45 | 96.73 |
| Basin2 | 176.7141 | 773.3 | 14:30 | 83.54 |
| Basin3 | 211.6449 | 1854.0 | 12:45 | 84.92 |
| Basin4 | 175.6143 | 953.9 | 13:15 | 68.86 |
| Basin5 | 71.7606 | 622.8 | 13:00 | 97.29 |
| Basin6 | 176.9985 | 1463.0 | 13:00 | 94.48 |
| Basin7 | 187.4259 | 684.9 | 14:45 | 76.63 |
| Basin8 | 111.6531 | 683.9 | 13:30 | 88.65 |
| Basin9 | 169.74 | 89.4 | 18:45 | 20.62 |
| Basin10 | 457.362 | 509.1 | 18:15 | 40.48 |
| Basin11 | 290.1798 | 0 | 00:00 | 0 |
| | **DEM 12.5** | | | |
| **Sub basin** | **Drainage Area (KM$^2$)** | **Peak Discharge (M$^3$/S)** | **Time of Peak** | **Volume (MM)** |
| Basin1 | 291.143 | 1795.2 | 13:45 | 96.64 |
| Basin2 | 176.4781 | 772.2 | 14:30 | 83.44 |
| Basin3 | 211.5642 | 1780.5 | 12:45 | 84.54 |
| Basin4 | 175.5725 | 898.9 | 13:30 | 67.71 |
| Basin5 | 92.4642 | 723.4 | 13:15 | 94.91 |
| Basin6 | 154.125 | 1417 | 13:00 | 98.82 |
| Basin7 | 232.457 | 949.3 | 14:30 | 79.66 |
| Basin8 | 68.3189 | 411.1 | 13:45 | 88.31 |
| Basin9 | 158.4158 | 97.1 | 17:45 | 21.89 |
| Basin10 | 459.5961 | 526.5 | 18:00 | 40.78 |
| Basin11 | 283.5741 | 0 | 00:00 | 0 |

**Table 4.19:** Summary of runoff simulation for 25 years return period for all sub basin

| | DEM90 | | | |
|---|---|---|---|---|
| **Sub basin** | **Drainage Area ($KM^2$)** | **Peak Discharge ($M^3/S$)** | **Time of Peak** | **Volume (MM)** |
| Basin1 | 293.706 | 2134.2 | 13:45 | 113.29 |
| Basin2 | 180.9945 | 869.4 | 14:45 | 100.38 |
| Basin3 | 213.1434 | 2069.7 | 12:45 | 95.3 |
| Basin4 | 175.6809 | 961.1 | 13:15 | 72.18 |
| Basin5 | 92.4615 | 926.6 | 13:00 | 116.67 |
| Basin6 | 154.0377 | 1580.2 | 13:00 | 114.47 |
| Basin7 | 189.4914 | 840.2 | 14:45 | 93.48 |
| Basin8 | 112.0473 | 772.3 | 13:45 | 110.81 |
| Basin9 | 164.4381 | 101 | 19:30 | 25.58 |
| Basin10 | 394.1541 | 634.4 | 18:00 | 56.23 |
| Basin11 | 362.2077 | 0.4 | 12:00 | 0.03 |
| | **DEM 30** | | | |
| **Sub basin** | **Drainage Area ($KM^2$)** | **Peak Discharge ($M^3/S$)** | **Time of Peak** | **Volume (MM)** |
| Basin1 | 290.817 | 2128 | 13:45 | 113.36 |
| Basin2 | 176.7141 | 924.3 | 14:30 | 100.29 |
| Basin3 | 211.6449 | 826.5 | 08:45 | 94.75 |
| Basin4 | 175.6143 | 450.2 | 09:30 | 73.81 |
| Basin5 | 71.7606 | 746.2 | 13:00 | 117.37 |
| Basin6 | 176.9985 | 1739.1 | 13:00 | 113.1 |
| Basin7 | 187.4259 | 840.1 | 14:45 | 93.91 |
| Basin8 | 111.6531 | 857.8 | 13:30 | 111.8 |
| Basin9 | 169.74 | 109.9 | 18:30 | 25.05 |
| Basin10 | 457.362 | 624 | 18:15 | 49.26 |
| Basin11 | 290.1798 | 0 | 00:00 | 0 |
| | **DEM 12.5** | | | |
| **Sub basin** | **Drainage Area ($KM^2$)** | **Peak Discharge ($M^3/S$)** | **Time of Peak** | **Volume (MM)** |
| Basin1 | 291.143 | 2092.3 | 13:45 | 113.33 |
| Basin2 | 176.4781 | 922.5 | 14:30 | 100.11 |
| Basin3 | 211.5642 | 804.7 | 08:45 | 94.4 |
| Basin4 | 175.5725 | 433.7 | 09:30 | 72.57 |
| Basin5 | 92.4642 | 877.6 | 13:15 | 115.98 |
| Basin6 | 154.125 | 1646.1 | 12:45 | 115.57 |
| Basin7 | 232.457 | 1179.3 | 14:30 | 99.04 |
| Basin8 | 68.3189 | 501 | 13:30 | 108.1 |
| Basin9 | 158.4158 | 120.8 | 17:45 | 26.85 |
| Basin10 | 459.5961 | 385.8 | 15:45 | 49.3 |
| Basin11 | 283.5741 | 0 | 0.5 | 0 |

**Table 4.20:** Summary of runoff simulation for 50 years return period for all sub basin

According to above tables which show the summary of yearly average runoff simulation for different return periods for all sub basin differences between sub basin in simulated and runoff volume where the lowest runoff was related to sub basin number 9, 10, 11 while the peak discharge outputs have increased across other all sub basins. The percentage of variation for the runoff varied from 13.18 mm to 76.53 mm within runoff Simulation for 10 years return period, while the percentage of variation ranging from 20.62 mm to 98.82 mm within runoff Simulation for 25 years return period and from 25.05 mm to 115.98 mm within runoff Simulation for 50 years return period , it is noted that the sub-basin number 9 is the least value during three different periods, while the highest value variation among different sub basins 5 and 6 Figure 4.31 and 4.32.

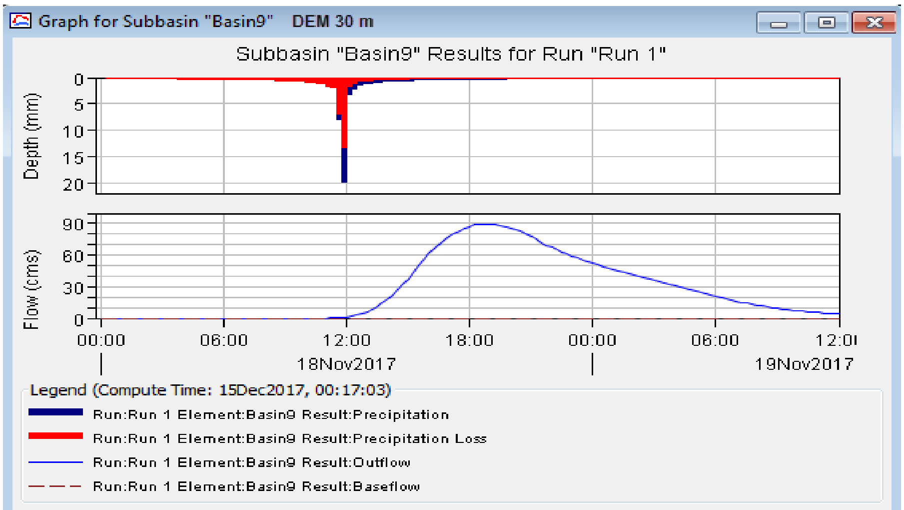



**Figure 4.31:** Hyetograph/Hydrograph of sub basin 9 within 25 years return period

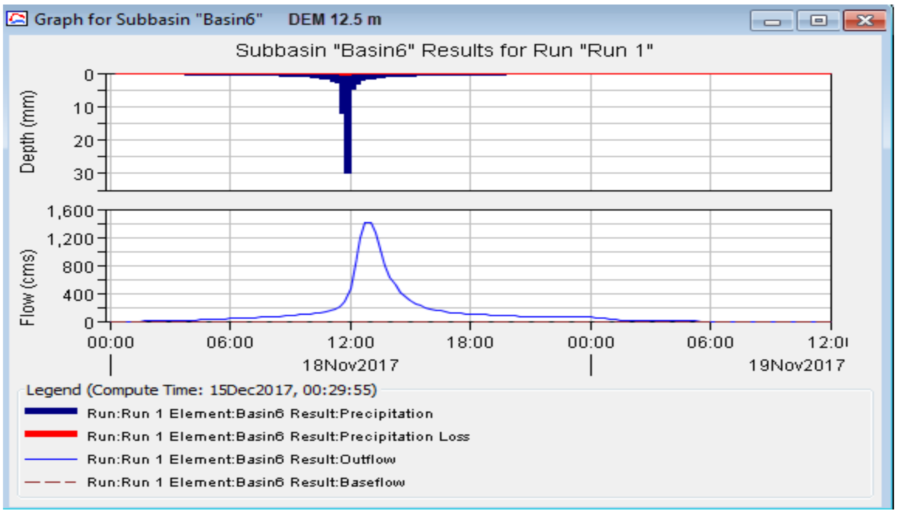



**Figure 4.32:** Hyetograph/Hydrograph of sub basin 6 within 25 years return period

In comparison the lowest and highest sub basins in runoff which are shown in the Table 4.21 that show values of 25 years return period as an example of comparison where sub basins 9 and 10 are lowest basins in runoff while sub basins 6 and 1 are the highest basins in the runoff.

| No of Sub basin | 25 Years Return Period | | | | | | |
|---|---|---|---|---|---|---|---|
| | Drainage Area ($KM^2$) | Basin length (Km) | Peak Discharge ($M^3/S$) | loss Volume (MM) | Run off Volume (MM) | SCS Lag(min) | CN |
| 9 | 158.41 | 27.14 | 97.1 | 51.45 | 21.89 | 5.09 | 74 |
| 10 | 459.59 | 39.62 | 526.5 | 38:00 | 40.78 | 5.46 | 79 |
| 1 | 291.143 | 34.44 | 1795.2 | 13.47 | 96.64 | 1.80 | 95 |
| 6 | 154.125 | 19.73 | 1417 | 11.33 | 98.82 | 1.01 | 96 |

**Table 4.21:** Summary of runoff simulation in lowest and highest sub basins

This discrepancy in simulated runoff between the four sub basins it can be observed that due to some reason that can be summarized in the effect of land use on excess runoff potential despite almost the same area for each sub basins 9 and 6 where we find that the low in CN value in sub basin 9 Influenced the runoff value and increased the loss volume, another reason in some physical features of the basin such as length of the basin affecting the hydrograph where a long drainage basin usually indicates a long runoff removal time this is shown in Figure 4.33 that the time of peak discharge to outlet of sub basin 9 up to 17:45 hr. while in outlet of sub basin no 1 up to 13:45 hr. which is longer than sub basin 9 this is due to the association of land use factor in addition to physical features of the basin.

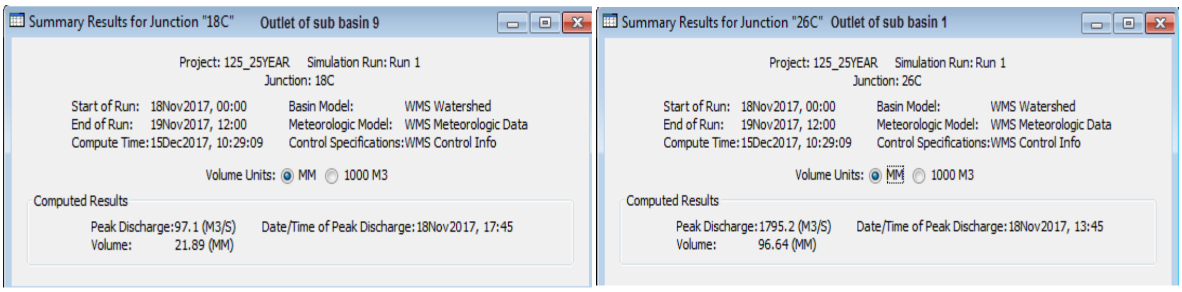
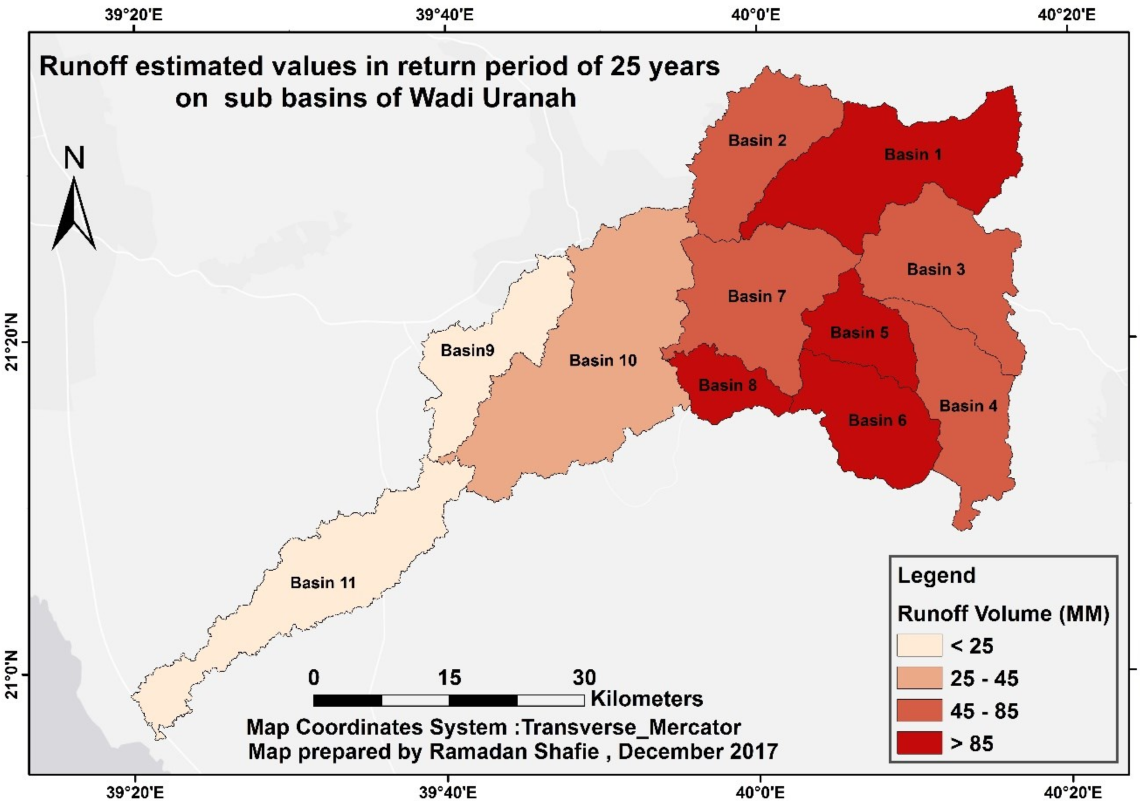



**Figure 4.33:** The time of peak discharge to outlet of sub basin 1 and 9

Whereas excess runoff in sub basins 6 and 1 shows the impact of Cn value where findingwas that intensity of peak values are increasing due to CN value up to 98 and therefore less in loss volume and infiltration.




**Map 4.12:** Runoff estimated values in return period of 25 years

Map 4.12 shown the estimate the surface runoff in return period of 25 years along the sub basins of Wadi Uranah which show the highest and lowest areas of Wadi Uranah in the runoff.

### 4.7.3 Effect of DEM Resolution on Runoff Simulation

In addition to the spatial and temporal characteristics of rainfall, there are some Factors affecting the runoff hydrograph which are related to the physical features of the basins such as drainage area, drainage density, drainage length, and as it was one of the objectives of this study was to assign a relationship between hydrology outputs 'surface runoff and DEM resolution and its impact on the basins characteristics that derived from it, this part to addressed and assessing this the relationship.

The most important factor affecting the magnitude of peak flows is the drainage area of a basin considering the effect of this factor in the study area and the effect of changing the basin area resulting from changing the DEM resolution used. As such, Sub basin No. 7 is the largest changing in the area between DEM resolutions used, according to the Table 4.22 that show all attributes for sub basin 7 regards to the runoff simulation results for same of sub basin that derived from different DEM resolution.

| DEM resolution | (Sub basin 7) Runoff Simulation of 25 Years Return Period | | | | | | |
|---|---|---|---|---|---|---|---|
| | Drainage Area ($KM^2$) | Peak Discharge ($M^3/s$) | Time of Peak(hr.) | loss Volume (MM) | Run off Volume (MM) | SCS Lag(min) | CN |
| 90 | 189.4914 | 684.3 | 15:00 | 38.53 | 76.10 | 169.33 | 85 |
| 30 | 187.4259 | 684.9 | 14:45 | 38:00 | 76:63 | 168.132 | 86 |
| 12.5 | 232.4570 | 949.3 | 14:30 | 34.97 | 79.66 | 152.904 | 87 |

**Table 4.22:** Summary of Runoff Simulation in Sub basin 7

The above table shows the difference in the basin area according to the DEM resolution used where the rate of change up to 7.3% and in view of the peak discharge value we found the rate of change up to 11.43% despite the same rainfall event. Thus, based on these results we can observe that a large drainage area led to a large peak flow and The drainage area is most sensitive to changes in DEM resolution, that affects the distribution of the time and value of peak discharge, so selecting an appropriate DEM resolution is particularly important when the rainfall event is of a short duration that will be particularly useful in simulating events on large watersheds. Below Figures 4.34, 35, 36 and 4.37 show the results of the hydrographs of sub basin 7.

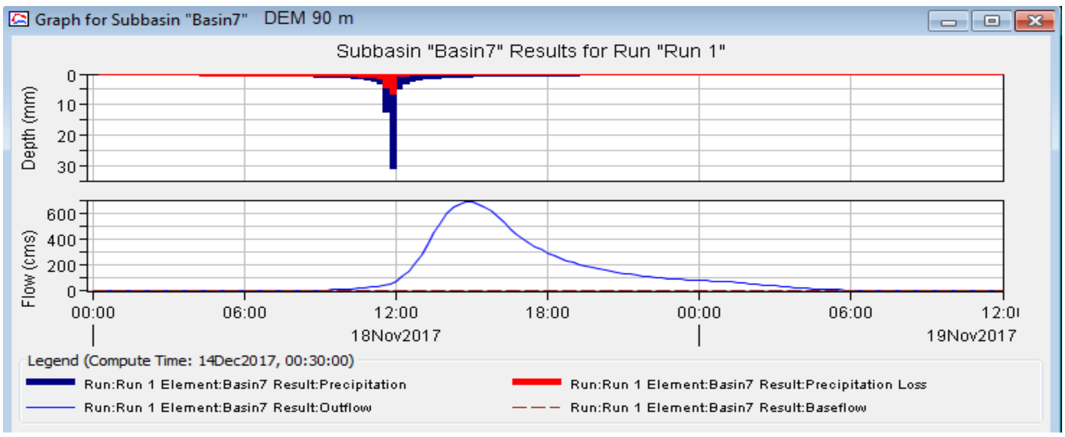



**Figure 4.34:** Hyetograph/Hydrograph for sub basin 7 that derived from DEM 90 m

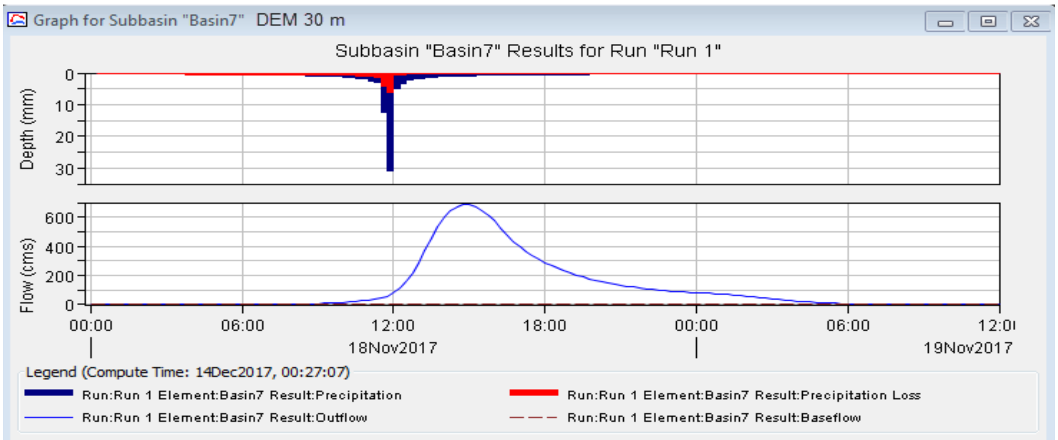



**Figure 4.35:** Hyetograph/Hydrograph for sub basin 7 that derived from DEM 30 m

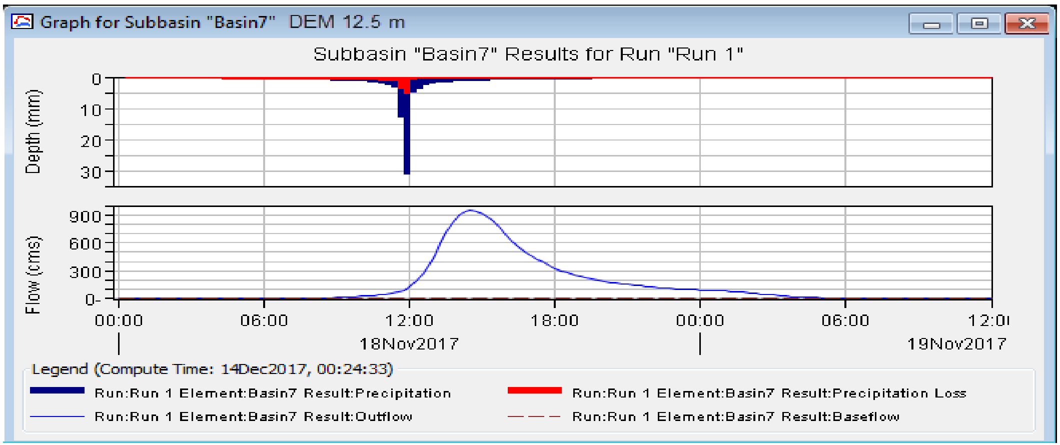



**Figure 4.36:** Hyetograph/Hydrograph for sub basin 7 that derived from DEM 12.5 m

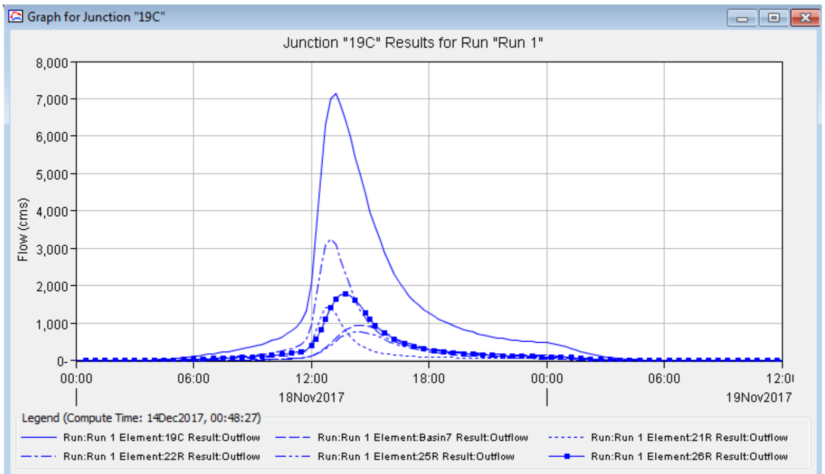



**Figure 4.37:** Result of outlet main for sub basin 7

The following table shows another example of the effect the area for same sub basin due used different DEM resolution on peak discharge which appears in the sub basin No. 10 that illustrates the complexity of many factors where changing the area influenced in the average of CN value for the same sub basin, As well as the length sub basin effect on the value of losses regardless of change in runoff Volume.

| DEM resolution | (Sub basin 10) Runoff Simulation of 25 Years Return Period | | | | | | |
|---|---|---|---|---|---|---|---|
| | **Drainage Area ($KM^2$)** | **Basin length (Km)** | **Peak Discharge ($M^3/S$)** | **Time of Peak(hr.)** | **loss Volume (MM)** | **Run off Volume (MM)** | **CN** |
| 90 | 394.1541 | 37.55 | 503.1 | 18:00 | 44.93 | 44.87 | 81 |
| 30 | 457.362 | 40.37 | 509.1 | 18:15 | 49.28 | 40.48 | 79 |
| 12.5 | 459.5961 | 39.62 | 526.5 | 18:00 | 49.03 | 40.78 | 79 |

**Table 4.23:** Summary of runoff simulation in sub basin 10

A summary of this chapter: This chapter presented and discussed the results from the watershed delineations using different DEM resolution .and compared the implications of spatial resolution of DEM on hydrologic modeling that there are several variables that impact on runoff estimation some of them related to the spatial and temporal characteristics of rainfall and others are related to the physical features of the basins that depend on the resolution of the digital elevation model (DEM). For example, the runoff volume estimated with each DEMs resolution that used in this study for the same sub basins which had the same the spatial and temporal characteristics of rainfall nevertheless, have different runoff volume estimated due to differences in the area of the same sub basin as a result of DEMs resolution that used.

# Chapter-5: Conclusions

This study addressed the issue of DEM resolution effects on the watershed characteristics and hydrological modeling and runoff by using three datasets of DEM 90, 30 and 12.5 meters for the study area, which were used to delineate the watershed of Wadi Uranah to investigate the relationship between variations in basin morphometric and rainfall characteristics and the responses of runoff. The results exhibit strong correlations between the basin parameters and the runoff indices, where the resolution of the DEM affecting the delineation of the watershed, which at the same time will affecting the runoff estimation.

Accordingly, were compared watersheds parameters that created from three different DEMs, the results of comparison showed that DEM resolution affects the watershed delineation and it is found that the mean slopes and the area and lengths of sub basins and stream network, discharge density decrease with coarser DEMs resolution. Where there found differences between the three sets of watersheds when compared their morphometric parameters especially in in flat areas in contrast in relief areas which is very clear in boundary of the basin which was not identical in flat areas conversely in relief areas which resulted in a difference in the basin area up to 0.4% in the main basin but it is increasing in sub basin where the percentage of difference up to 65%, 72% in sub basin no.10 and no.11 respectively.

Whereas there are a variety factors of affecting in runoff including the physical factor that depends on the resolution of the DEM, A hydrologic modeling of Wadi Uranah was must be conducted based on the three watersheds of Wadi Uranah that derived from different DEM to represent impact of DEM resolution on simulated runoff. The HEC-HMS hydrological modeling has been used to predict and simulate runoff events for different return period. Were three hydrologic models were created for the same sub basins, where that the sub basins have same spatial and temporal characteristics of rainfall but the physical features of the sub basins changing with change the resolution DEM.

The runoff volume estimated with all DEMs of the sub basin was compared, where simulation results over different years return period showed that the higher runoff volume has found in the sub basin number 1 and 6. While the discrepancy in a simulated runoff in the tow sub basin 7 and 10 due to the difference in the basin area according to the DEM resolution used where the rate of differencing 11.43% despite the same rainfall event. Thus, the drainage area is most sensitive to changes in DEM resolution that affects the distribution of the time and value of peak discharge.

Accordingly, the results would not be ideal when used one of the less accurate sets of watersheds were used in a hydrologic model especially in the flat areas so the accurate input data is essential To give a better picture of the hydrologic process modeling. The results from DEM 30 meters much closer to the observed data than DEM 12.5 meters which did not produce significantly different runoff simulations. However, it will likely be used DEM 12.5 as the best available elevation data for free.

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