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# Application of Remote Sensing and GIS in Geomorphology and Flash Flood Hazard (Case study of Wadi Namera, Jordan)

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**Abstract**

Flash floods are considered as catastrophic phenomena possessing major hazardous threat to many of infrastructure facilities, especially new construction projects in Jordan. This study deals with the evaluation of flash flood hazard in the ungauged Wadi Namera basin depending on its detailed morphometric characteristics, geomorphological studies, meteorological Analysis, and hydrological modeling. For this study, ASTER data were used for preparing digital elevation model (DEM), geographical information system (GIS) was used in the evaluation of linear, areal and relief aspects of morphometric parameters, Remote sensing data (Landsat8) to analysis and preparing Digital Land Use/ Land cover mapping, using some special software for rainfall analysis and estimating IDF curves and finally using WMS and HES-RAS for Hydrological analysis and hydraulic modeling. Thus can predict the probability occurrence of floods at various frequency times and determine the intensity of the flood (depth and velocity of flood water) inside the stream of the Wadi, and in case of important construction exposed to the risk of floods must to develop optimal solutions that control of flood waters and through the establishment of different protection works such as dams and storage lakes and drainage channels and culvert ... and other. So it was important to make sufficient hydrological studies to safety this sites of the Probabilities dangers of flooding.

**Keywords:** Wadi Namera, GIS, Rs, morphometric analysis, Hydrological analysis, hydraulic modeling.

## 1 INTRODUCTION

Many of infrastructure facilities affected, especially new construction projects in Jordan by rainfall water and floods flash which has badly damaged in facilities built infrastructure established in those areas, and as a result of rainfall frequency and resulting from floods on a regular basis due to the different temporal distribution and spatial rainfall and also due to the different times frequency rain storms moving from area to another. The hydrological study of the Wadi Nemera in Al Karak, include rainfall and floods data analysis and to identify the different characteristics of geological and geo-morphological, and thus can predict the probability occurrence of floods at various frequency times and determine the intensity of the flood (depth and velocity of flood water) inside the stream of wadi, and in case of important construction exposed to the risk of floods must to develop optimal solutions that control of flood waters and through the establishment of different protection works such as dams and storage lakes and drainage channels and culvert ... and other. So it was important to make sufficient hydrological studies to safety this sites of the Probabilities dangers of flooding. Flood hazard mapping is very important for catchment management (i.e. for sustainable development of the water resources and for protection from the flood hazard and drought). Rainfall and runoff data are the essential hydrological elements in the flood mapping of basin systems. So, because the study area is suffering from scarcity of data and the flood inundation maps are dependent on the topographic and geomorphic features of the Wadi (Şen et al. 2012), this study is based on the integration between physiographic features of the study area and GIS techniques. The integration of GIS to create flood hazard maps and disaster decision support has been continually upgraded and widespread since the beginning of the twenty-first century, as a result of the increased availability of spatial databases and GIS software (Zerger and Smith 2003). Several studies are cited in the literature, relating to flood hazard mapping and zonation using GIS (Sui and Maggio 1999; Merzi and Aktas 2000; Guzzetti, and Tonelli 2004; Sanyal and Lu 2006; He et al. 2003; Fernandez and Lutz 2010). Drainage basin characteristics in many areas of the world have been studied using conventional geomorphologic approaches (Horton 1945; Strahler 1964; Rudriaih et al. 2008; Nageswararao et al. 2010; Al Saud 2009). Gardiner (1990) indicated that in some studies, the morphometric characteristics of basins have been used to predict and describe flood peaks and estimation of erosion rate, underlying the importance of such studies. The application of geomorphological principles to flood potential or flood risk has led to a noteworthy number of researches, attempting to identify the relationships between basin morphometric and flooding impact (Patton 1988). Identification of drainage networks within basins or subbasins can be achieved using traditional methods such as field observations and topographic maps, or alternatively with advanced methods using remote sensing and digital elevation model (Macka 2001; Maidment 2002).

### 1.1 LOCATION

The Wadi Namera is located in the western part of Jordan at Al Karak City. It lies between 35.5and 35.7 longitudes and 31 and 31.1 latitudes with an area about 99 km$^2$ and length about 20 km.

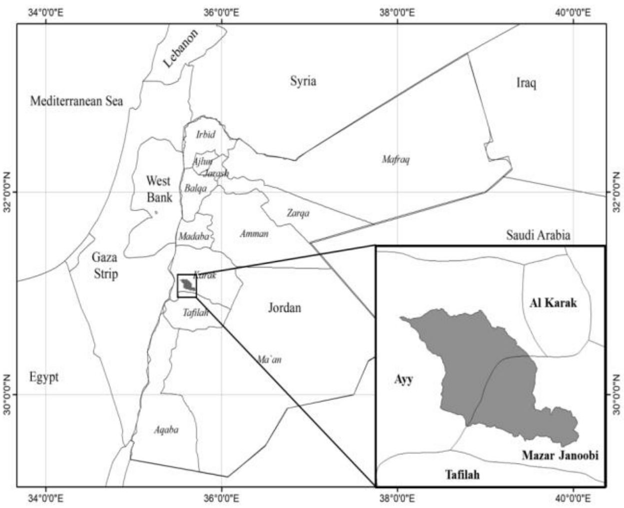


**Figure 1:** Location of Wadi Namera.

## 1.2 METHODOLOGY

The Developed of method and research manners in the field of floods risk in accordance with the data sources in technique of remote sensing (RS) and geographic information systems (GIS), as well as mathematical and statistical methods and software mechanism to build geographic databases, and the study depends on methodology of science of geographic information systems (GIS) and science of remote sensing (RS), and their method in the analysis and modeling of natural risks and areas threatened by flooding. Figure 2 shows a schematic representation of the proposed model along with different input, output, and processing elements. The first step is obtained a Digital Elevation Model (DEM) from ALOS Global Digital Surface Model "ALOS World 3D - 30m (AW3D30) figure 3 & figure 4.

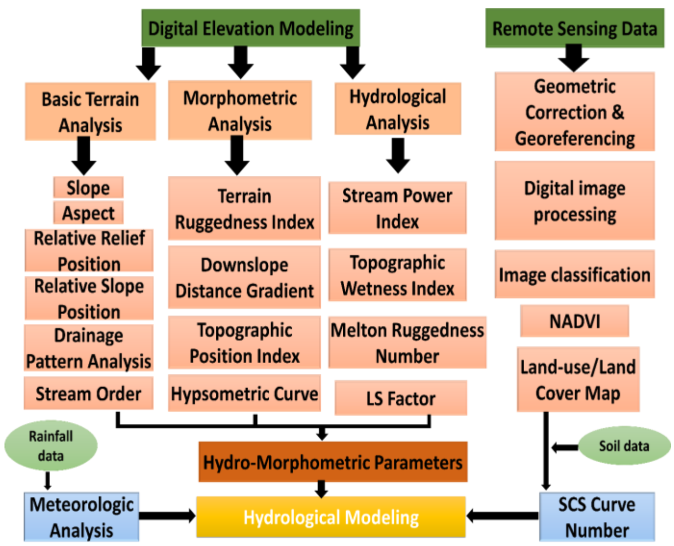


**Figure 2:** Flow chart of the hydrological model for Wadi Namera.

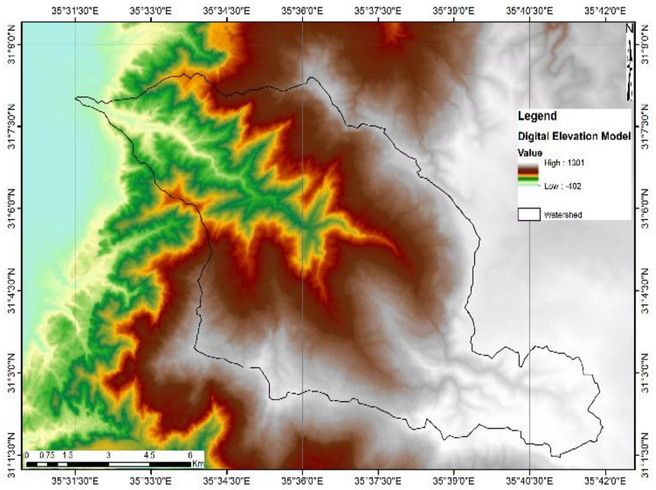


**Figure 3:** Digital Elevation Model from ALOS 3D DEM scene.

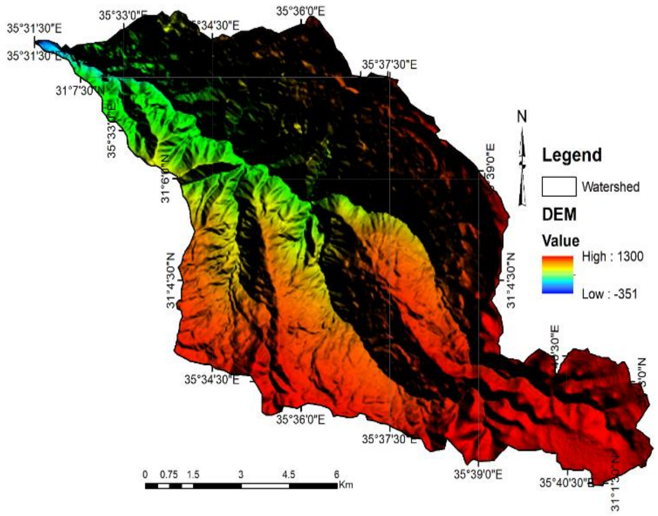


**Figure 4:** Hillshaded Digital Elevation Model of Wadi Namera cropped from from ALOS 3D DEM scene.

## 1.3 TOPOGRAPHICAL & GEOLOGICAL CHARACTERISTICS OF THE BASIN

Topography of the basin area is moderate to high relief, with hilly and rugged terrains, where the elevations range from -350 m to 1300 m above sea level as seen from DEM figure 4.

The surface geology of the area is mainly characterized by the outcropping of Sandstone of Tubyllite, Umm Ishrine, karstified, fractured limestone of the Wadi As Sir and Nau'r Formation (Figure 5); the exposures of this unit are prominent along the slopes and hill slopes in the site area.

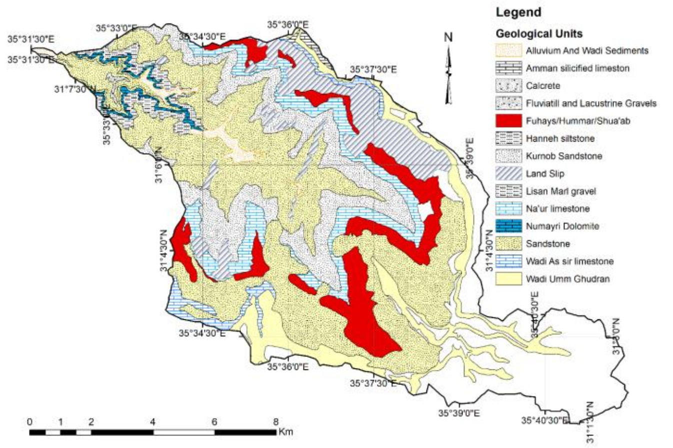


**Figure 5:** Geological map of the Wadi Namera Basin.

## 2 BASIC TERRAIN ANALYSIS

The Digital Elevation Model of the basin area has been used to derive the basic terrain analysis as Basin Slope, Aspect, Relative Relief Position, Down slope Distance Gradient and The Terrain Ruggedness Index.

### 1.1 SLOPE

Slope analysis is an important parameter in geomorphological studies for watershed development and important for morphometric analysis (Magesh et al. 2011; Gayen et al. 2013). A slope map of the study area is calculated using the spatial analysis tool in ARC GIS-10.7. The degree of slope in "Wadi Namera" watershed varies from 0˚ to 66˚.

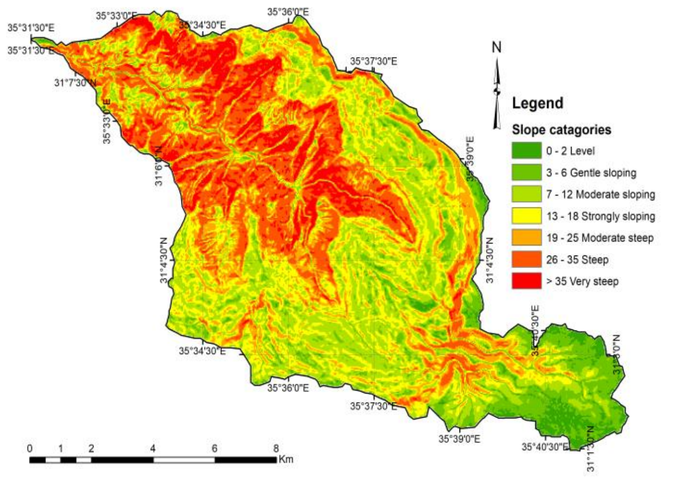


**Figure 6:** Slope map of the Wadi Namera Basin.

The slope map is shown in figure 6. Has higher slope degree results in rapid runoff and increased erosion rate (potential soil loss) with less ground water recharge potential. Higher slope is identified in North-western part of the basin where it originates.

### 1.2 ASPECT

The aspect of a slope can make very significant influences on its local climate because the sun's rays are in the west at the hottest time of day in the afternoon, and so in most cases a west-facing slope will be warmer than sheltered east-facing slope. This can have major effects on the distribution of vegetation in the watershed area. The aspect map of "Wadi Namera" basin is shown. It is clearly seen that west-facing slopes mainly occur in the basin. Therefore, these slopes have a lower moisture content and higher evaporation rate although and some parts are falling towards east facing which a higher moisture content and have a lower evaporation rate.

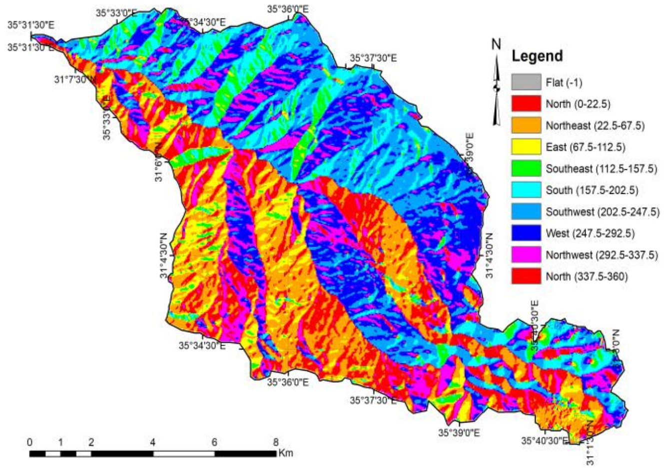


**Figure 7:** Aspect map of the Wadi Namera Basin.

### 1.3 RELATIVE RELIEF

Relative relief is difference in height between the highest altitude for a given area, and base level, lowest altitude for a given area (Dury, 1962, p. 174). It plays an important morphometric variable used for the assessment of morphological characteristics of any topography (Gayen et al. 2013. The highest relative relief is calculated as 528 m, while the lowest value is recorded as 0.6 m figure 8. Almost the most of the basin area is moderately high relative relief.

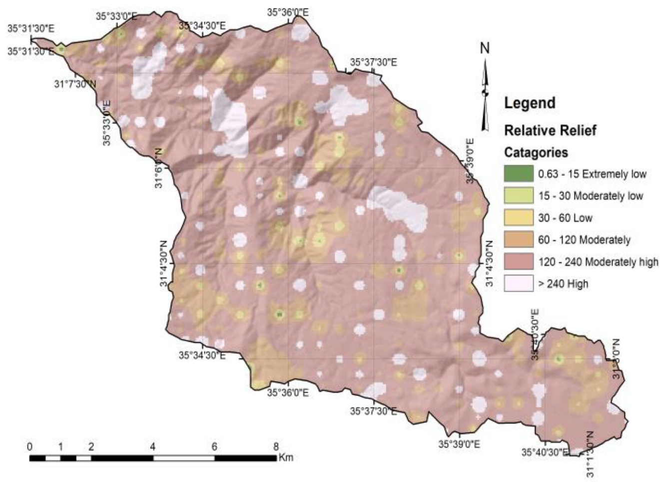


**Figure 8:** Relative relief map of the Wadi Namera Basin.

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### 1.4 DOWNSLOPE DISTANCE GRADIENT

This index has become widely used in hydrology, but it utilizes a relatively small portion of the information contained in a digital elevation model (DEM). One potentially important feature not considered in the implementation of the ln(a/tanß) index is the enhancement or impedance of local drainage by downslope topography. This effect could be important in some terrain for controlling hydraulic gradients (K. N. Hjerdt, et.al 2004).

Applied this index to our study Area shows high values at the Western part of the basin and minor sites in the Northern and eastern parts which refer to high local drainage areas that feeding the main stream of the Basin (Figure 9).

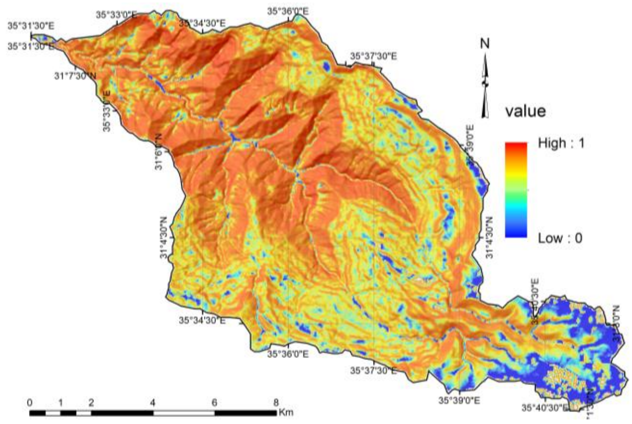


**Figure 9:** Down slope distance gradient map of the Wadi Namera Basin.

### 1.5 THE TERRAIN RUGGEDNESS INDEX (TRI)

The terrain ruggedness index (TRI) is a measurement developed by Riley, et al. (1999) to express the amount of elevation difference between adjacent cells of a digital elevation grid (Figure 10).

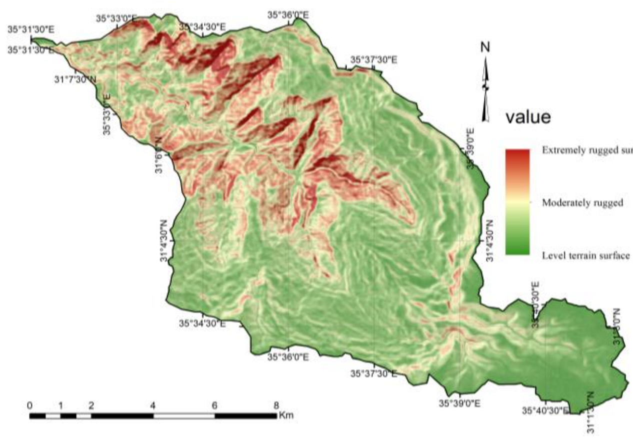


**Figure 10:** The terrain ruggedness index (TRI) map of the Wadi Namera Basin.

### 1.6 RELATIVE SLOPE POSITION

Landscapes can be classified into discrete slope position classes, Jones, K. Bruce et al 2000.

- ridge > + 1
- upper slope > 0.5 =< 1
- middle slope> -0.5, < 0.5, slope > 5 deg
- flats slope >= -0.5, =< 0.5 , slope <= 5 deg
- lower slopes >= -1.0, < 0.5
- valleys < -1.0

The major of the Basin Area is middle slope and upper Slope delineated at East and West of the basin. There relationships between soil moisture content and a relative slope position (upslope, midslope, and downslope) were qualitatively understandable even in the early twentieth century (Zakharov, 1913). Quantitatively, the dependence of soil moisture content on catchment area (which, in fact, describes the relative position of a point on the topographic surface) was probably first described by Zakharov (1940, p. 384) as follows: “water amount per unit area increases from upslope to down slope due to additional water supply.” Thus, as CA increases, soil moisture content also increases.

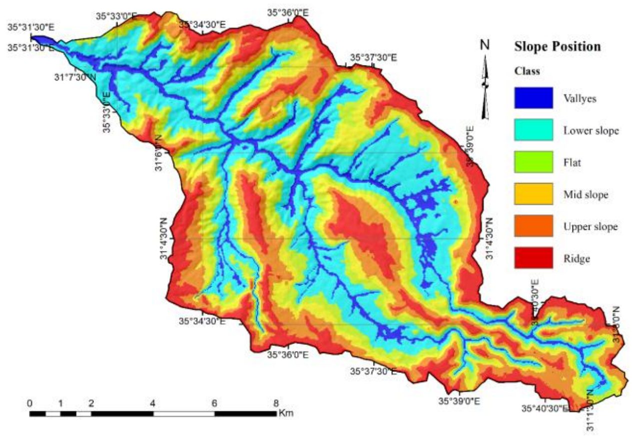


**Figure 11:** The Relative slope position map of the Wadi Namera Basin.

### 1.7 HYPSOMETRIC CURVE

Hypsometric curves are non-dimensional measure of the proportion of the catchment area above a given elevation. According to Schumm (1956), Strahler (1964), Leopold et al. (1964) and Hurtrez et al. (1999), hypsometric curves are related to geomorphic and tectonic evolution of drainage basins in terms of their forms and processes.

The curve is created by plotting the proportion of total basin height against the proportion of total basin area. The slightly Curved (S-Shaped) Convex hypsometric curves characterize the less eroded and youngest basin while the deeply eroded and oldest basin shows highly curved s-shaped curve as seen in the shape.

The estimated hypsometric curve of the basin showing that the basin is young and slightly eroded (figure 12)

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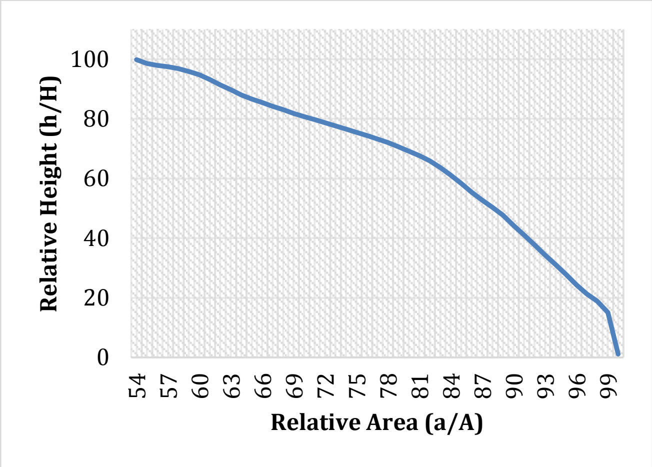
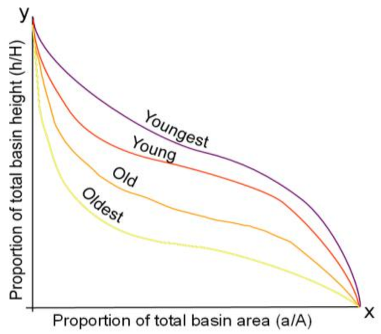



**Figure 12:** Hypsometric curve of the Wadi Namera Basin.




## 3 HYDROLOGICAL ANALYSIS & MORPHOMETRIC PARAMETERS

### 1.8 HYDROLOGICAL ANALYSIS

Hydrological analysis is based on a digital elevation model (DEM) raster data to establish a water system model, which is used to study the hydrological characteristics and simulation of surface hydrological process.

Hydrological analysis contains filling sinks, calculating flow direction, calculating flow accumulation and Catchment drainage map (figure 13).

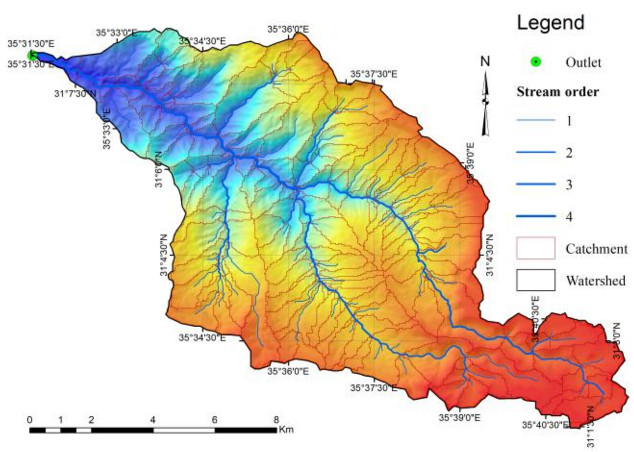



**Figure 13:** Catchment drainage map of the Wadi Namera Basin.

#### 1.8.1 Stream Order

The ranking of streams has been carried out based on the method proposed by Strahler (1964). stream orders are classified up to four orders in the “Wadi Namera” Basin. The maximum stream order frequency is observed in case of first-order streams and then for second order. Hence, it is noticed that there is a decrease in stream frequency as the stream order increases and vice versa.

#### 1.8.2 Stream Number

Number of streams of different orders and the total number of streams in the basin are counted and calculated in GIS platforms. During calculation it is identified that the number of streams gradually decreases as the stream order increases; the variation in stream order and size of tributary basins is largely depends on physiographical, geomorphological and geological condition of the region. 85 stream line is recognized in the whole basin, out of which 40 % (68) is 1st order, 30 % (13) 2nd order, 20 % (3) 3rd order, 10 % (1) 4th order. (Table 1).

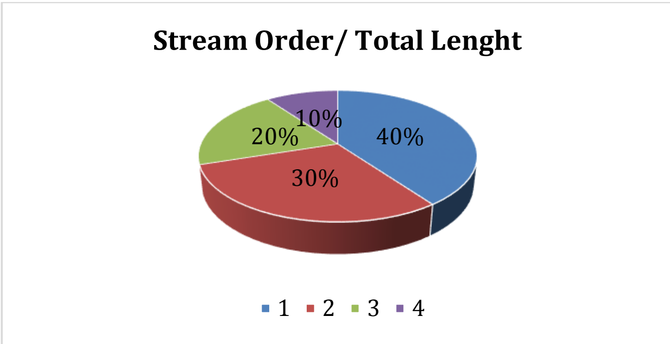



**Figure 14:** 2D Pie graph showing the percentage of the stream orders to their total length of the Wadi Namera Basin.

**Table 1:** Stream Characteristics and Bifurcation ratio

| Stream Order | Nu Stream Order | Stream Order Length | Stream Length Ratio | Mean Stream Length | Bifurcation ratio (Rb). |
|---|---|---|---|---|---|
| **4** | 1 | 9.874 | 0.094321959 | 9.874 | 3 |
| **3** | 3 | 19.37 | 0.185033052 | 6.456666667 | 4.333333333 |
| **2** | 13 | 19.44 | 0.185701731 | 1.495384615 | 5.230769231 |
| **1** | 68 | 56 | 0.534943258 | 0.823529412 | |
| **10** | **85** | **104.684** | **Total** | | |

#### 1.8.3 Stream Length (Lu)

The stream length is a measure of the hydrological characteristics of the bedrock and the drainage extent. Wherever the bedrock and formation is permeable, only a small number of relatively longer streams are formed in a well-drained watershed, a large number of streams of smaller length are developed where the bedrocks and formations are less permeable (Sethupathi et al. 2011). The result of order stream length in Wadi Namera basin is shown in the Table 1.

It is clearly identified that the cumulative stream length is higher in first-order streams and decreases as the stream order increases.

### 1.8.4 Mean Stream length (Lsm)

Mean stream length (Lsm) reveals the characteristic size of components of a drainage network and its contributing surfaces (Strahler 1964). It has been computed by dividing the total stream length of order 'u' by the number of streams in the same order u. It is noted that Lsm value of any stream order is greater than that of the lower order and less than that of its next higher order in the basin as shown in table 1.

### 1.8.5 Bifurcation ratio (Rb)

According to Schumn (1956), RB is a dimensionless parameter as the ratio of the number of the streams of a given order ($N_u$) to the number of streams of the next higher order ($N_{u+1}$). Which showing the degree of integration between streams of various orders in a drainage basin. Chorley (1969) had noted that the lower the bifurcation ratio, the higher the risk of flooding, particularly of parts and not the entire basin. The bifurcation ratios of the study area vary from 3.0 to 5.2, which indicates that the geologic structures do not distort the drainage pattern. The higher values of Bifurcation ratio indicate strong structural control in drainage pattern while the lower values of Rb are characteristics that the basin has suffered less structural disturbances (Dwivedi, 2011).

The mean bifurcation ratio is 4.1 of the Wadi Namera Basin, which indicates that geological structures are less distortion the drainage pattern.

## 1.9 MORPHOMETRIC PARAMETERS

The morphometric analysis of a watershed indirectly reflects hydrogeological status of the watershed. The watershed area is probably the most important basin parameter for hydrologic design which reflects volume of water that can be generated from the rainfall.

The Wadi Namera basin parameters such as area, perimeter, basin length drainage density, drainage texture, stream frequency, relief ratio, form factor, elongation ratio, circularity ratio, length of overland flow are the most common morphometric parameters are presented in Table 2. All the values were extracted from the basin using the calculate geometry tool available in ArcGIS 10.7.

**Table 2:** Computation of basic, linear, shape, and relief morphometric parameters.

| S. No. | Parameter | Parameter | Value |
|---|---|---|---|
| **1** | Basic | Watershed area (Km) | 99.29 |
| **2** | | Length of watershed (km) | 20 |
| **3** | | Perimeter (Km) | 57 |
| **4** | Linear | Drainage density (Dd) (km/km$^2$) | 1.05 |
| **5** | | Stream frequency (Fs) (no./km$^2$) | 0.86 |
| **6** | | Drainage Texture Ratio (T) (no./km$^2$) | 1.84 |
| **7** | | Length of Overland Flow (Lo) (km) | 0.52 |
| **8** | | Infiltration Number (FN) | 0.9 |
| **9** | | Constant of channel maintenance (C) | 0.95 |
| **10** | Relief | Ruggedness number (Rn) | 1.74 |
| **11** | | Relative Relief (Bh) | 1651 |
| **12** | | Relief Ratio (Rh) | 0.083 |
| **13** | | Average slope (S) | 0.83 |
| **14** | Shape | Form Factor (Rf) | 0.25 |
| **15** | | Basin shape (Bs) | 4.02 |
| **16** | | Circularity ratio (Rc) | 0.38 |
| **17** | | Elongation ratio (Re) | 0.56 |
| **18** | | Compactness Coefficient (Cc) | 1.61 |

### 1.9.1 Drainage density (Dd)

Drainage density (Dd) is a measure the total stream length in a given basin to the total area of the basin (Strahler 1964). The lower drainage density of the Wadi Namera basin is 1.05 km/km$^2$, which indicates that basin area has a highly permeable subsurface material with highly drainage, high relief, good vegetation, and low roughness, and the opposite conditions produce high Dd. Low drainage density leads to coarse drainage texture while high drainage density leads to fine drainage texture, high runoff and erosion potential of the basin area. (Strahler 1964).

### 1.9.2 The stream frequency (Fs)

Stream frequency (Fs) is ratio the total number of streams of all orders per unit area (Horton 1932). The stream frequency of the Wadi Namera basin is 0.86 km/ km$^2$ which shows a low value that indicates sparse drainage network favoring groundwater recharge.

### 1.9.3 Drainage Texture (T)

Drainage texture is the total number of stream segments of all orders per perimeter of that area (R.E. Horton,1945). The drainage texture depends upon a number of natural factors such as rainfall, vegetation, climate, rock and soil type, infiltration capacity, relief and stage of development (K.G. Smith,1950). According to Smith, drainage texture is classified into four levels: rough (less than 4), moderate (4–10), soft (more than 10), and ultra-soft (or highland topography) (more than 15). According this classification the basin has a drainage texture of 1.84 which indicates the rough drainage texture.

Similarly, the low drainage texture and low value of drainage density indicates the presence of high permeable material with high relief (limestone and Sandstone).

### 1.9.4 Constant of Channel Maintenance (C)

Schumm (1956) used the inverse of drainage density as a property termed constant of stream maintenance C. This constant, is an indicator reflects infiltration and the control of flow to the basin outlet. The value C of basin is 0.95 which means that on an average 0.95 sq.m surface is needed in basin for creation of one linear meter of the stream channel.

### 1.9.5 Length of Overland Flow (Lo)

The flow length is the distance from any point in the watershed to the watershed outlet, and is one of the most important independent variables affecting both hydrologic and physiographic development of drainage basins This factor is lower for steeper slopes and higher for more mild slopes. Lo = ½ Dd. Lo= 0.52.

### 1.9.6 Infiltration Number (If)

Infiltration number of a drainage basin is the product of drainage density and stream frequency. Wadi Namera basin has the infiltration number of 0.9. The higher the infiltration number, the lower will be the infiltration and higher will be the run-off (Rao Liaqat et.al., 2011)

### 1.9.7 Elongation Ratio (Re)

The elongation ratio (Re) is the ratio between the diameter of the circle of the same area as the drainage basin and the maximum length of the basin Schumm (1956). Higher values of elongation ratio show high infiltration capacity and low runoff, whereas lower Re values which are characterized by high susceptibility to erosion and sediment load (Reddy et al. 2004). The values can be categories as circular (>0.9), oval (0.9–0.8) and less elongated (<0.7). Values close to 1.0 are typical of region of very low relief, whereas values of 0.6–0.8 are usually associated with high relief and steep ground slope (Strahler 1964). The Basin shows Re value of 0.56 which falls in the less elongated class. This reveals that the majority of the area has high relief and steep sloped.

### 1.9.8 Circularity Ratio (Rc)

Circularity ratio is a dimensionless value that expresses the degree of circularity of the basin. Rc is estimated by the ratio of the basin area to the area of a circle having the same circumference perimeter as the basin Miller's (1953). It is related by several basin characteristics such as the length and frequency of stream, geological structures, landuse / landcover, climate, relief and slope of the basin. High Rc indicates a circular basin with moderate to high roughness, high infiltration, less elongated, lower roughness, and low infiltration. The Circularity Ratio of the basin is 0.38 which indicates strongly elongated and extremely permeable homogenous geologic materials.

### 1.9.9 Form Factor (Rf)

Horton (1932) stated that the form factor Rf is a dimensionless ratio of basin area (A) to the square of basin length (L). The value of form factor should be always be less than 0.7854 (this value corresponding to a perfectly circular basin). The smaller the value of the form factor, more elongated will be the basin. Watersheds with high form factors experience larger peak flows of shorter duration, indicating less contact time and less infiltration. Rf value of the Wadi Namera basin is 0.25 which is more elongated basin with lower peak flows of longer duration than the average. Flood flows of such elongated basins are easier to manage.

### 1.9.10 Basin shape (Bs)

Basin shape or shape factor is estimated by the ratio of square of basin length ($L^2$) to the area of the basin Horton (1932) The shape factor for Wadi Namera basin is 4.02.

### 1.9.11 Compactness Coefficient (Cc)

It is the ratio between basin perimeters to the perimeter of a circle to the same area of the watershed (Horton, 1945). The Cc is directly linked to infiltration capacity. The highest value 1.61 of the Wadi Namera basin indicates that the surfaces have high permeability.

### 1.9.12 Basin Relief (Bh)

Basin relief is the difference in elevation between the highest and lowest points in the basin. The high relief value indicates high gravity of water flow, low permeable and high runoff conditions. Hadley and Schumm (1961) showed that sediment load increases exponentially with basin relief. The high relief value indicates high gravity of water flow, low permeable and high runoff conditions. The highest point of the studied basin is 1300 and the lowest point is -351 meters. Thus, the basin relief interval for the studied area is 1651 meters.

### 1.9.13 Relief Ratio (Rh)

Schumm (1956) states that the Rh is the ratio between the basin relief and basin length. The high value of relief ratio of the Wadi Namera basin is 0.083 is characteristics of hilly areas with high runoff production and soil erosion which reflects the highly permeable of sedimentary rocks of the basin and high degree of slopes.

### 1.9.14 Average Slope (S)

Gradient ratio or Average slope it is computed by the ratio of difference between upstream and pour point elevation of major stream of basin to maximum length of major stream of that basin. It plays a vital role for estimating flood hazardous where steep slopes could lead to severe flash floods. Velocity of water increases with increasing slopes; this means time required for water decrease. So, hazard increases with increasing slope. The high gradient ratio of wadi Namera basin is 0.83 m/km, which indicates steep slope and high runoff.

### 1.9.15 Ruggedness Number (Rn)

Strahler's (1958) states that ruggedness number is the product of the basin relief and the drainage density. This parameter reflects the geometrical characteristics of the basin. The high Ruggedness number of Wadi Namera basin is 1.74, which indicates increasing in erosivity of the basin.

## 2 METEOROLOGICAL ANALYSIS

Rainfall is an important climatological factor. It is important to analyze the rainfall data for estimating the probability of flash flooding and its duration frequency, in addition for cropping and agriculture. Rainfall intensities of various frequencies and durations are the basic inputs in hydrologic design, and they are the main effective factor on flood formation. They are used, for example, in the design of storm sewers, culverts and many other structures as well as inputs to rainfall-runoff models. Precipitation frequency analysis is used to estimate rainfall depth at a point for a specified exceedance probability and duration.

## 2.1 FREQUENCY ANALYSIS OF MAXIMUM DAILY RAINFALL:

The precise amounts of rainfall on the basin, the most important factors that help flood accruing from these rains accounts accurately, as is the right foundation for the statistics of water and the potential for recurrence of floods, and contributes to the distribution of rainfall measurement and floods properly stations, to provide reliable information which covers the entire region and lead to avoid errors in the readings or in the registry between stations, is the depth of the rain (Rainfall Intensity) is the main factor affecting the composition of the floods, which must be taken into consideration when planning the construction and development projects. Through the available information on stations around the study area and around the water basins.

In poorly gauged regions, rainfall data are often short or even absent. The availability rainfall data are collected from the nearest metrological station (Karak Station) from Jordanian Meteorological Department. Which the annual rain over the area for a period extending from 1963 to 2014 (table 3 & 4) for being the nearest rain gauge of the study area stations, it has been possible to extract the values of the rain periods frequency depth (3, 5,10,20,50,100 years) where it was a statistical analysis of the maximum values of the rain and daily use of various probability distributions and tested for rain value at different return periods, by using statistical analysis software (hyfran) and apply different statistical distributions. Six methods of frequency distribution widely used in metrological analysis have been used to represent the maximum annual series.

By applied various probability distributions for annual rainfall data precipitation at the station using Normal, Log-Normal, Log-Pearson Type III, Pearson Type III, Gumbel and Exponential methods figures (15,16,17,18,19,20) and thus was used to make a probabilistic analysis to determine the values of rain depth for different return periods table (table 5).

To choose between tested distributions, the Akaike Information Criterion (AIC), and Bayesian Information Criterion (BIC) can be used. Both criteria are based on the deviation between the fitted distribution and the empirical probability with a penalization that is function of the number of parameters of the distribution and the sample size. The distribution having the smallest BIC and AIC is the one that best fits the data. The Pearson type 3 (Maximum Likelihood) distribution has shown to be the strongest fitting distribution as shown in the table (6).

**Table 3:** The Annual maximum rainfall Meteorological Station Karak station type code 6.

| Year | Annual maximum rainfall | Year | Annual maximum rainfall |
|---|---|---|---|
| **1963** | 70 | **1989** | 55 |
| **1964** | 30 | **1990** | 60 |
| **1965** | 100 | **1991** | 125 |
| **1966** | 55 | **1992** | 53.5 |
| **1967** | 40 | **1993** | 55.5 |
| **1968** | 40 | **1994** | 80 |
| **1969** | 37 | **1995** | 40 |
| **1970** | 56 | **1996** | 41 |
| **1971** | 115 | **1997** | 39 |
| **1972** | 60 | **1998** | 49 |
| **1973** | 40 | **1999** | 53 |
| **1974** | 85 | **2000** | 44 |
| **1975** | 62 | **2001** | 28 |
| **1976** | 42 | **2002** | 79 |
| **1977** | 40 | **2003** | 33 |
| **1978** | 32 | **2004** | 80 |
| **1979** | 84 | **2005** | 42 |
| **1980** | 140 | **2006** | 73 |
| **1981** | 52.5 | **2007** | 64 |
| **1982** | 47.5 | **2008** | 35 |
| **1983** | 98.8 | **2009** | 51 |
| **1984** | 46 | **2010** | 131 |
| **1985** | 84.5 | **2011** | 31 |
| **1986** | 39.8 | **2012** | 62.5 |
| **1987** | 54 | **2013** | 72 |
| **1988** | 61.4 | **2014** | 68.6 |

**Table 4:** Summary of Basic statistics and annual record data chart rainfall of Karak meteorological station.

| Basic statistics | |
|---|---|
| Number of observations | 52 |
| Minimum | 28 |
| Maximum | 140 |
| Mean | 60.7 |
| Standard deviation | 26.4 |
| Median | 54.5 |
| Coefficient of variation (Cv) | 0.435 |
| Skewness coefficient (Cs) | 1.31 |
| Kurtosis coefficient (Ck) | 4.03 |

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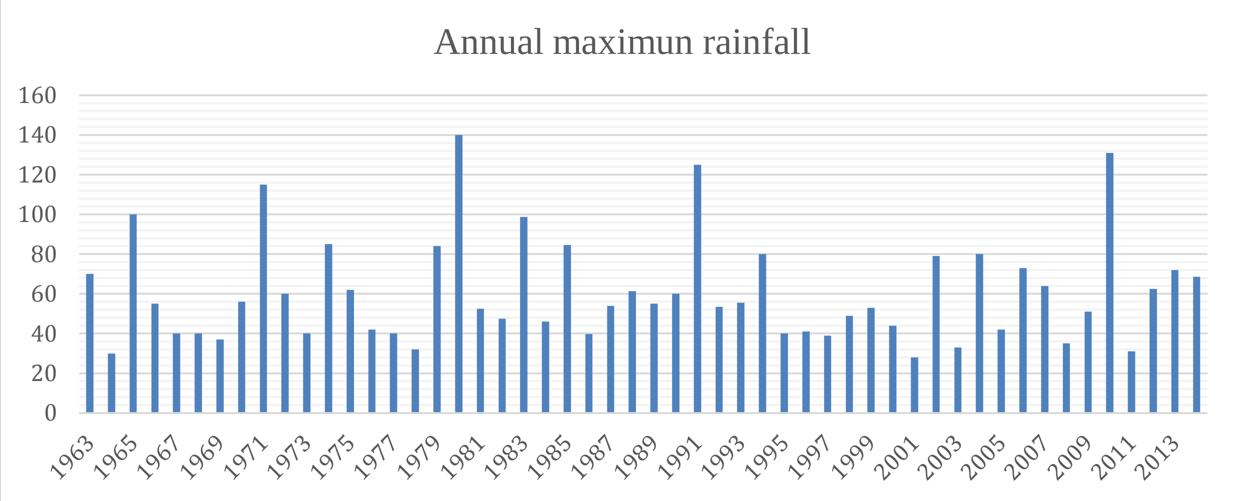


**Table 5:** Rainfall statistical distribution of Karak meteorological station at different return period 2-100 years.

| Statistical distribution | Rainfall depth designing for different return period Statistical distribution | | | | | | |
|---|---|---|---|---|---|---|---|
| | **2** | **3** | **5** | **10** | **20** | **50** | **100** |
| **Normal** | 60.7 | 72.1 | 83 | 94.6 | 104 | 115 | 122 |
| **Log-Normal** | 56 | 66.4 | 78.2 | 93 | 107 | 126 | 141 |
| **Person Type III** | **53.9** | **65.8** | **78.8** | **96.4** | **113** | **135** | **152** |
| **Log-Person Type III** | 54.4 | 65 | 77.3 | 94.5 | 113 | 139 | 160 |
| **Exponential** | 50.5 | 64 | 81.1 | 104 | 127 | 158 | 181 |
| **Gumbel** | 79.7 | 95.2 | 110 | 129 | 144 | 158 | 191 |

**Table 6:** Comparison test fitting of the Akaike Information Criterion (AIC), and Bayesian Information Criterion (BIC)

| Model | XT | P(Mi) | P(Mi \| x) | BIC | AIC |
|---|---|---|---|---|---|
| **Pearson type 3 (Maximum Likelihood)** | 151.80 | 16.67 | 39.45 | **475.56** | **469.7** |
| **Exponential (Maximum Likelihood)** | 181.00 | 16.67 | 22.55 | 476.682 | 472.78 |
| **Lognormal (Maximum Likelihood)** | 140.694 | 16.67 | 21.83 | 476.747 | 472.844 |
| **Log-Pearson type 3 (WRC)** | 160.099 | 16.67 | 10.56 | 478.2 | 472.347 |
| **Gumbel (Method of moments)** | 143.615 | 16.67 | 5.61 | 479.464 | 475.561 |
| **Normal (Maximum Likelihood)** | 122.212 | 16.67 | 0 | 495.007 | 491.104 |
| P(Mi): A priori probability | | | | | |

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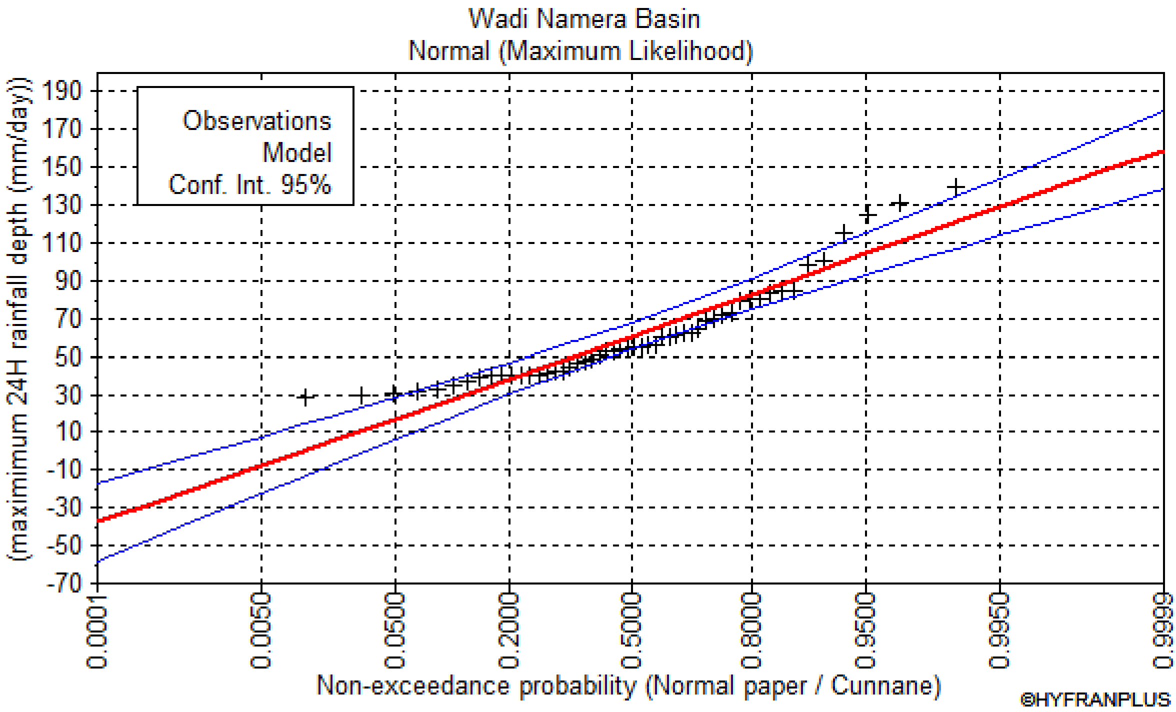


**Figure 15:** The probability distribution curve to the rainfall precipitation data by a Normal method

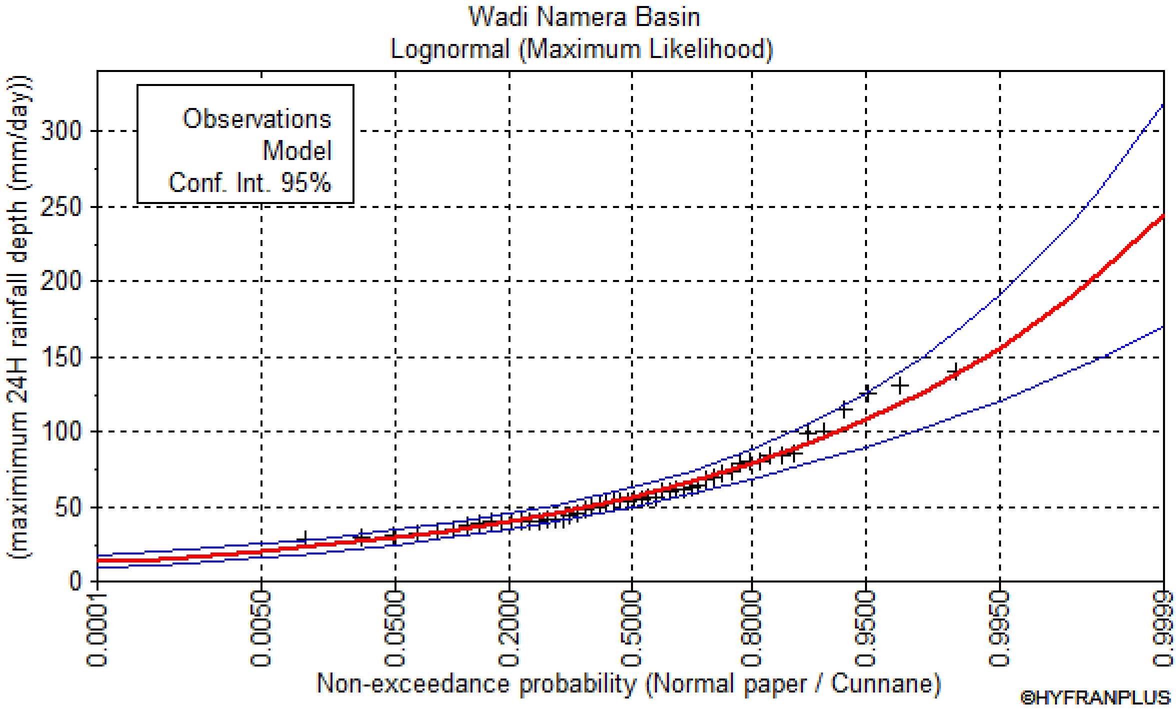


**Figure 16:** The probability distribution curve to the rainfall precipitation data by a Log-Normal method

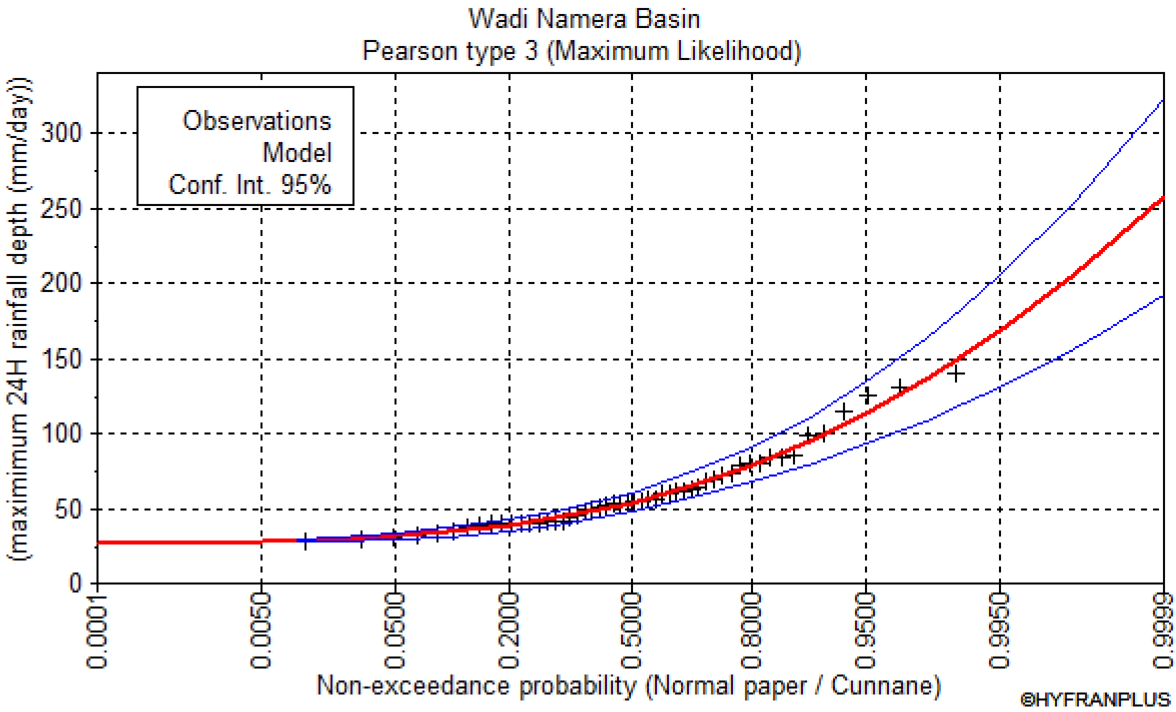


**Figure 17:** The probability distribution curve to the rainfall precipitation data by a Pearson Type 3 method

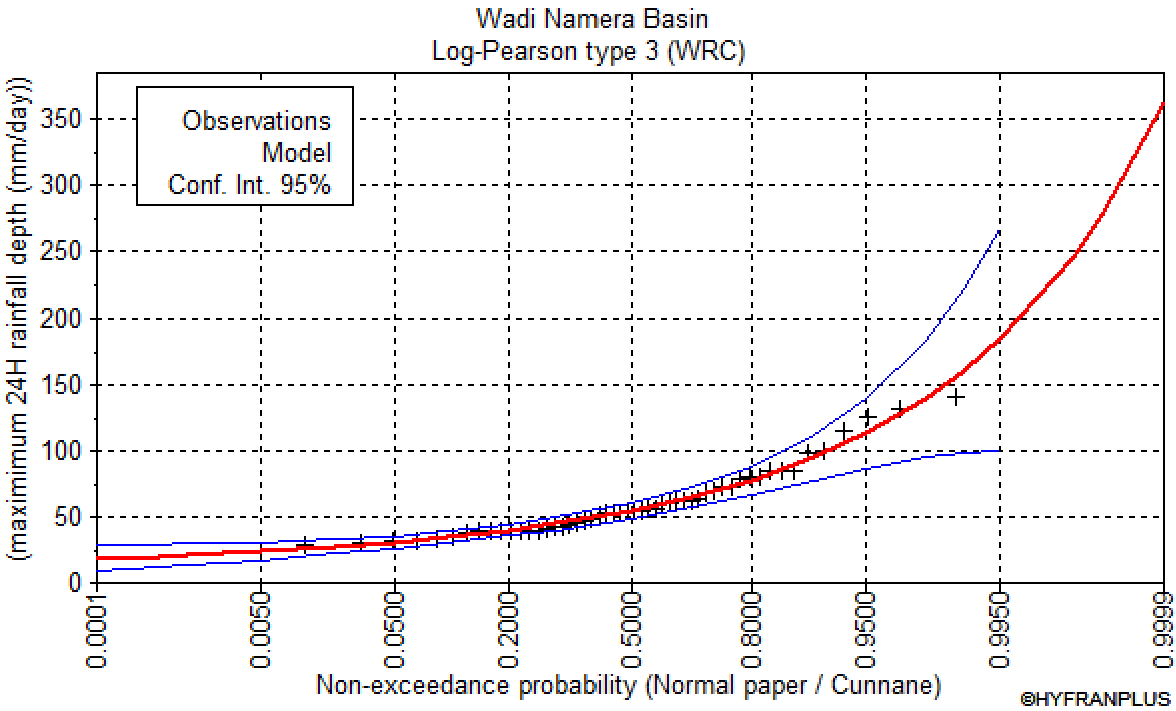


**Figure 18:** The probability distribution curve to the rainfall precipitation data by a Log- Pearson Type 3 method

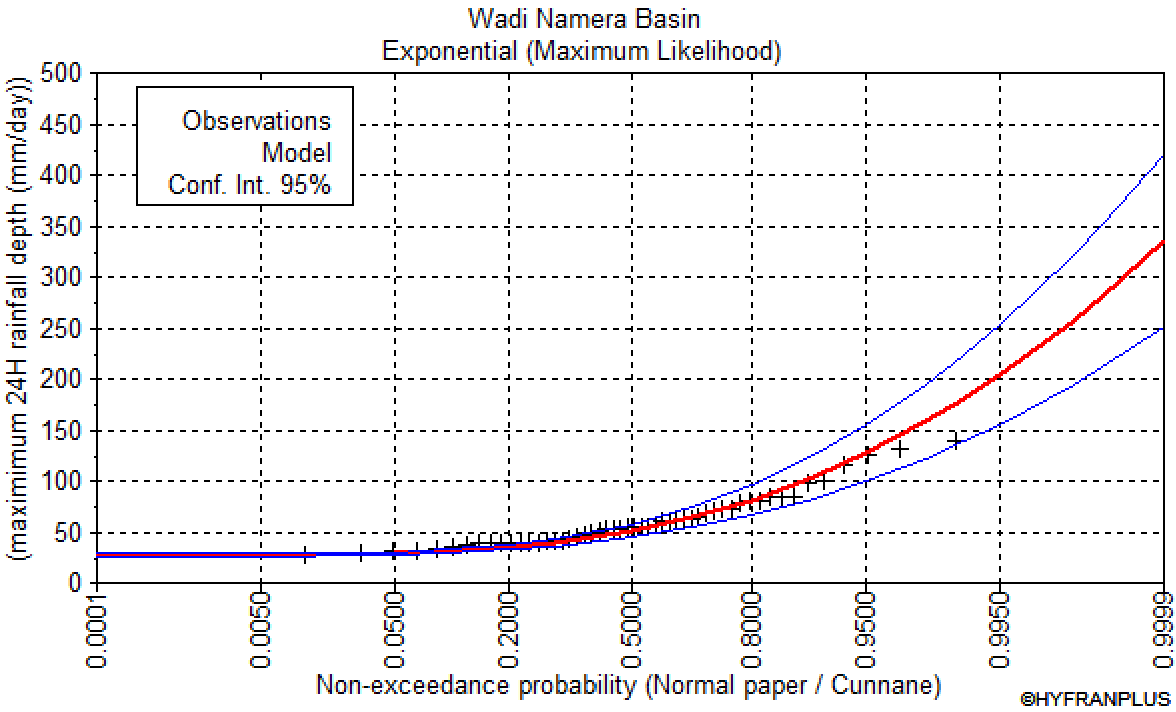


**Figure 19:** The probability distribution curve to the rainfall precipitation data by Exponential method

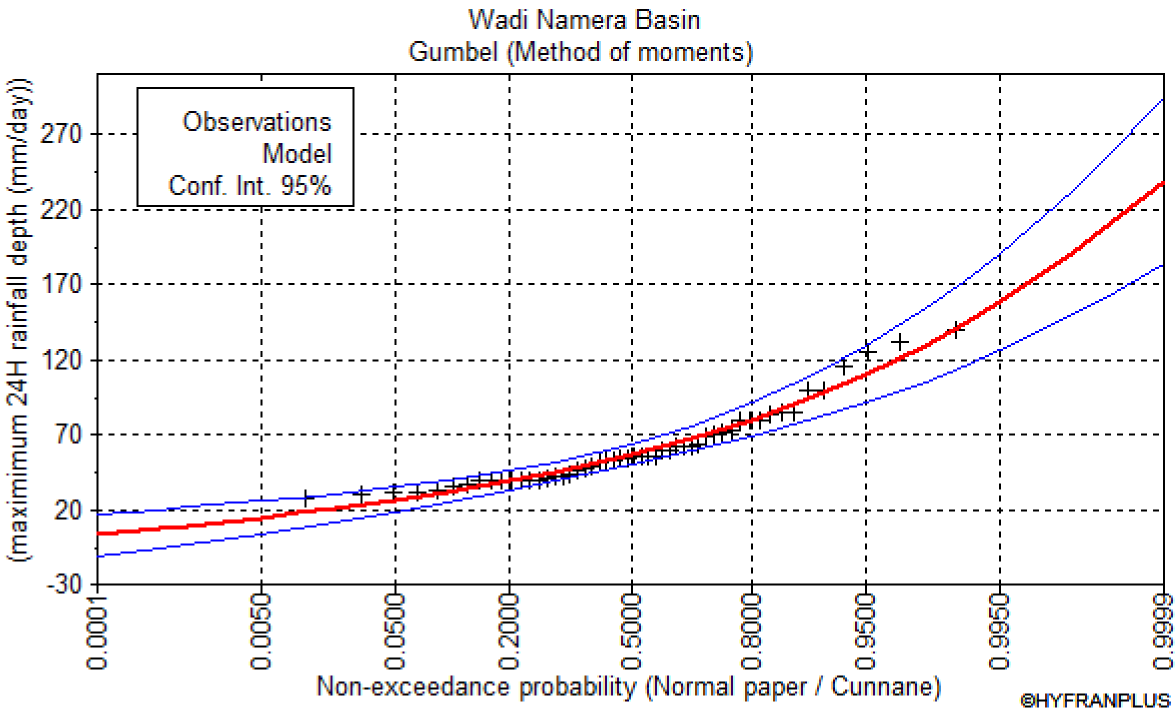


**Figure 20:** The probability distribution curve to the rainfall precipitation data by Gumbel method

## 2.2 INTENSITY-DURATION-FREQUENCY (IDF) CURVES

The Previous section was showing the purpose of fitting data to statistical distributions to be able to estimate the probability of extreme precipitation intensities for a given return period (T). Firstly, the maximum amount of precipitation for a given storm duration is calculated (Pt) (table 7), and is then converted into an intensity (commonly with units of mm/hour). This intensity value is needed for many design calculations, most commonly for determining peak flow or peak runoff. The estimated return values are needed to construct Intensity Duration Frequency curves (IDF curves), which are widely used in engineering applications. These curves show the relationship between the intensity of the precipitation and the duration of the storm for a given return period. The IDF curves are developed for a specific location, with a specific return period.

**Table 7:** Frequency analysis results for the Pearson type 3 (Maximum Likelihood) distribution.

| Return period | XT (mm) | Standard deviation (mm) | Confidence interval (95%) (mm) |
|---|---|---|---|
| 100 | 152 | 16.4 | 120 - 184 |
| 50 | 135 | 13.9 | 108 - 163 |
| 20 | 113 | 10.6 | 92.7 - 134 |
| 10 | 96.4 | 8.16 | 80.4 - 112 |
| 5 | 78.8 | 5.83 | 67.4 - 90.3 |
| 3 | 65.8 | 4.28 | 57.4 - 74.1 |
| 2 | 53.9 | 3.09 | 47.8 - 59.9 |

Determining precipitation intensities for various storm lengths is an important aspect for safely designing structures and infrastructure to manage flooding. Often short storm durations are desired as they can give high intensities (mm/hr). A theoretical ratio of 1.13 to 1.14 is adopted to transform the daily rainfall values and 24-hr values [4]. In the absence of short duration records or any similar information, sub-daily rainfall duration ratios could be assumed between rainfall intensities of 24-hr and those of the 12-, 6-, 3-, 2-, 1-hr, 30-, 15-, and 5-min ratios.

Account rainfall value for extended time 5,10,15,20,30 minutes and 1,2, 3,6,12 and 24 hours as a percentage of the previous daily rain value calculated for different times of the frequency using Bell's Ratios shown in Table 8.

Then inferred curves density values - Duration - frequency shown in the table (9) by Using the following equation: [5,6].

(I)= (XT * B) / (T / 60)

Where

I = Rain Fall Intensity (mm/hr)

XT = 1.14 (HYFRAN XT)

B = Bell Ratio as per below table. T = Duration (min).

**Table 8:** Ratios between 24-Hr duration and other storm duration intensities.

| Storm Duration (min) | 5 | 10 | 15 | 20 | 30 | 60 | 120 | 180 | 360 | 720 | 1440 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Bell's ratios | 0.14 | 0.2 | 0.24 | 0.28 | 0.34 | 0.44 | 0.57 | 0.63 | 0.75 | 0.88 | 1 |

**Table 9:** IDF values - Duration - frequency of different return periods.

| Return Period Year | Durations (min) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 5 | 10 | 15 | 20 | 30 | 60 | 120 | 180 | 360 | 720 | 1440 |
| 100y | 289.03 | 207.94 | 165.66 | 145.04 | 118.87 | 75.38 | 48.95 | 36.16 | 21.66 | 12.66 | 7.22 |
| 50y | 256.71 | 184.68 | 147.13 | 128.81 | 105.58 | 66.95 | 43.48 | 32.11 | 19.24 | 11.25 | 6.41 |
| 20y | 214.87 | 154.58 | 123.15 | 107.82 | 88.37 | 56.04 | 36.39 | 26.88 | 16.10 | 9.41 | 5.37 |
| 10y | 183.31 | 131.88 | 105.06 | 91.98 | 75.39 | 47.80 | 31.05 | 22.93 | 13.74 | 8.03 | 4.58 |
| 5y | 149.84 | 107.80 | 85.88 | 75.19 | 61.62 | 39.08 | 25.38 | 18.74 | 11.23 | 6.57 | 3.74 |
| 3y | 125.12 | 90.01 | 71.71 | 62.79 | 51.46 | 32.63 | 21.19 | 15.65 | 9.38 | 5.48 | 3.13 |
| 2y | 102.49 | 73.74 | 58.74 | 51.43 | 42.15 | 26.73 | 17.36 | 12.82 | 7.68 | 4.49 | 2.56 |

Drawing a relationship between the intensity - duration - frequency (IDF Curve) as shown in Figure (33)

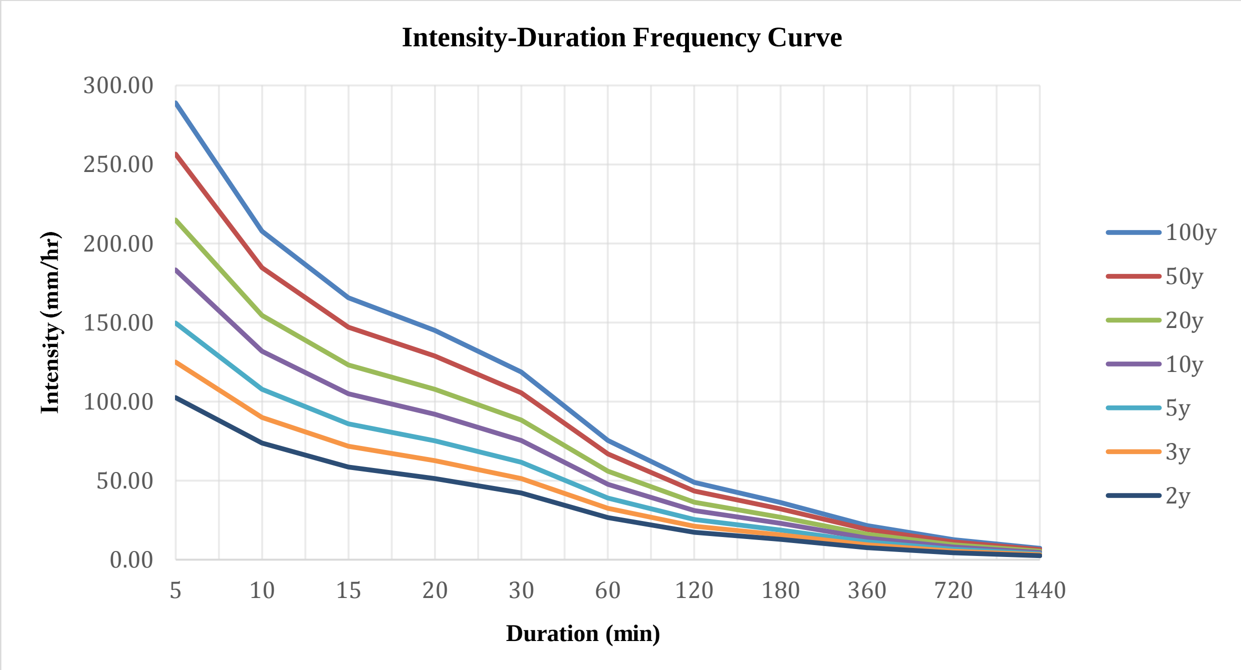


**Figure 21:** IDF curve for of Karak meteorological station at different return period 2-100 years.

Rainfall intensity is defined as 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).

So, after constructing the IDF Curve then the estimation of rainfall depth values (table 10) from the below equation.

D = (I*T)/60

Where

D = Rain Fall Depth (mm)

I = Rain Fall Intensity (mm/hr)

T = Duration (min)

**Table 10:** Rainfall depth for different return periods.

| Return Period Year | **Durations (min)** | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 5 | 10 | 15 | 20 | 30 | 60 | 120 | 180 | 360 | 720 | 1440 |
| 100y | 24.1 | 34.7 | 41.4 | 48.3 | 59.4 | 75.4 | 97.9 | 108.5 | 130.0 | 152.0 | 173.3 |
| 50y | 21.4 | 30.8 | 36.8 | 42.9 | 52.8 | 66.9 | 87.0 | 96.3 | 115.4 | 135.0 | 153.9 |
| 20y | 17.9 | 25.8 | 30.8 | 35.9 | 44.2 | 56.0 | 72.8 | 80.6 | 96.6 | 113.0 | 128.8 |
| 10y | 15.3 | 22.0 | 26.3 | 30.7 | 37.7 | 47.8 | 62.1 | 68.8 | 82.4 | 96.4 | 109.9 |
| 5y | 12.5 | 18.0 | 21.5 | 25.1 | 30.8 | 39.1 | 50.8 | 56.2 | 67.4 | 78.8 | 89.8 |
| 3y | 10.4 | 15.0 | 17.9 | 20.9 | 25.7 | 32.6 | 42.4 | 47.0 | 56.3 | 65.8 | 75.0 |
| 2y | 8.5 | 12.3 | 14.7 | 17.1 | 21.1 | 26.7 | 34.7 | 38.5 | 46.1 | 53.9 | 61.4 |

## 3 HYDROLOGICAL ANALYSIS

Hydrological study was conducted by using a mathematical model; watershed modeling system (WMS), it's one of the advanced software, Affiliated with the University of Birmingham, USA. they use model to determine discharge of sub valleys in drainage basin and network discharge of main an sub valleys through DEM for the area of topographic survey, and identify the outlets which are concentrated by flood water discharge, It also was used to calculation of the curve Hydrograph floods for different drainage basins In addition to its use in estimating the computation of flood water quantities and flow rates which using in the designing of any industrial work proposed, the hydrological studies includes preparation of curves flood water discharge and flood duration Frequency (FDF) for each drainage basin until the return period 100-year, And preparation the design tables that show the flood water characteristics and times of runoff and periods of occurrence.

### 3.1 Storms design

Hydrological calculations based on the accounts of a storm designing use statistical rain precipitation on the rainfall stations in the study area, Accordingly the maximum depth is determined by the value of the daily rainfall of various return periods for each drainage basin, to calculate the values of discharge and runoff resulting, they are distribution this depth by assuming a duration of the storm to determine the distribution of the daily rainfall depth curve through the duration of the storm design to feeding the models. They has been used the storm design distributions witch known Universally by Soil Conservation Service, or simply known (SCS), Where is assumed duration of the storm 24 hours, Will be selected distribution SCS-TYPE II, Where they are best suited for arid and semi-arid areas, they assumed that about 60% of the daily rain falls depth of less than two hours and the remaining is distributed to the rest of the day, and the distribution of the daily rainfall depth curve shows that through the storm design according to distribution of SCS-Type II, which will be used in a hydrological model to calculation the maximum values of designing discharge figures (22).

The SCS methodologies will be used here to illustrate the kinds of hydrologic parameters typically required of deterministic models. Some of these parameters include rainfall depth (and an included temporal distribution), losses from a runoff coefficient or CN value, and a time of concentration or lag time used in conjunction with a unit hydrograph.

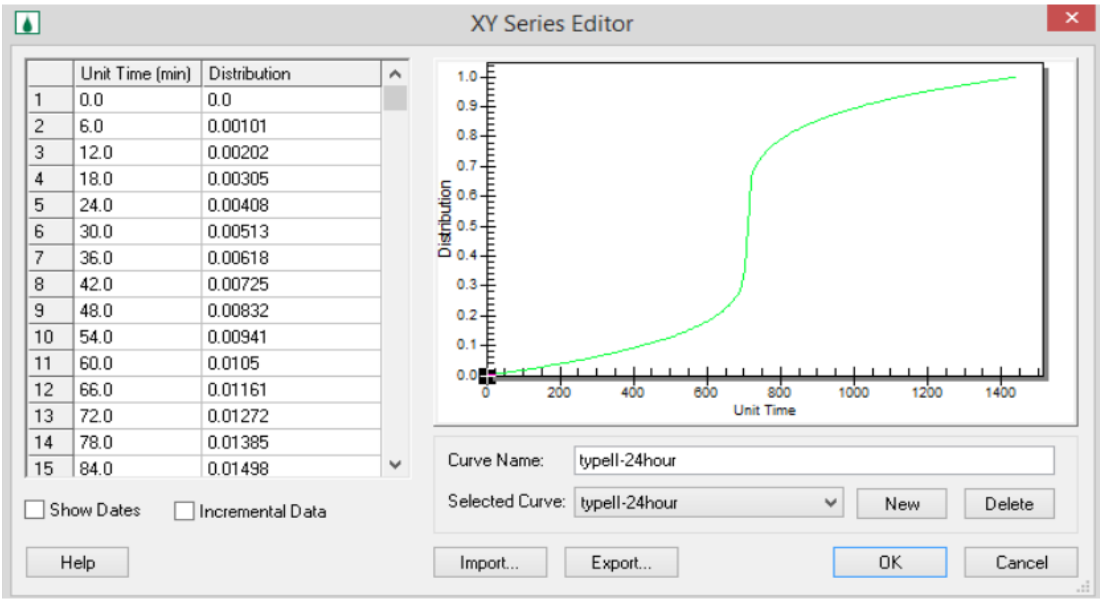


**Figure 22:** Distribution of the daily rain depth curve during a storm, according to the distribution of SCS-type II

### 3.2 Land use/Land cover (LULC)Mapping

Using Arc-map for mapping the land use of the basin generated from the unsupervised classification method of Landsat 8 image according to a GIS table of Anderson land use codes was used along with the hydrologic soil group for the map unit, then importing and mapped in WMS for automatically computing the CN for the Basin.

In TM False color 7.6.4 Vegetation types are variations of green; urban features and bare field are light grey. Infrared" composite image This composite simulates the color of a color infrared aerial photo and can be interpreted using the same logic. Vegetation types are variations of magenta as shown in figure 23.

Supervised classification method with maximum likelihood algorithm was applied in Arc GIS.10.7according to a GIS table of Anderson land use classification codeswas used. The Basin has been classified for land use/land cover into three classes; Mixed built-up land, Cropland and pasture and Mixed Barren land. The detail statistics of LULC for the study area is shown in table 12and in figure 24.

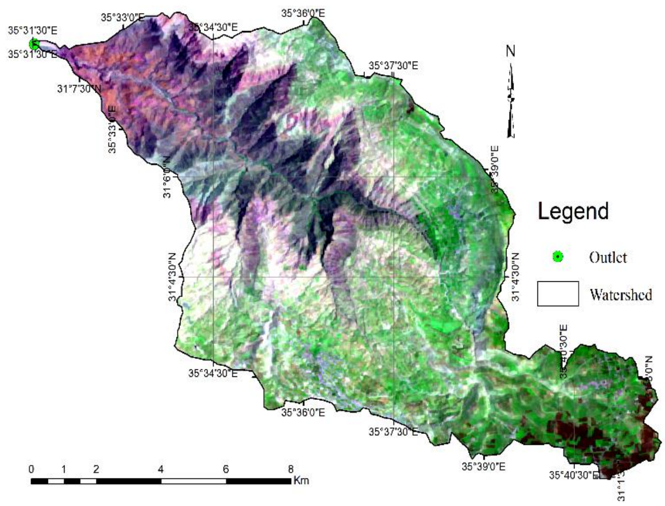


**Figure 1:** The watershed map of Landsat 8 Operational Land Imager (OLI)/Terra Band Composite 764 for the year 2020 at a resolution of 30*30 m was used for LULC classification.

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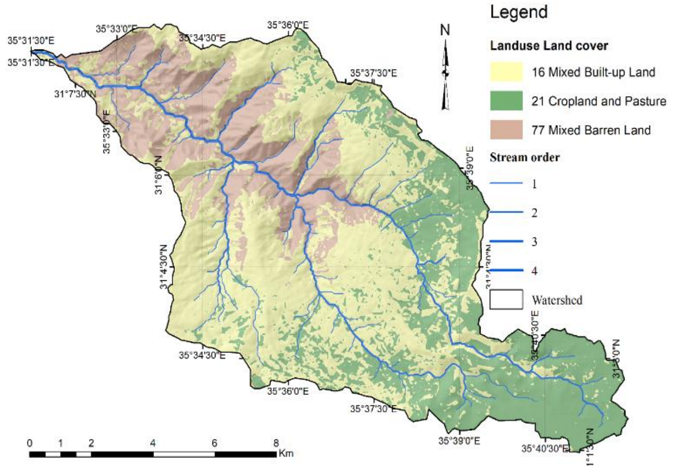


**Figure 2:** The watershed map of landuse / Landcover

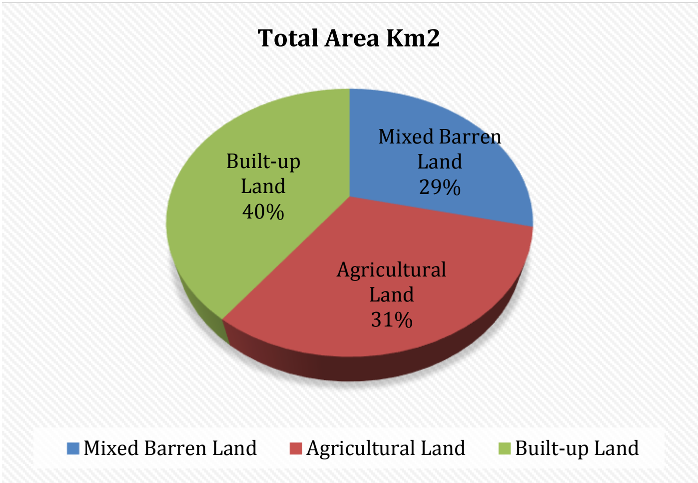


**Table 1:** Anderson classification system used in USGS LULC datasets.

| Level I | Level II |
|---|---|
| 1 Urban or Built-up Land | 11 Residential<br>12 Commercial and Services<br>13 Industrial<br>14 Transportation, Communications and Utilities<br>15 Industrial and Commercial Complexes<br>16 Mixed Urban or Built-up Land<br>17 Other Urban or Built-up Land |
| 2 Agricultural Land | 21 Cropland and Pasture<br>22 Orchards, Groves, Vineyards, Nurseries, and Ornamental Horticultural Areas<br>23 Confined Feeding Operations<br>24 Other Agricultural Land |
| 3 Rangeland | 31 Herbaceous Rangeland<br>32 Shrub and Brush Rangeland<br>33 Mixed Rangeland |
| 4 Forest Land | 41 Deciduous Forest Land<br>42 Evergreen Forest Land<br>43 Mixed Forest Land |
| 5 Water | 51 Streams and Canals<br>52 Lakes<br>53 Reservoirs<br>54 Bays and Estuaries |
| 6 Wetland | 61 Forested Wetland<br>62 Nonforested Wetland |
| 7 Barren Land | 71 Dry Salt Flats<br>72 Beaches<br>73 Sandy Areas Other than Beaches<br>74 Bare Exposed Rock<br>75 Strip Mines, Quarries, and Gravel Pits<br>76 Transitional Areas<br>77 Mixed Barren Land |
| 8 Tundra | 81 Shrub and Brush Tundra<br>82 Herbaceous Tundra<br>83 Bare Ground<br>84 Wet Tundra<br>85 Mixed Tundra |
| 9 Perennial Snow or Ice | 91 Perennial Snowfields<br>92 Glaciers |

**Table 2:** Statistical data of LULC classes and their corresponding areas and percentages.

| Landuse Landcover | Total Areakm$^2$ | Area % |
|---|---|---|
| **Mixed Barren Land** | 28.36 | 28.60 |
| **Agricultural Land** | 31.29 | 31.56 |
| **Built-up Land** | 39.5 | 39.84 |

### 3.3 Soil Mapping

The soil map has been obtained from The Ministry of Agriculture, Jordan at URL- /http://moa.gov.jo/ar-jo. The map has been converted into digital soil map having 21 units. The soil map for the basin area was reclassified and grouped into the three hydrologic soil groups (HSGs) according to the Natural Resource Conservation Service. The soil textures were classified by the fractions of each soil separate A, B and D(sand, loam, and clay) present in a soil.

The three hydrologic soil groups, covered the wadi Namera Basin area based on their minimum infiltration rate (SCS, 1972) group **A**covers 30.8%, group **B** covers 54.2 %, and group **D** covers 15 % as shown in figure 25.**Group A** is sand, loamy sand or sandy loam types of soils. It has low runoff potential and high infiltration rates even when thoroughly wetted. They consist chiefly of deep, well to excessively drained sands or gravels and have a high rate of water transmission.**Group B** is silt loam or loam. It has a moderate infiltration rate when thoroughly wetted and consists chiefly or moderately deep to deep, moderately well to well drained soils with moderately fine to moderately coarse textures.**Group D: S**oils are clay loam, silty clay loam, sandy clay, silty clay or clay. This HSG has the highest runoff potential. and slow infiltration, (Schulze, 1992; Mc. Cuen**,** 1982).

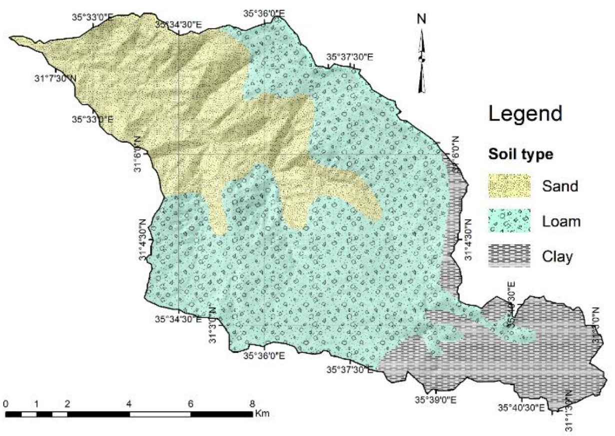


**Figure 3:** The Hydrologic soil map of wadi Namera according to the Natural Resource Conservation Service.

### 3.4 SCS CURVE NUMBERESTIMATION

The SCS curve number method is a simple, widely used and efficient method for determining the approximate amount of runoff from a rainfall even in a particular area. Although the method is designed for a single storm event, it can be scaled to find average annual runoff values.

A composite curve number for the basin computed by (WMS software) taking an area-weighted average of the different curve numbers for the different regions (hydrological soil groups (HSGs)and land use combinations) within a basin (table 13).

### 3.5 COMPUTATION TRAVEL TIME, LAG TIME AND TIME OF CONCENTRATION.

#### 3.5.1Travel time (Tt)

Travel time (Tt) is the time it takes water to travel from one location to another. Travel time between two points is determined using the following relationship: [2] Tt= l/3600V

where: Tt = travel time, h

l= distance between the two points under consideration, ft

V = average velocity of flow between the two points, ft/s

3,600 = conversion factor, s to h

The Travel Time automatically computed in WMS for the basin equals 3.530 hrs.

**Table 3:** SCSCurve Number estimation using WM

```
==============================================================================
                          Runoff Curve Number Report
                              (Generated by WMS)
==============================================================================
Thu Nov 05 19:31:36 2020

Runoff Curve Number Report for Basin Wadi Namera

HSG  Land Use Description                          CN   Area        Product
                                                        km^2        CN x A

B    Mixed Urban or Built-up Land                  88     13.990    1231.159
B    Mixed Barren Land                             86     23.584    2028.214
C    Mixed Urban or Built-up Land                  91     45.149    4108.572
C    Cropland and Pasture                          79     17.628    1392.608
C    Mixed Barren Land                             91      3.118     283.726
B    Cropland and Pasture                          69      0.140       9.653

CN (Weighted) = Total Product \ Total Area
=========================================
                                  87.3854
```

Lag time and Time of Concentration. Lag time and time of concentration are variables often used when computing surface runoff using unit hydrograph methods available in the hydrologic models supported in WMS. These variables indicate the response time at the outlet of a watershed for a rainfall event, and are primarily a function of the geometry of the watershed. WMS provides two powerful methods of computing travel times for lag time and time of concentration from the geometric data being used for basin delineation and parameter estimation.

#### 3.5.2Lag Time Computation

Lag is the delay between the time runoff from a rainfall event over a watershed begins until runoff reaches its maximum peak. The lag time was estimated according to SCS method by using WMS was 1.425 hours. (table 14).

**Table 4:** Computing Lag Time according to SCS method using WMS

```
**********************************************************************
        Lag Time / Time of Concentration Data Computed in WMS
                     Fri Nov 06 00:13:26 2020
**********************************************************************
BASIN Wadi Namera   AREA 103.942 km^2
Equations:
Lag Time     L^0.8 * ((((1000/CN)-10) + 1) ^0.7)/(1900*sqrt(Y))     1.42562 hrs.
Variables:
L     Watershed length           83918.3 ft
CN    SCS curve number           87.3303
Y     Watershed slope in percent   36.1145 %
```

#### 3.5.3Time of Concentration (Tc)

Time of concentration is the time required for runoff to travel from the hydraulically most distant point in the watershed to the outlet. The hydraulically most distant point is the point with the longest travel time to the watershed outlet, and not necessarily the point with the longest flow distance to the outlet. Time of concentration is generally applied only to surface runoff and may be computed using many different methods. Time of concentration will vary depending upon slope and character of the watershed and the flow path. The time of concentration estimated according to Kirpich method by using WMS was 2.31 hours (table 15).

**Table 5:** Computing Time of concentration according to Kirpich method using WMS

```
**********************************************************************
        Lag Time / Time of Concentration Data Computed in WMS
                     Fri Nov 06 01:06:59 2020
**********************************************************************
BASIN Wadi Namera   AREA 103.942 km^2
Equations:
Time of Concentration    m * 0.00013 * (L^0.77/S^0.385)    2.31245 hrs.
Variables:
m     Earth type coefficient 1
L     Length of overland flow     83918.3 ft
S     average overland slope      0.0643309
```

### 3.6 HEC-1 HYDROLOGIC SIMULATION MODEL

Hydrological simulation includes study of the return period estimation of rainfall of given precipitation, i.e. the 100 year storm or the 100 year flood, 50 year, 30 ...3years etc. 100 year flood, 50 year storm, or 200 year flood, as a description of the magnitude of a storm or flood. We understand that the larger the number before 'year flood', the greater will be the effect on river levels and on anything out on the river's flood plain. Return Period (T) - The average length of time in years for an event (e.g. flood or river level) of given magnitude to be equaled or exceeded. The design storm was often developed from frequency-duration-intensity curves based on rainfall records. Early discussed in Part V and estimated for the basin.

The HEC series of software is produced by the U.S. Army Corps of Engineers Hydrologic Engineering Center. Keeping the Curve Number and the time of concentration constant, 7 different design storms were run in the model.

A range of curve numbers were run in HEC1 using a 7 Return distribution design storm of 24-hour duration. The following hydrographs resulted. The higher curve numbers result in a larger amount of runoff and therefore a higher peak flow and flow volume.

The Analysis of Hydrograph curves, indicated that the food volume through 2-100-year Return Duration range from 2698864.2 $m^3$ to 11980315.8 $m^3$ while the peak flow of flood ranges from 207.81 Cms to 945.24 Cms as shown in figure 26.

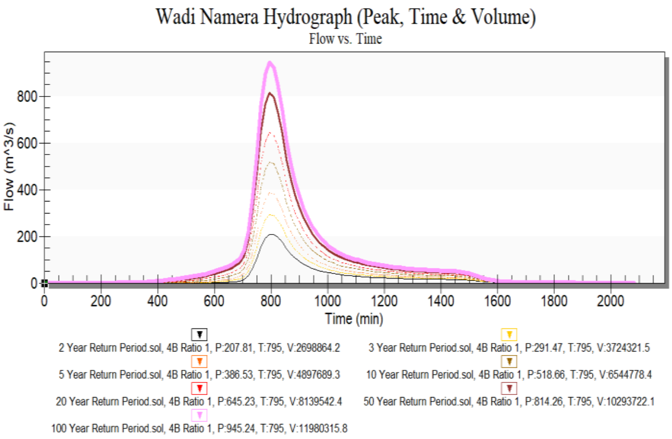


**Figure 4:** The Hydrograph of wadi Namera Basin at different return period from 2 to 100 years

### 3.7 Conclusion

The SCS-CN method is widely used as a method for estimating the surface runoff volume for a given rainfall event, Most of the sub-basins are indicating high curve number value, which is more than 80, that indicates high runoff in the study area. The maximum run off are indicated the low infiltration rate. Total surface runoff volume of Wadi Namera at 100-year return period 11980315.8$m^3$.

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