RESEARCH ARTICLE OPEN ACCESS

Hydrological modeling for Al Hasa catchment area using GIS Technique.

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ABSTRACT
Jordan is located in arid to semi-arid areas, therefore water studies is one of the most important researches for Jordan, This study was undertaken to calculate runoff values for Al Hasa catchment area by using three different hydrological modeling methods, Time of concentration method, Curve Number method and Unit hydrogaph . Wadi Al Hasa basin or Al Hasa basin is located in the southern part of the Hashemite Kingdom of Jordan with a maximum length of 112.5 km from east to west and it extends for 50 km from north to south.
Runoff calculation results were 88.93 MCM /year for both Time of concentration method and Unit hydrogaph method, and 48.94 MCM/year for Curve Number method. These results of the three methods are approximated and acceptable, however, time of concentration method have the highest value because it takes all ideal variables considering, and ignored external variables effects.
Keywords: Runoff Modeling, Curve Number method, Time of concentration method, Al Hasa catchment area, Unit hydrogaph.

Date Of Submission: 24-01-2019 Date Of Acceptance:08-02-2019

I. INTRODUCTION

In arid and semi-arid zones, there is a shortage of data needed for hydrological processes such as runoff amounts (Khalil, 2017). In these zones thunderstorms and flash flooding happened suddenly and affects both human and infrastructure. However, defining rainfall-runoff relationship leads to calculate runoff properties such as runoff depth, peak discharge, runoff speed, and runoff volume. When runoff discharge data records are missed, there are many approaches to estimate runoff depth and volume based on soil and surface properties (landuse) of the catchment area and that what was done in this study.

There are many procedures and methods to calculate runoff value, the most important of them are: Time of concentration method, Curve number (Rainfall-Runoff model approach) method, and Unit hydrograph method. This study will calculate runoff using these three methods.

Remote sensing imageries considered a major source of spatial data especially for wide area or when the ground surveys are not available. They can be used to generate land use, soil and geological maps needed for flood estimation. Geographic Information System (GIS) is a powerful tool in hydrological modelling because of its capability to handle large amount of spatial and attribute data. Delineation of hydrological catchments, map overlay and analysis, which are basics of GIS software, help for derivation and aggregation of hydrologic parameters from the input data like DEM, soil map, land use map, and rainfall data. The hydrological analysis tool in the ArcGIS software can help researchers analyze the movement of water across a surface area. (Zhao,. et. al., 2009)

Remote sensing (RS) images and Geographic Information System (GIS) techniques have been used in flood hazard studies by many researchers (Khalil, 2017).

Objectives of the study:
1. Making hydrological and geomorphological studies of Al-Hasa catchment area.
2. Determining the amount of rainwater that can be collected in the study area.
3. Making models to determine the best uses for lands in the study area.
4. Studing the climate change on the hydrological parameters and its affects on land use in the study area.
5. Studyind the flood scenarios that happened in the study are.

II. THE STUDY AREA

The study area is known as Wadi Al Hasa basin or Al Hasa Basin, which is located in the southern part of the Hashemite Kingdom of Jordan. It extends between longitude 35º 32´ and 36º 27´ east, and the latitudes 30º 30´ and 31º 4´ north as it shown in (Figure 1) the maximum length of the basin is 112.5 km from east to west, while it extends for 50 km from north to south.

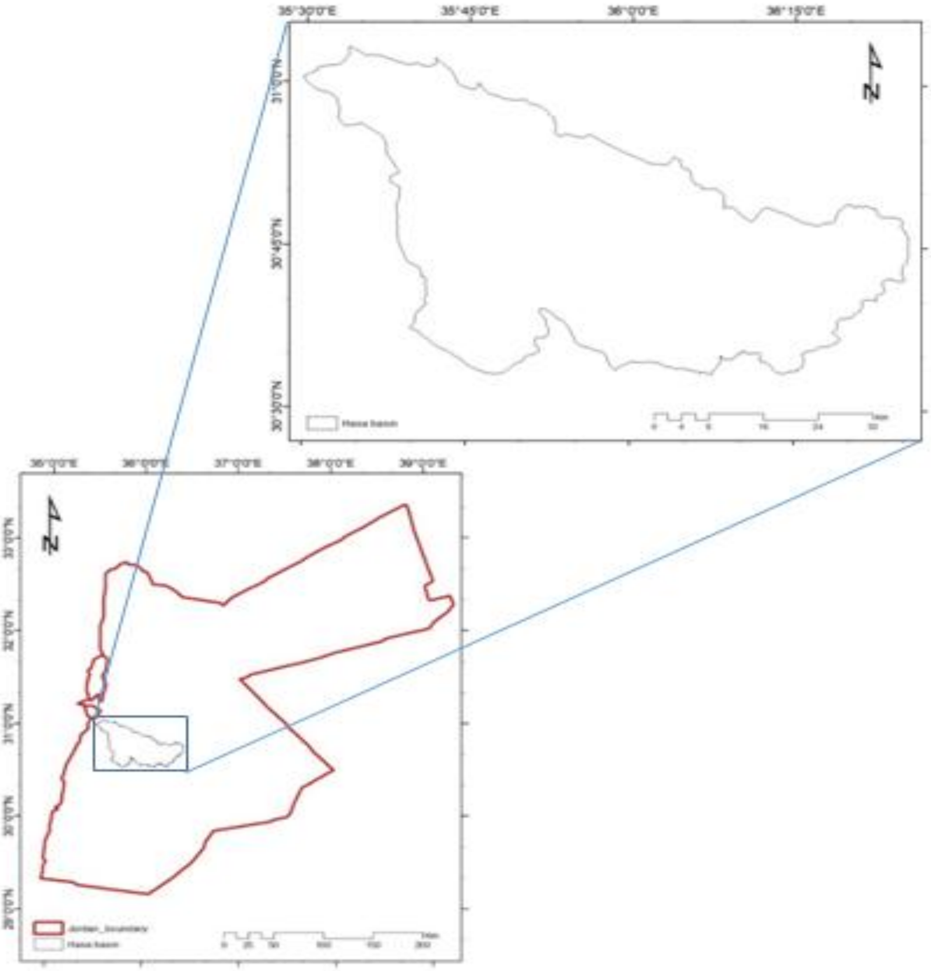

Figure 1: Wadi al Hasa catchment area location.

The physical characteristics of the basin affect indirectly the volume of the flood that forms in it. These characteristics include the climate, the soil, the geology and the vegetation. The climate of Wadi Al Hasa is characterized by drought, as the annual average of rainfall in the basin is less than (200 mm). It is also characterized by high rates of evaporation, where the potential annual evaporation in AlHasa stations is 3606 mm. This high evaporation rates due to aridity climate which characterize by high temperature in most time of the year. The average annual temperature is (19.5 ºC) in Al-Hasa station (Abu Salim, 2014).

There are five types of soil in Al-Hasa basin according to the classification of Ministry of Agriculture in Jordan (1993), namely: Typic Calciorthid, Typic Camborthid, Xerochreptic Calciorthid, Calcixerollic Xerochrept, and Typic Xerachrepts.

The soil's texture is loamy and muddy with low content of sand and becomes more coherent and harder at 25 cm deep as a result of the cohesion of soil particles (Abu Salim, 2014). These characteristics contributed to increase the amount of water flow in the upper parts of the Valley.

There are different types of rock formations exposed in the basin (Figure 2). In the western upper areas, there are two types of rock formations, namely: Wadi Es Sir Formation (A7) and Amman (B2) Formation. Wadi Es Sir is mainly consisting of lime-dolomite rocks, which is characterized by medium permeability. These formations have been exposed to fractal movements and weathering processes which have contributed to increase their permeability (Abu Salim, 2014). Amman Formation consists of limestone, flint stone and phosphate stone. This formation is characterized by a large number of cracks and joints that have contributed directly to increased water leakage rates of flows, and reduced their ability to form a stream floods. This formation goes back to the Campanian Age (Bender, 1974). In the central areas of the basin, there are two types of formations, namely: Al-Muwaqqar (B3) Formation and Um Rjam (B4) Formation. Al-Muwaqqar Formation consists of marl and chalk rocks and it goes back to the Maastrichtian Age (Bender, 1974). It features by an abundance of joints and cracks, which increases the permeability of this formation and therefore reduces the coefficient of water flow of the river tributaries that their riverbeds are formed from this formation (Abu Salim, 2014). The formation of Um Rjam (B4) is composed of flint-limestone which goes back to the Tertiary era of modern life. It is characterized by medium permeability which increases the size of water discharge of the river tributaries that their riverbeds are formed from this formation (Abu Salim, 2014). The surface formations of the eastern plateau of the basin consists of valleys sediments except the northern areas of the plateau which consists of Lower Ajlun formation. These sediments consist of rock debris of flint, limestone, boulders and dirt and go back to the Pleistocene Age. They are characterized by their high permeability which reduces the volume of water discharge in the valleys, and causes a delay in the velocity of water flow to the main stream, hence, reducing the possibility of flooding (Abu Salim, 2014).

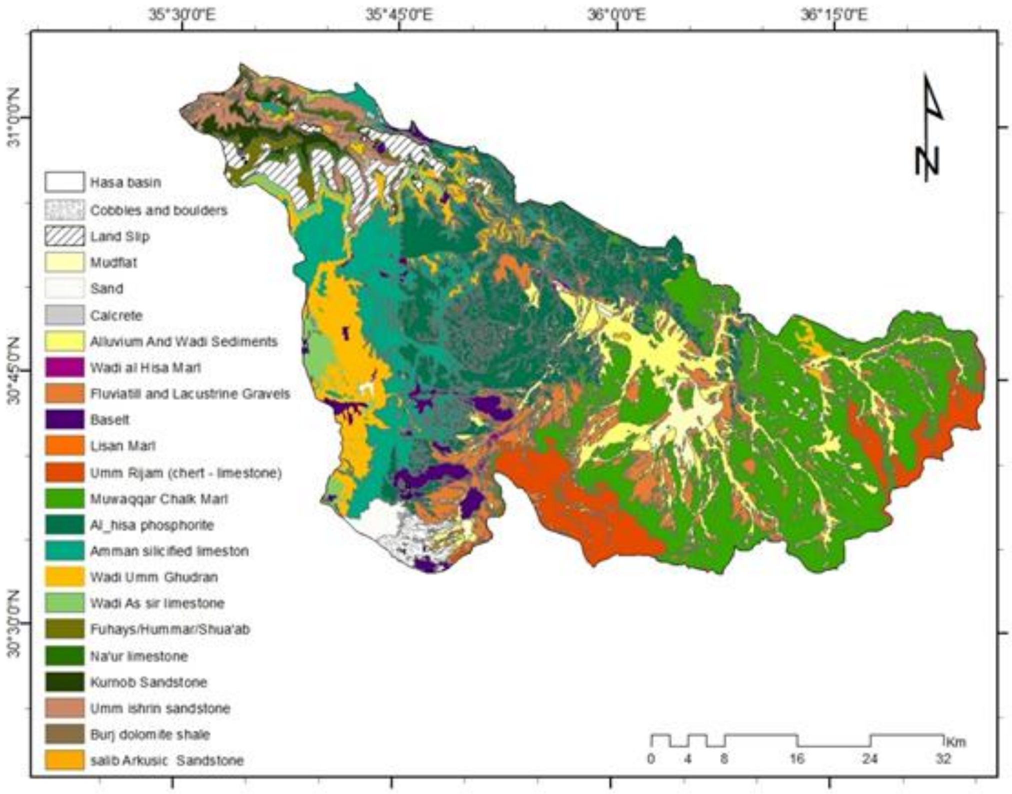

Figure 2: Geological map of Wadi Al Hasa.

III. METHODOLOGY

Runoff volume was calculated using three different methods: Curve number (Rainfall-Runoff model approach), Time of Concentration, and Unit hydrograph method. These methods were explained in schematic representation in Figure (3).

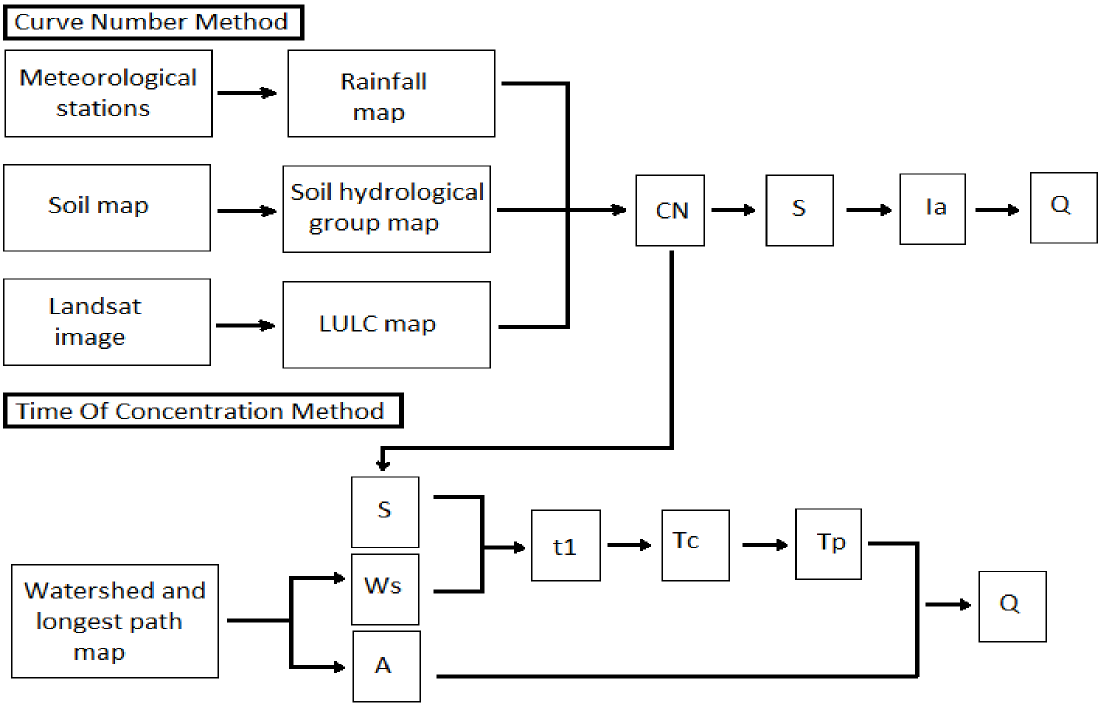

Figure 3: schematic representation for methods of calculating runoff

3.1 Curve number (Rainfall-Runoff model approach)

Estimating rainfall discharge is difficult in large catchment areas with varying topography so that three ArcGIS-based hydrological models were developed to estimate rainfall discharge for storms that occur anywhere. The test results approved the potential for GIS to aid in the creation of highly accurate hydrological models (Kirkby, et. al., 2011).

Three models were developed: a Provincial Design Flow Method; the Rational Method, and Soil Conservation Service Curve Number Model (SCSCN). The latter two incorporate coefficient values to designate changes in topography. Runoff coefficients ranging from 0.01 (stagnant water) to 1 (steep sloping asphalt road) were derived from soil type, ground slope and vegetation cover. Curve number values ranging from 1 (asphalt road) to 100 (stagnant water) were assigned based on differences in soil type and vegetation cover (Kirkby, et. al., 2011).

The SCS-curve number method is the model approach which used to predict runoff volumes and peak flows. With this model, the precipitation excess can be calculated; the maximum retention and the watershed characteristics are related throw the curve number (CN). The SCS-curve number method is used in many event based models to establish the initial soul moisture condition and the infiltration characteristics (USDA, 1993). The SCS runoff equation is:

$$Q = \frac{(p - 0.2\,S)^2}{(p + 0.8S)} \quad (1)$$

Where:
Q: runoff depth (mm)
P: precipitation depth (mm)
S: the total losses of the rainfall depending on soil type (mm) and it can be calculated by the following equation:

$$S = \frac{25400}{CN} - 254 \quad (2)$$

Initial abstraction (Ia) is all losses before runoff begins. It includes water retained in surface depressions, water intercepted by vegetation, evaporation, and infiltration. Ia is highly variable but generally is correlated with soil and cover parameters.

$$Ia = 0.2\,S \quad (3)$$

Where:
Ia: Initial abstraction (mm).

3.2 Time of Concentration:

Time of Concentration is the time required for the most remote drop of water to reach the outlet of the watershed.
Many equations have been proposed for the time of concentration. Below are equations of the most

commonly used from Soil Conservation Service (SCS, 1982).

$$S = \frac{1000}{CN} - 10 \quad (4)$$

Where:
S: potential maximum retention (inch)
CN: Curve number.

$$t_1 = \frac{L^{0.8} * (S+1)^{0.7}}{1900 * W_S} \quad (5)$$

Where:
t_1: lag time (hours)
L: hydraulic length (feet)
S: potential maximum retention (inch)
Ws: average slope of watershed (%).

$$Tc = 1.67 * t_1 \quad (6)$$

Where:
Tc: time of concentration (Hours)
T_1: lag time (hours)

The Time of peak (Tp) was calculated by:

$$Tp = \frac{D}{2} + 0.6 * Tc \quad (7)$$

Where:
Tp: time of peak (Hours)
D: duration equal 1 hour.
Peak discharge calculated by:

$$Qp = \frac{2.08 * A}{Tp} \quad (8)$$

Where:
Qp: peak discharge of the unit hydrograph (m^3/s)
2.08: constant value
A: area (km^2).
Arc Hydro tool was used to derive the longest path and the area of the catchment, Arc Hydro is a set of data models and tools that operates within ArcGIS to support geospatial and temporal data analyses for water management.
With Arc Hydro you can delineate and characterize watersheds in raster and vector formats, define and analyze hydro geometric networks, manage time series data, and export data to numerical models (Arc hydro tool tutorial, 2015).

3.3 Unit hydrograph

The Unit Hydrograph (UH) of a watershed is defined as the direct runoff hydrograph resulting from a unit volume of excess rainfall of constant intensity and uniformly distributed over the drainage area. (Ramírez, 2000).

The unit hydrograph approach is used to determine the peak discharge and its magnitude value and to calculate the optimum size of the flow drainage elements.

Watershed Processing: functions dealing with watershed and sub watershed delineation, and basin characteristic determination. They operate on top of the spatial data prepared in the terrain preprocessing stage.

IV. RESULTS

4.1 Time of Concentration:

The variables of the equations were estimated from Wadi Al Hasa watershed which was established by Arc Hydro tool in GIS which shown in (Figure 4).

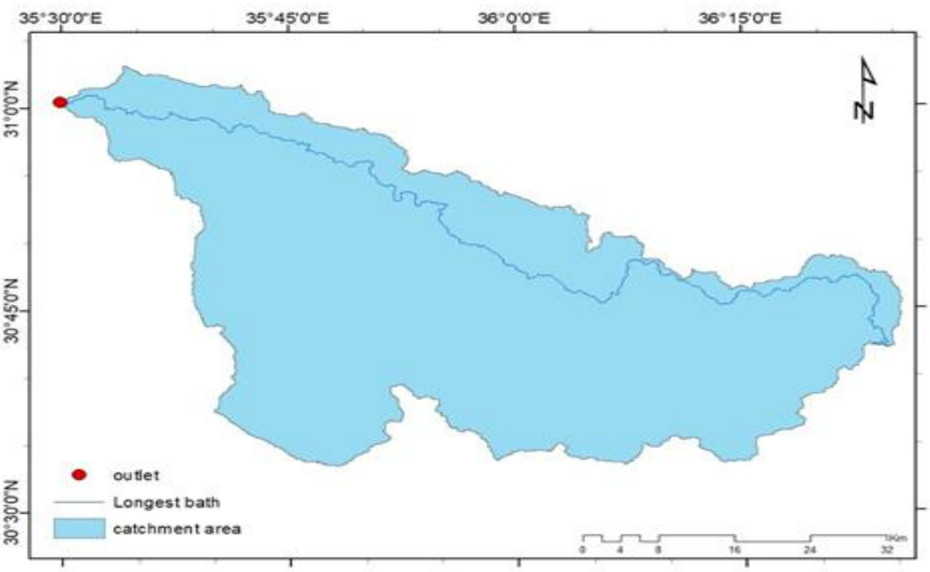

Figure 4: Watershed with the longest path and outlet map.

Wadi Al Hasa catchment characteristics are found to be; the highest elevation is 1585 m and the lowest is -258 below sea level, longest path of the wadi is 149.183 km which equals 92.7 mile, the average slope (%) of the longest path is 1.235%, the catchment area is 2433 (km^2) which is equal to 939.386 ($mile^2$). The equations were applied and the results shown in table1.

Table 1: Hydrological parameters of Wadi Al Hasa catchment by using SCS Method

S (mm)	t_l (hours)	T_c (hours)	T_p (hours)	Q_p (m^3/hr)	Q_p (m^3/y)
1.628	29.84	49.8475	29.9085	169.20	88931520

4.2 Curve number (Rainfall-Runoff model approach):

Eleven stations inside or outside the catchment area were studied to construct the isohytal rainfall map.

The interpolated rainfall map was established from rainfall data of the meteorological stations using kriging method. The stations and rainfall map are shown in Figure (5).

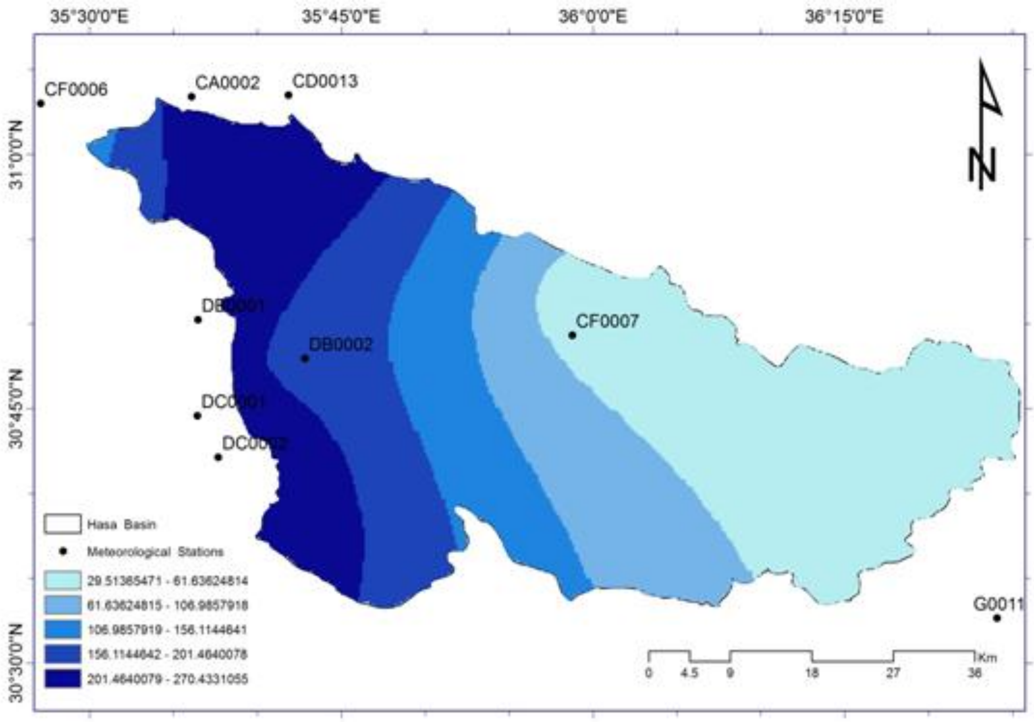

Figure 5: Meteorological stations and rainfall map of Wadi al Hasa catchment area.

The varies types of soils in the study area differ in their ability to increase the severity of water flood formed in the Wadi Al Hasa according to the water ability to penetrate into their sections depends on their landuse. These types were reclassified into three hydrological groups (Figure 6).

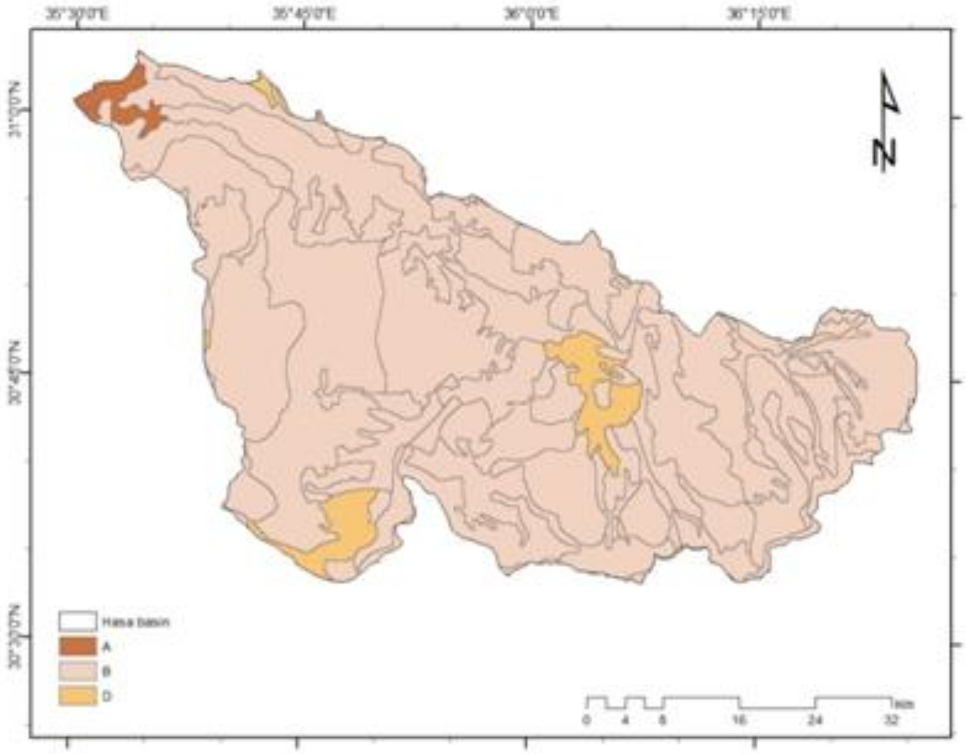

Figure 6: Soil hydrological group of Wadi Al Hasa map.

land use map in Figure (7) was created using on screen digitizing of Landsat image which was downloaded from USGS website (https://lpdaac.usgs.gov/data_access/usgs_earthexplorer) acquired on 31/7/2017.

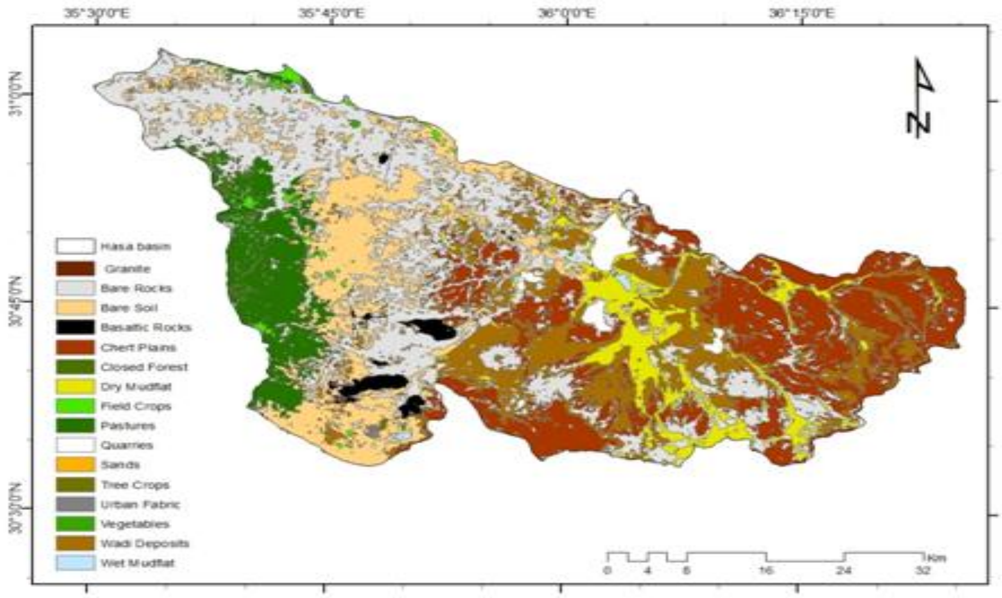

Figure 7: Landuse map of 2017 for Wadi Al Hasa catchment area.

Curve Number (CN) was derived from Urban Hydrology for Small Watersheds TR-55 and all above equations were applied to find Runoff values for DB0002 in table (2) and Figure (8) shows the verities in runoff values for both stations during 1990 to 2016.

Table 2: Runoff values for DB0002 Station

Runoff (DB0002)	Oct	Nov	Dec	Jan	Feb	March	April	May	Total (mm)	total*A (m^3)
1990	0.000	0.000	0.000	1.854	0.002	3.080	21.936	0.000	26.872	65379474.04
1991	0.000	0.000	9.850	0.038	0.074	21.639	0.000	0.000	31.601	76885136.91
1992	0.000	0.617	6.249	0.211	1.352	0.429	0.000	0.000	8.858	21551432.45
1993	0.000	0.000	0.070	0.132	36.968	0.000	0.000	0.000	37.169	90432891.97
1994	0.374	6.855	7.643	16.471	15.140	0.000	0.000	0.000	46.483	113092656.7
1995	0.374	0.000	0.000	0.000	0.723	0.000	0.000	0.000	1.096	2667651.718
1996	0.000	0.000	0.000	0.800	0.023	24.147	0.000	0.000	24.970	60753089.93
1997	0.000	0.000	0.000	28.217	4.467	1.715	0.000	0.000	34.399	83691764.45
1998	0.000	0.000	0.000	0.000	4.335	0.891	0.000	0.000	5.226	12714133.38
1999	0.000	0.000	0.002	10.495	0.000	1.985	0.000	0.000	12.482	30369622.92
2000	0.132	0.000	0.957	1.327	0.133	0.000	0.000	1.764	4.312	10491933.34
2001	0.000	3.555	0.309	0.418	3.312	2.698	1.854	0.000	12.146	29550483.48
2002	0.393	0.000	6.816	1.651	2.792	2.792	0.013	0.000	14.456	35172492.69
2003	0.000	0.000	0.000	33.135	0.071	0.169	0.000	0.000	33.375	81200958.05
2004	0.000	6.373	0.054	0.039	0.134	0.069	0.079	0.000	6.749	16419571.25
2005	0.000	0.000	0.013	0.000	0.132	0.000	0.371	0.000	0.515	1253291.211
2006	0.000	0.000	14.027	15.709	6.016	5.321	0.000	0.000	41.072	99929304.77
2007	0.000	0.000	0.000	15.709	6.016	5.321	0.000	0.000	27.046	65802377.99
2008	0.036	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.036	86480.93427
2009	0.000	0.000	4.335	0.000	5.553	5.579	0.000	0.000	15.467	37631388.13
2010	0.000	0.000	0.079	7.054	12.793	0.028	0.000	0.000	19.955	48549777.5
2011	0.000	0.069	0.114	0.040	9.933	0.000	2.592	0.000	12.749	31018059.03
2012	0.000	0.246	0.000	5.893	8.942	7.202	0.000	0.000	22.283	54215226.21
2013	0.000	0.000	6.489	43.213	0.000	0.000	0.000	0.000	49.702	120924932.1
2014	0.000	2.252	0.146	0.070	0.543	19.136	0.000	0.000	22.147	53884546.68
2015	0.870	0.000	0.000	12.435	0.000	0.000	0.000	0.000	13.306	32372735.34
2016	0.000	0.000	0.000	0.458	3.867	13.190	1.183	0.000	18.699	45494336.15
average										48945768.49

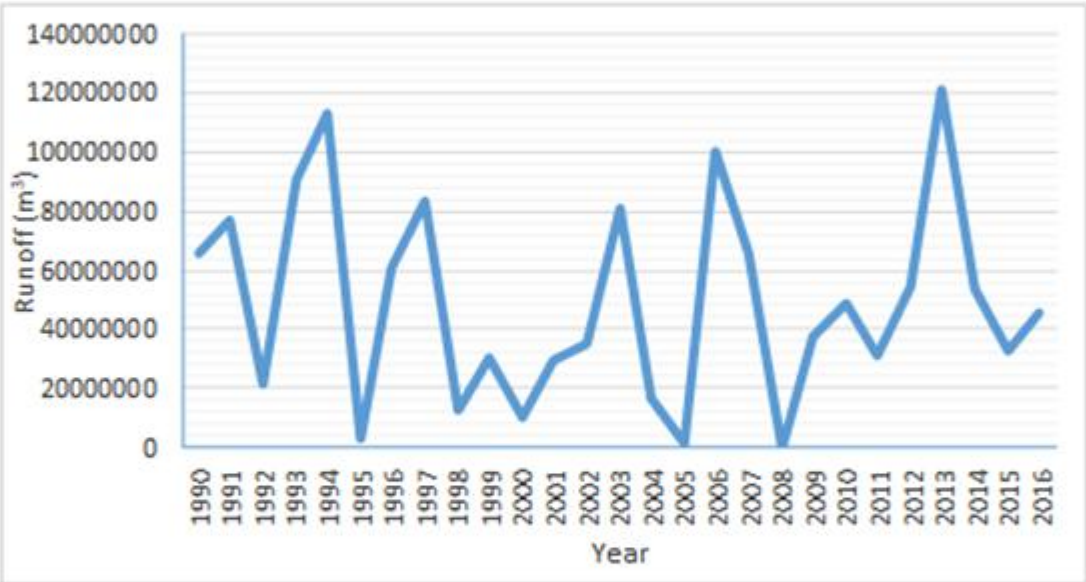

Figure 8: the varieties in runoff values in DB0002 during 1990 to 2016.

1.3 Unit hydrograph

Results of unit hydrograph are listed in Table 3 and Figure 9.

Table 3: Calculation of Unit Hydrograph discharge of Wadi Al Hasa watershed.

Tp = 29.9 hour							
Qp = 169.2 m^3/s							
t (hour)	**t/tp**	**q/qp**	**Q (m^3/s)**	**t (hour)**	**t/tp**	**q/qp**	**Q (m^3/s)**
0	0	0	0	**59**	2	0.28	53.09
1	0	0	0	**60**	2	0.28	52
2	0.1	0.03	5.076	**61**	2	0.28	50.32
3	0.1	0.03	7	**62**	2.1	0.28	49.1
4	0.1	0.03	10	**63**	2.1	0.28	47.376
5	0.2	0.1	16.92	**64**	2.1	0.28	46
6	0.2	0.1	24	**65**	2.2	0.207	44.12
7	0.2	0.1	28	**66**	2.2	0.207	40.6
8	0.3	0.19	32.148	**67**	2.2	0.207	37.76
9	0.3	0.19	38	**68**	2.3	0.207	35.0244
10	0.3	0.19	40	**69**	2.3	0.207	34.5
11	0.4	0.31	46.5	**70**	2.3	0.207	32
12	0.4	0.31	52.452	**71**	2.4	0.147	30
13	0.4	0.31	63.7	**72**	2.4	0.147	26.8
14	0.5	0.47	79.524	**73**	2.4	0.147	25
15	0.5	0.47	87	**74**	2.5	0.147	24.8724
16	0.5	0.47	99.4	**75**	2.5	0.147	24
17	0.6	0.66	111.672	**76**	2.5	0.147	23.5
18	0.6	0.66	119	**77**	2.6	0.107	22.9
19	0.6	0.66	127.9	**78**	2.6	0.107	21
20	0.7	0.82	138.744	**79**	2.6	0.107	20.06
21	0.7	0.82	143	**80**	2.7	0.107	19.45
22	0.7	0.82	150.56	**81**	2.7	0.107	18.6
23	0.8	0.93	157.356	**82**	2.7	0.107	18.1044
24	0.8	0.93	160	**83**	2.8	0.077	17
25	0.8	0.93	165	**84**	2.8	0.077	16
26	0.9	0.99	167.508	**85**	2.8	0.077	15
27	0.9	0.99	168	**86**	2.9	0.077	14
28	0.9	0.99	168.508	**87**	2.9	0.077	13.0284
29	1	1	169	**88**	2.9	0.077	12
30	1	1	169.2	**89**	3	0.055	10
31	1	1	168.2	**90**	3	0.055	9.87
32	1.1	0.99	167.508	**91**	3	0.055	10
33	1.1	0.99	165	**92**	3.1	0.055	9.5
34	1.1	0.99	163.6	**93**	3.1	0.055	9.306
35	1.2	0.93	160.76	**94**	3.1	0.055	9
36	1.2	0.93	157.356	**95**	3.2	0.04	8.56

37	1.2	0.93	150	**96**	3.2	0.04	8.23
38	1.3	0.86	145.512	**97**	3.2	0.04	8
39	1.3	0.86	142	**98**	3.3	0.04	7.8
40	1.3	0.86	140	**99**	3.3	0.04	7
41	1.4	0.78	131.976	**100**	3.3	0.04	6.768
42	1.4	0.78	127	**101**	3.4	0.029	6.5
43	1.4	0.78	123	**102**	3.4	0.029	6.38
44	1.5	0.68	115.056	**103**	3.4	0.029	6
45	1.5	0.68	112	**104**	3.5	0.029	5.9068
46	1.5	0.68	109.76	**105**	3.5	0.029	5.254
47	1.6	0.56	102	**106**	3.5	0.029	4.9068
48	1.6	0.56	94.752	**107**	3.6	0.021	4.35
49	1.6	0.56	89.98	**108**	3.6	0.021	4
50	1.7	0.46	87.54	**109**	3.6	0.021	3.7532
51	1.7	0.46	77.832	**110**	3.7	0.021	3.5532
52	1.7	0.46	70.43	**111**	3.7	0.021	3.126
53	1.8	0.39	65.988	**112**	3.7	0.021	2.7
54	1.8	0.39	63.267	**113**	3.8	0.015	2.538
55	1.8	0.39	60	**114**	3.8	0.015	2.5
56	1.9	0.33	56.897	**115**	3.8	0.015	2.5
57	1.9	0.33	55.836	**116**	3.8	0.015	2.5
58	1.9	0.33	54	**117**	3.8	0.015	2.5

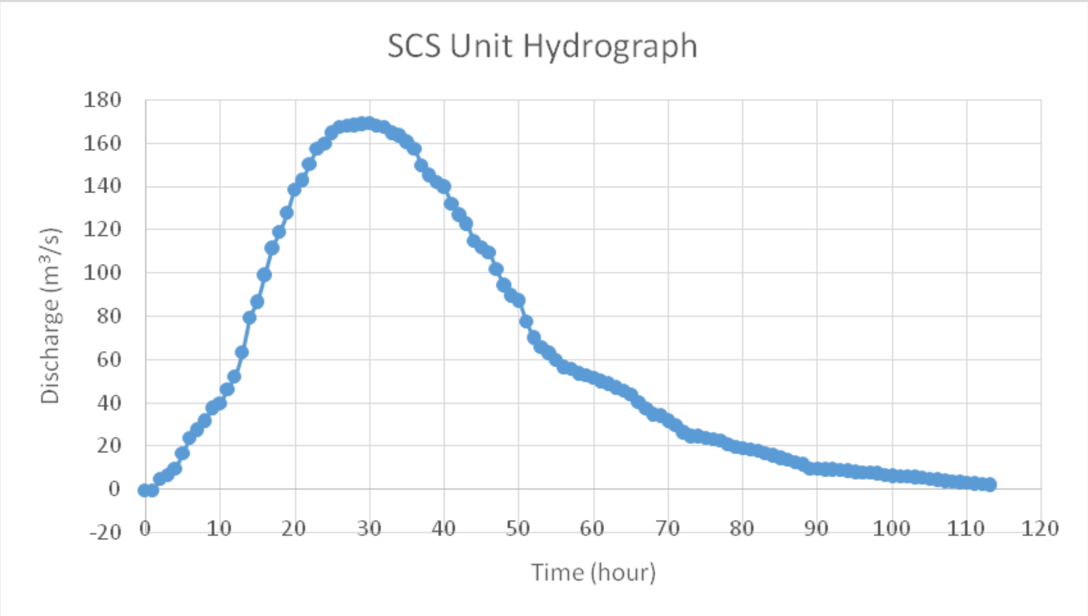

Figure 9: Synthetic Unit Hydrograph for Wadi Al Hasa

V. DISCUSSION:

The runoff model was calibrated using the daily data of rainfall that recorded at the outlet of the study watershed for the years 1990 to 2017, the total runoff computed by the model was found to be 88.93MCM/year and 48.94MCM/year for Time of concentration method and Curve Number method respectively,

The proposed approach of using GIS applying the CN method for runoff coefficient estimation has many advantages over other approaches. Firstly, it uses one software to perform all procedure steps. Secondly, only satellite image, soil maps and DEM are needed to calculate the runoff parameters. Thirdly, all needed calculations are done within the GIS environment using field calculation. Fourthly, it can be modeled using model builder so, runoff parameters estimation process can be efficient, faster, and easily performed for several return period scenarios and for any regions.

VI. CONCLUSIONS:

This research article presented an efficient approach to accurate determination of potential runoff coefficient in Al Hasa catchment area using GIS technique. The effects of land use, soil hydrological characteristics, surface slope, were considered in calculating runoff coefficient and consequently runoff depth and runoff volume. The results of the research show that the total runoff volume for a rainfall depth of 200 mm is 88931520 m3. Results also show that the main factors affect the total flood volumes, are the basin area, and the flow length. Additionally, it has been concluded that the higher CN value and slope percent, the higher runoff and flood hazards.

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