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Hydrological Simulation of Wadi Al-Kouf, Libya

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Abstract

Surface water scarcity poses a serious threat to sustainable development and one of the main restrictive factors of economic growth in Libya. However, the average rainfall records ranged in north of Libya from about 200 to 500 mm, with a maximum of recording on the regions of the Green Mountain where was about 850 mm. Digital Elevation Model (DEM), The Soil Conservation Service- Curve Number (SCS-CN) method and the Watershed Modeling System (WMS, Version 8.1) has been applied to analyze and simulate the surface runoff storms of Wadi Al-Kouf using Hydraulic Engineering Center model (HEC-1). This model was used to simulate runoff volumes and hydrographs. Al-Kouf watershed is located in the central part of Al Jabal Al Akhdar of north Libya. The investigated basin is enclosed approximately between latitudes 32.5° N and 32.8° N and longitudes 21.4° E and 22.00° E. The rainfall data for period (2002-2003) were used for the analysis and estimation of the direct runoff for the study area. Different simulated cases have been studied which showed a good agreement compared with the measured results. The main purposes for embarking on the study determine the amount of runoff and peak flow rate generated from rainfall storms and harvest runoff water surface, by suggestion a set of weirs at various locations in the strategic parts in the study basin may be built to avoid future flooding of the cities and the roads. In this study, we were able to know peak of discharge and volume of each basin outlet and find out where to put weirs. The simulation results reveal that about 190 Million cubic meters of surface water could be harvested.

Keywords: *Green Mountain, Wadi Al-kouf, Surface Runoff, Watershed Modeling System (WMS).*

1. Introduction

Libya is a part of the arid and semi-arid area of the Middle East and North Africa. The climate of the region is affected by Mediterranean depressions in the winter season as a result of its geographical location. Thunderstorms and heavy showers (rain storms) are observed in various places with drop of hail in sometimes as well, particularly on the mountainous areas in the west and the east, sometimes also the snow was falling when the country influenced by Atlas' mountains and Siberiain depressions. The average rainfall records ranged in these areas (north of Libya) from about 200 to 500 mm, with a maximum of recording on the regions of the Green Mountain where was about 850 mm [1].

The Green Mountain is the rainiest area in Libya, in which receives the highest rainfall amounts on Shahat for more than 600 mm / year [2] Wadi AL-Kouf is considered the most important sub-basin located at the center of the Green Mountain basin shown in Fig.1. Green Mountain Basin climate is the jewel in Libya while it receives about 7 billion cubic meters of rainfall. This basin topography is divided according to the division of water to the line: External basin constitutes 40% of Green Mountain Basin area of water loss in the Mediterranean Sea as shown in Fig.2. While Internal basin accounts for 60% of the mountain basin area and the majority of its water is lost by seep and evaporation of the hundreds of arroyos and a thousand ponds and lakes located on the north of the Sahara [3]The study area was subjected to rainstorms followed by floods, which caused disastrous impacts on roads, bridges and settlement, This thunderstorm was commonly an accident, unpredictable and short duration(4 hours), and amount of water formed torrential floods recorded in1988, 1996. In Qandulah town, 2005 many animals were killed, while in 2010 destroyed many buildings in AL- Abraq area as shown in Fig.2 [4]

(1966-1965). The Yugoslavian Company Hydro Project prepared study and it is about a general survey of water resources and agricultural potential in Wadi AL-kouf. The study pointed out that the rate of annual precipitation on the basin is high, it reached 440mm and thus it becomes among the best promising regions in the Green Mountain, Also, the study pointed out that the most appropriate locations for hydraulic structures engineering as well as establishment of a group of weirs, and storage dams on the parts of the Wadi-AL-kouf. [5]

The aim of this research is to simulate the watershed modeling system of wadi AL-kouf with the HEC-1 model in order to determine the amount of runoff and peak flow rates due to rainfall storms and the potentiality of harvesting the generated surface run-off

Kazemi et al. (2008) [6] used Watershed Modeling System (WMS) model for the Kama basin in the north of Torbat Heydarieh.

The results of this study showed high accuracy and speed of simulated hydrological and hydraulic models. Akbarpoor and FalahTafti (2004) [7] implemented WMS model for the basin in Bigeand Roshtkhar in Khorasan province. The results of the sensitivity analysis showed that the soil moisture peak is important factor in estimation of the flow. Mousavi et al. (2007) [8] examined the floods of

West Gilan using the WMS model SCS synthetic hydrograph and expressed accurate calculation of the amount and timing of peak flow. Arturka et al. (2006) [9] examined the flood hydrograph simulation through WMS for a number of basins in Turkey. The use of WMS model in this study showed that the results of this model can be used to determine the basin management strategies.

The paper is divided into four sections. The first section is introduction contains the problem identification and objectives. The second section is study area /methodology. This section describes Wadi AL-kouf in Green Mountain and present the type of the data needed to carry out the modeling process of the hydrologic studies which include Precipitation, Geology and Topography and Land Use/Land Cover. The third section is model calibration and verification. The last section is Results and discussion.

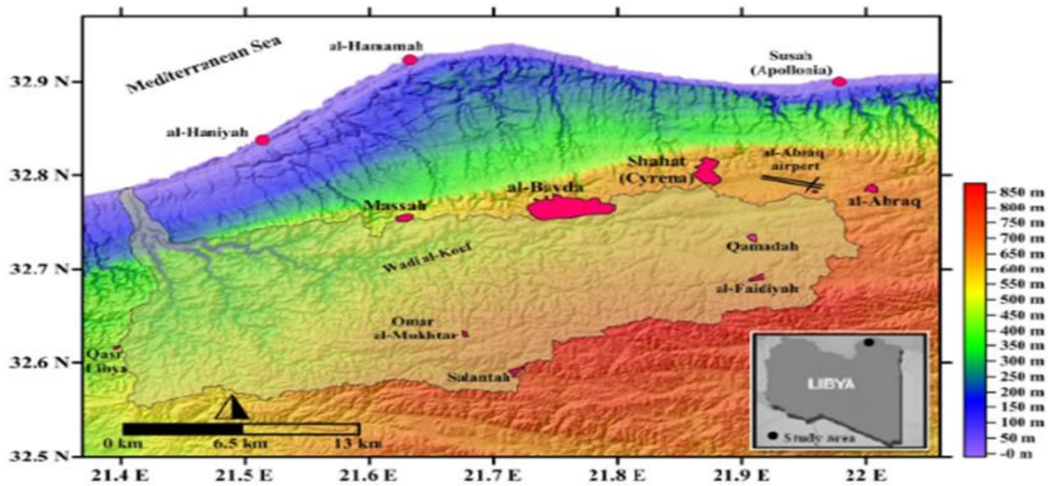

Figure 1 Location the Study Area and drainage basin outline (Wadi AL-kouf Watershed).

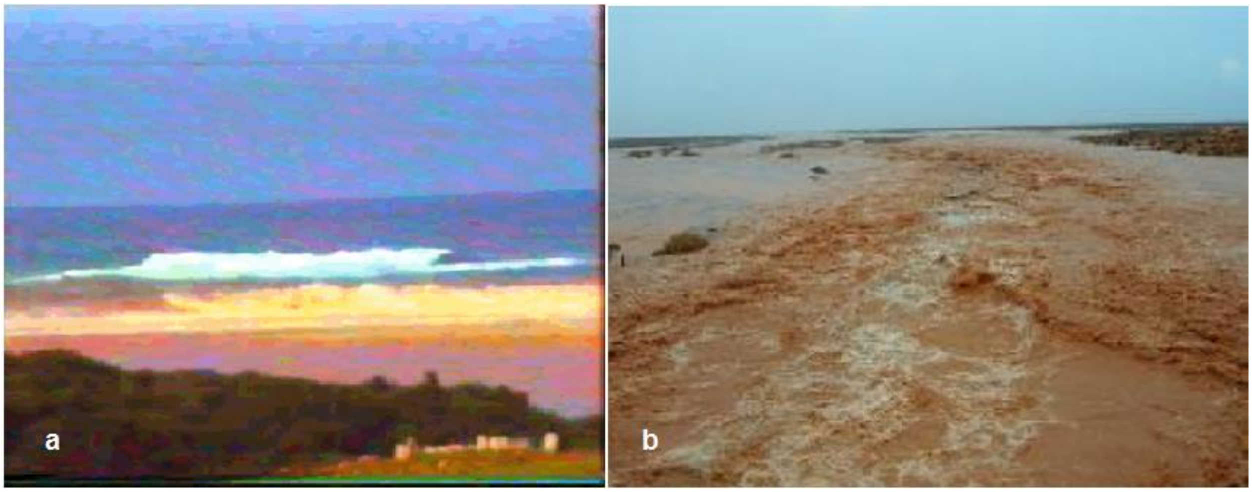

Figure 2. (a).Loss of storm water in the Mediterranean sea and (b). Field photograph shows the flash flood event in Al -Abraq area in November, 2010.

2. The Study Area

2.1 The Study Area Characteristics

AL-kouf basin is located approximately between latitudes 32.5° N and 32.8° N and longitudes 21.4° E and 22.00° E, covering an area of 921 km², filling in the central part of Green Mountain, NE, Libya. The study area encountered a lot of famous Libyan cities and villages such as al-Bayda, Shahat, Massah, Omar Al-Mukhtar, Salantah, al-Faidiyah and Qarnada as well as al-Abraq airport in the upper reaches of the studied basin as demonstrated in Fig1.

Climatologically, the study area enjoys a Mediterranean climate of arid and semi-arid in nature with rare meteorological stations. The nearest meteorological station is located in Shahat city at the upper reaches of the studied basin. The temperature ranges from 13 °C in January to 25 °C in August. The level of humidity is relatively high due to close proximity to the sea and ranges from 61.6% in the summer to 73.3% in the winter [10].

2.2. Geology and Topography

Lithologically, the stratigraphic sequence of Wadi Al-Kouf basin is represented mainly by carbonate rocks, ranging in age from Eocene to early Miocene. Four formations have been recognized namely; Darnah, Al-Bayda, Al-Abraq and al-Faidiyah arranged from oldest to youngest as shown in Fig 3. Structurally, on a regional scale, Green Mountain defines a gentle doubly plunging anticlinorium with axis trends roughly N50°E and plunges gently to the northeast and southwest. Abd El-Wahed and Kamh (2013) [11] recorded in Wadi Al-kouf region three folds; two synclines and one anticline. They also, given three main fault systems, first is a set of E-W striking faults, second is a set of N-S striking faults and third is a system of normal NW-SE striking faults. These structural elements play an important role in the growth of the drainage pattern of Wadi AL-kouf basin.

The surface drainage of Wadi AL-kouf may be broadly divided into three sub-catchments as shown in Fig.4 according to drainage namely; the biggest tributary is Wadi Jrjar Omah sub-catchment which covers an area of 614.69 km^2 divided into 10 sub-basins (k1,k2,k3,k4,k5,k6,k7,k8,k9 and k10) and, the second is Bait Saleh sub-catchment that covers an area of 174.65 km^2 divided into 4 sub-basins (k11,k12,k13 and k14) and the third is Wadi Bait Al-Sudan sub-catchment that covers an area of 131.68 km^2 divided into 3 sub –basins (k15,k16and k17). Wadi Al- kouf is the confluence of the three sub-catchments and represents about 921 km^2.

The tributaries of the main channel of Wadi AL-kouf are arranged in NW-SE direction in a sub-parallel drainage pattern. The topography of Wadi Al-kouf basin is notice by three cliffs, first from 250-300 m runs parallel to shoreline, the second cliff ranges between 450-600 m and runs NE-SW direction and the third cliff is up to 880 m near Salantah village. The topography of the basin is engraved by deep, narrow and meandering valleys. These valleys running generally from east to west with decreasing in the general gradient, having steep to very steep sides.

2.3 Land Use/Land Cover.

Depending on the Geologic map of Wadi AL-Kouf watershed and four formations (Darnah, al-Bayda, al-Abraq and al-Faidiyah) illustrated in fig.3, the information soil texture and infiltration were used to determine the soil group. Based on the SCS soil classification (SCS 1985), soils are categorized into one of four different types ranked from A to D on the basis of their runoff potential. Results shows that the surface deposits of the basin under study is belonged to soil group (C) [12]. The Land use/ land cover information of Wadi AL-kouf is presented in Fig.6. The required information for the hydrological modeling was derived from ARCGIS (v.9.1). Wadi AL-kouf watersheds are dominated by bushes (green), agricultural field (light green), and forest (white). It shows that watershed is not yet developed for urban areas. Furthermore, the built-up areas in watershed are less than 10% in total. The Curve Number values of Wadi AL- kouf sub-Basin are presented in Table 1. The value of the Curve Number (CN) was obtained from standard tables according to the soil type and land cover of each sub-basin.

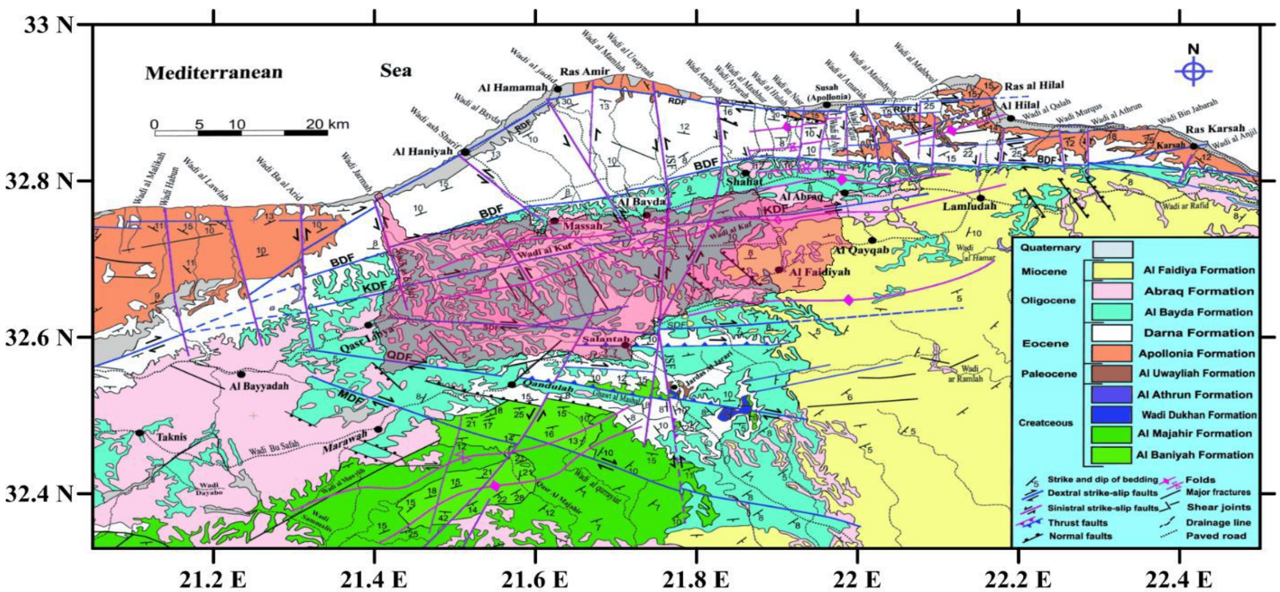

Figure 3. Geologic map of Wadi AL-Kouf watershed (after Rolich, 1974 and modified by Abd El-Wahed and Kamh, 2013).

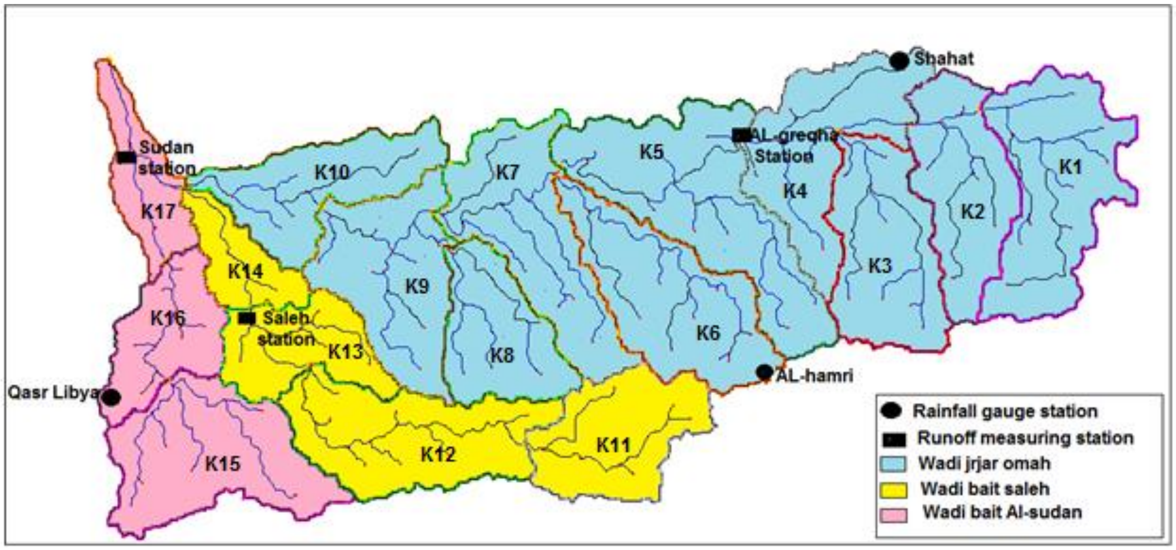

Figure 4 Wadi Al-kouf sub- catchment, sub-basins, Rainfall gauge station and Runoff measuring station.

2.4. Precipitation.

Rainfall is considered as one of the major input parameters required for hydrologic studies. The rainfall in arid and semiarid areas is commonly characterised by extremely high spatial and temporal variability (Wheater, 2005) [13]. The Green Mountain, receives the rate about 7 billion cubic meters in the year. The storm (3/1998) in Al-Ghreqh bottom of the al-Bayda city was produced runoff 2912 l\sec did not express them to the Wadi AL-kouf except 1387 l/sec, meaning that the wadi lost about 1525 l/sec by seep which the rate of 52.37% along 21 km between two measurements. The infiltration calculated rate is72.62 l\sec\km in average [14]. Wadi AL_kouf daily rainfall data sheets during 1981 to 1983 was obtained from three ground rain-gauge station data namely Shahat, Al-hamri and Qasr Libya shown in Fig.4. Which were used as input precipitation to the hydrological model, from Arab Center for the Studies of Arid Zones and Dry lands (ACSAD) [15] and Libyan National Meteorological Centre (LNMC). The annual average rainfall at shahat station for the period (1981-2010) are shown in Fig.5 which indicate that the maximum precipitation was 834.8 in 1991and the driest season was recorded in 1982 of 410 mm [16].

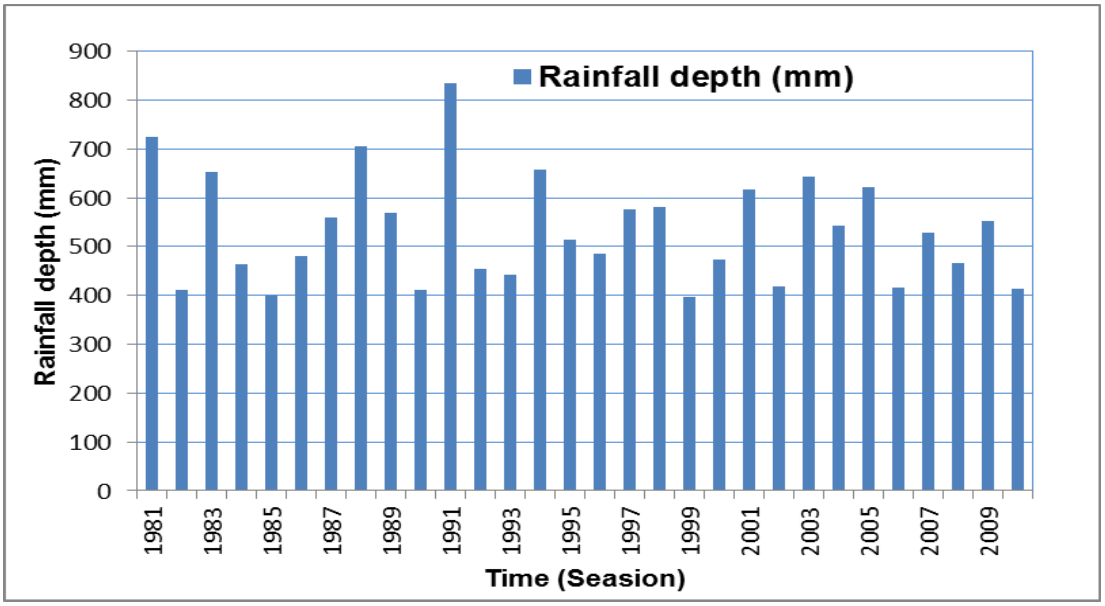

Figure 5 Annual rainfall depths of Shahat area for the period (1981-2010).

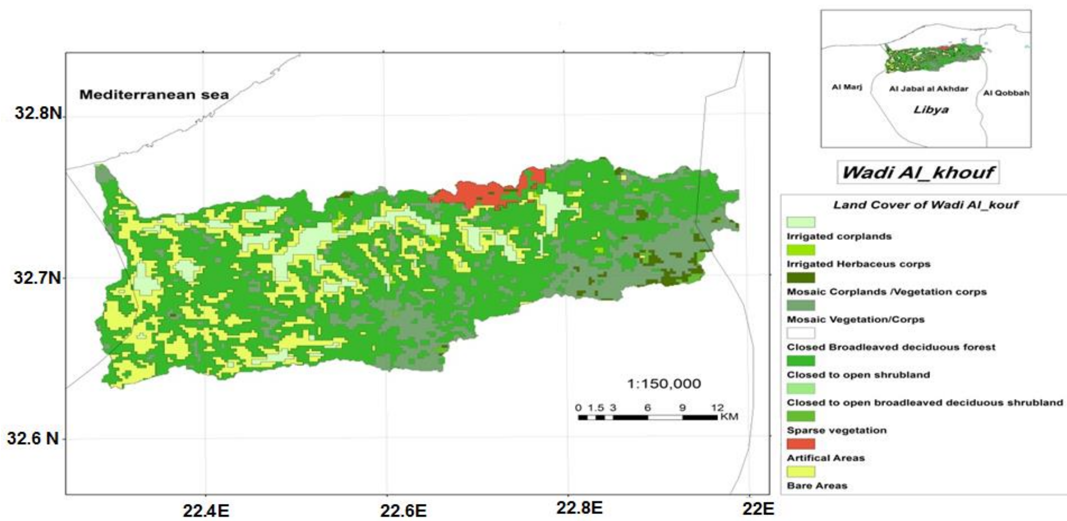

Figure 6 Land use/land cover map of the study area.

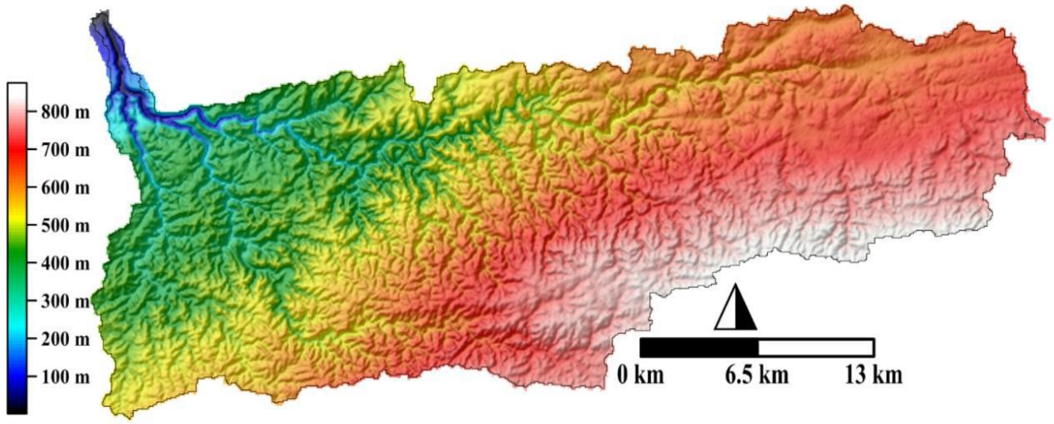

Figure7. Study Area Topographical map based on Digital Elevation Model (DEM).

Table1. Curve Number values of Wadi-AL kouf sub-Basin.

Sub Basin	CN	Sub Basin	CN
K1	85	K10	76
K2	85	K11	76.5
K3	85	K12	76.5
K4	85	K13	76.5
K5	87	K14	88
K6	84	K15	79.3
K7	86	K16	79.3
K8	84	K17	83
K9	84		

3. Methodology

Watershed modeling system (WMS) [17] was used to find out the quantity of rainfall that can be harvested in Wadi Al kouf watershed. The Digital elevation model (DEM) of Wadi AL-Kouf shown in Fig.7 was derived using Global Mapper (v. 12) [18]. A total of 17 sub-basins were delineated and the geometric data were computed as shown in Table 2. The HEC-1 parameters (precipitation, loss method and Unit Hydrograph method) were setup and the outflow hydrographs for the given rainfall events were generated. All the aforementioned data were projected on the Universal Transverse Mercator (UTM) withWGS84 datum. The water losses due to infiltration were computed using the Soil Conservation Service Curve Number (CN) method (SCS 1985). This method has been used in calculating water loss in arid and semi-arid regions (e.g., Sorman et al. 1990[19] Gheith and Sultan 2002[20]. Hammouri and El-Naqa 2007 [21] Ghoneim 2008[22]). With the DEM and CN, derived from the soil and land cover data, Wadi AL- kouf watershed model was executed. The main formula for SCS-CN method as described by the Soil Conservation Service, 1972 for the relationships between precipitation and runoff is expressed as [23].

$$p_e = \begin{cases} \frac{(p-0.2S)^2}{p+0.8S} & \text{if } p > 0.2S \quad (1) \\ 0 & \text{if } p \leq 0.2S \quad (2) \end{cases}$$

Where:

p_e = the direct runoff or rainfall excess (mm).

P = the storm rainfall (mm).

S = $\left(\frac{1000}{CN} - 10\right)$ x 25.4, the maximum potential soil water retention (mm).

CN = the curve number (dimensionless).

In large basins that consists of a variety of applications and soils, it is usually necessary to use composite curve number (CN_C) which is calculated by the following equation (Alizadeh, 2003) [24]

$$CN_C = \frac{\sum A_1 \, CN_1}{\sum A1} \qquad (3)$$

4. Model Calibration and Verification

Calibration is essential part of the modeling process in order to verify the adequacy of the numerical model with the study area. The calculated curve number CN is adjusted until the simulated Run-off computed by the model is reasonably close to measured data. The measured run-off data from stations Saleh, AL-Ghreqah and Sudan shown in Fig.4 were used in the calibration process. For calibration and determination of parameters of Al-Kouf basin, the rainstorms from 1981 to 1983 were chosen. Fig.7 (a, b and c) shows the resulted hydrograph at stations Saleh, AL-Ghreqah and Sudan that are successfully simulated different rainfall storms. Fig.7a shows the resulted hydrograph at Saleh station during the rainstorm (5/2/81-11/2/81) that continued for 93 hours. The model and measured results are in reasonable agreement regarding the peak flow rate (4.303m^3/s). However, it shows a discrepancy in the rising and falling limbs of the resulted hydrograph. Fig.7b shows the resulted hydrograph at AL-Ghreqah station during the rain storm (22/1/83-23/1/83), that continued for 27 hours, the peak was 0.24 m^3/s and the model 0.23 m^3/s. The model and measured results demonstration good agreement regarding peak and time. Fig.7c shows the resulted hydrograph at Sudan station during the rain storm (22/1/83-23/1/83) that continued for 36 hours, the peak was 0.41m^3/s and the model 0.4 m^3/s. The model and measured results show good peak and fair rising limb.

Table 2 Geometric characteristics of studied basins.

Sub Basin	UTM		Level	A	BS	L	P	AVEL	MSL	MSS	CTOSTR	CSD	CSS
	E	N											
K1	584733	3624961	631.16	70.71	0.0364	11927	58773	402.88	16904	0.0095	240.33	7990.5	0.0088
K2	580791	3624118	619.66	52.41	0.0352	11382	46530	508.55	13062	0.0114	156.9	6812	0.0082
K3	577090	3623650	602.54	58.01	0.0505	13039	46693	457.42	14153	0.014	1529.1	9384.4	0.0137
K4	571774	3623193	554.52	60.92	0.0563	11184	61108	606.34	11151	0.0067	601.07	4848	0.007
K5	562233	3621841	464.11	85.89	0.0917	17545	71107	764.62	24711	0.0135	243.98	11960	0.01
K6	561960	3621334	414.84	67.26	0.0946	16172	54204	468.26	19819	0.0176	480.66	14145	0.0187
K7	555451	3619343	338.9	65.68	0.1321	13737	61115	613.46	18618	0.0189	78.48	9107.2	0.0169
K8	556249	3617470	392.89	43.01	0.1319	10504	38456	565.79	11072	0.0239	182.64	6692.5	0.0283
K9	549418	3619635	226.94	61	0.1651	12855	52164	710	14424	0.0231	313.92	7281.2	0.0165
K10	542236	3620830	67.94	48.75	0.1906	14134	51671	644.46	16395	0.0218	180.25	9772.2	0.0231
K11	560365	3606804	665.18	49.47	0.0584	10245	42772	651.2	11562	0.0118	1332.6	6930.7	0.0106
K12	548855	3611145	397.02	66.51	0.1171	13806	56379	744.52	19184	0.0134	562.67	11343	0.0141
K13	545672	3614168	326.71	35.94	0.1276	9084.9	40593	697.45	9649.4	0.0201	897.24	5126.5	0.0118
K14	542048	3620568	87.67	22.66	0.2082	9153.7	31315	721.66	9077	0.0264	0	6133.7	0.0292
K15	541188	3610301	368.65	68.46	0.0835	11935	54331	391.24	12311	0.0146	547.93	5155.5	0.0209
K16	541117	3616655	237.24	36.74	0.1267	9360.12	37588.95	374.27	9218.89	0.0164	156.96	4794.19	0.0195
K17	538056	3627614	3.2	27.69	0.1951	12275.58	37829.44	215.6	12256.92	0.0186	480.05	7281.84	0.0119

A= basin area in KM^2 , BS= Basin Slope , L= Basin Length in M , P = Basin perimeter in KM , AVEL = Mean basin elevation

MSL = Max stream length in M , MSS = Max stream slope in M , CTOSTR = Distance from centroid to stream in M , CSD =Centroid stream distance in M

CSS = Centroid stream slope

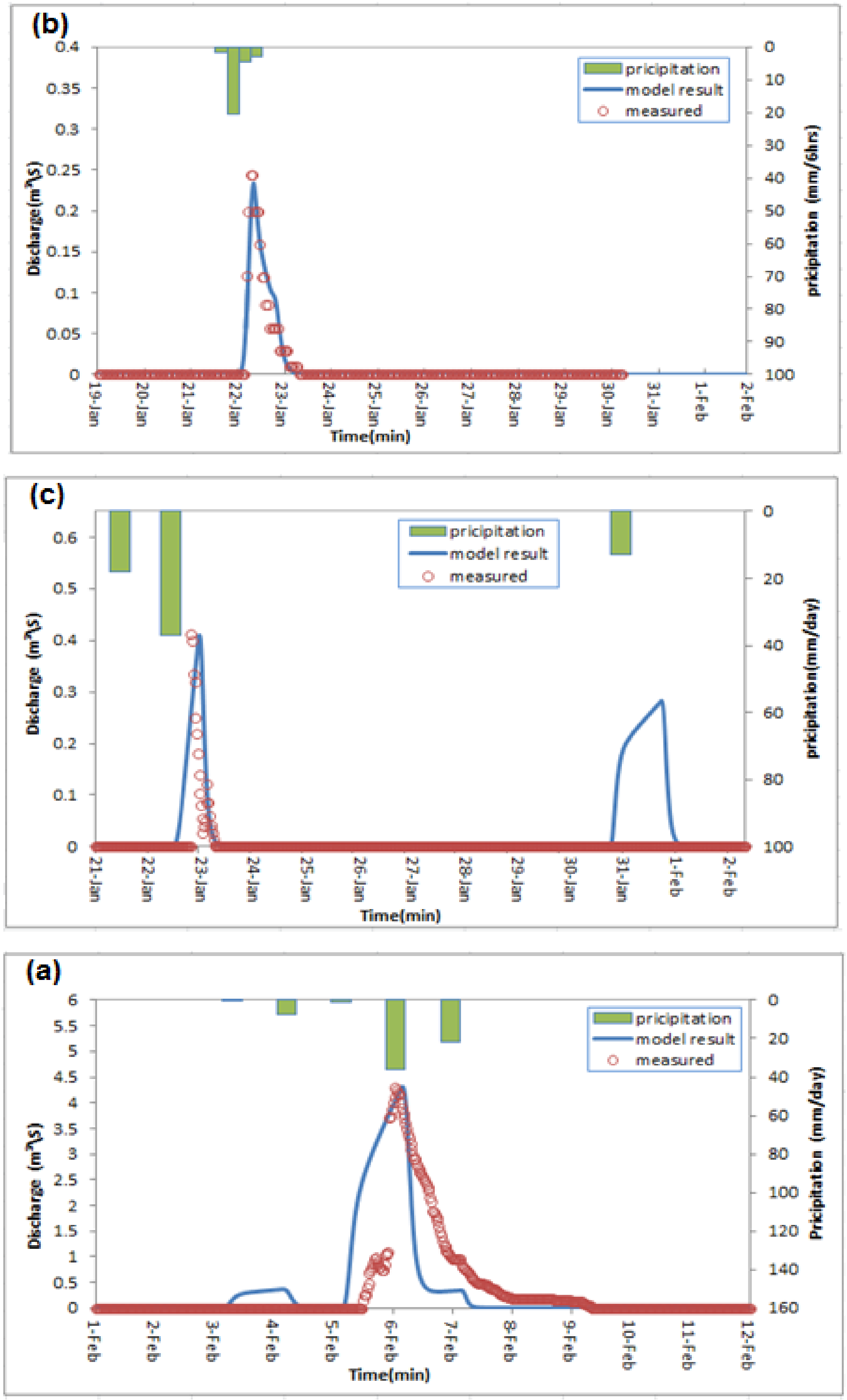

Figure7 Comparision between the model results and measured data of Wadi AL-kouf at three different station, (a) Saleh station, (b) AL-Ghreqah station, (c) Sudan station.

5. Results and Discussion

The main objective of the study is to evaluate Wadi Al-kouf basin by determine the amount of runoff and peak flow rate generated from rainfall storms and harvest runoff surface water. The HEC-1 and WMS rainfall runoff model to generate amounts of surface flows and peak flow rates from semi-arid watersheds. In order to simulate the runoff events in the catchment area of seventeen sub-basins with total area of 921 Km^2, the season 2002-2003 was selected based on the available measured data with total annually rainfall depth 502.2 mm which represent the average rainy seasons during the study period (December2002-March2003). The total is 60^{th} rainy days. These rainy days extended along 121^{st} days (length of season 2002- 2003). Seventeen outlet points have been selected based on sub-catchments of the target wadi for this simulation as illustrated in Fig.4

The rainy season 2002-2003 is a typical season for harvesting the generated surface run-off. Simulation results applied for each seventeen basins to find out the volume of water produced by the runoff that can be collected and stored. Furthermore, the downstream outlet at Wadi. Al-Kouf catchment, the flow was very severe 393.18m^3/s at (K17). This is a one of the sub-Basin of Wadi Al-Kouf, discharge was calculated about 18.66m^3/s, at (k8). We see the discharge of all sub-basins was also calculated. Time to peak and flow duration in flash flood simulations have been estimated. In terms of the evaluation of sub-catchments water contribution towards Wadi Al-Kouf, the flow volume of water that can reach the downstream point of each sub-basin has been arranged in Table 3.

The minimum total harvested runoff volume from the catchment areas of the 17 sub- basins was 8.8×10^6 m^3. Fig .8 shows Simulation of flash flood event of (2002-2003) at four sub-basins (k4, k7, k10 and k17). The peak flow rate is 105.72, 202.23, 266.19, 393.18 cubic meters per second (Cms) respectively.

The results showed that the harvested runoff volume ranged from 8.8 x10^6 to 132.1x10^6 m^3 in that year. Thus, the total annual harvested runoff reached about 190.2×10^6 m^3. These quantities can contribute in solving the problem of water shortage within the region.

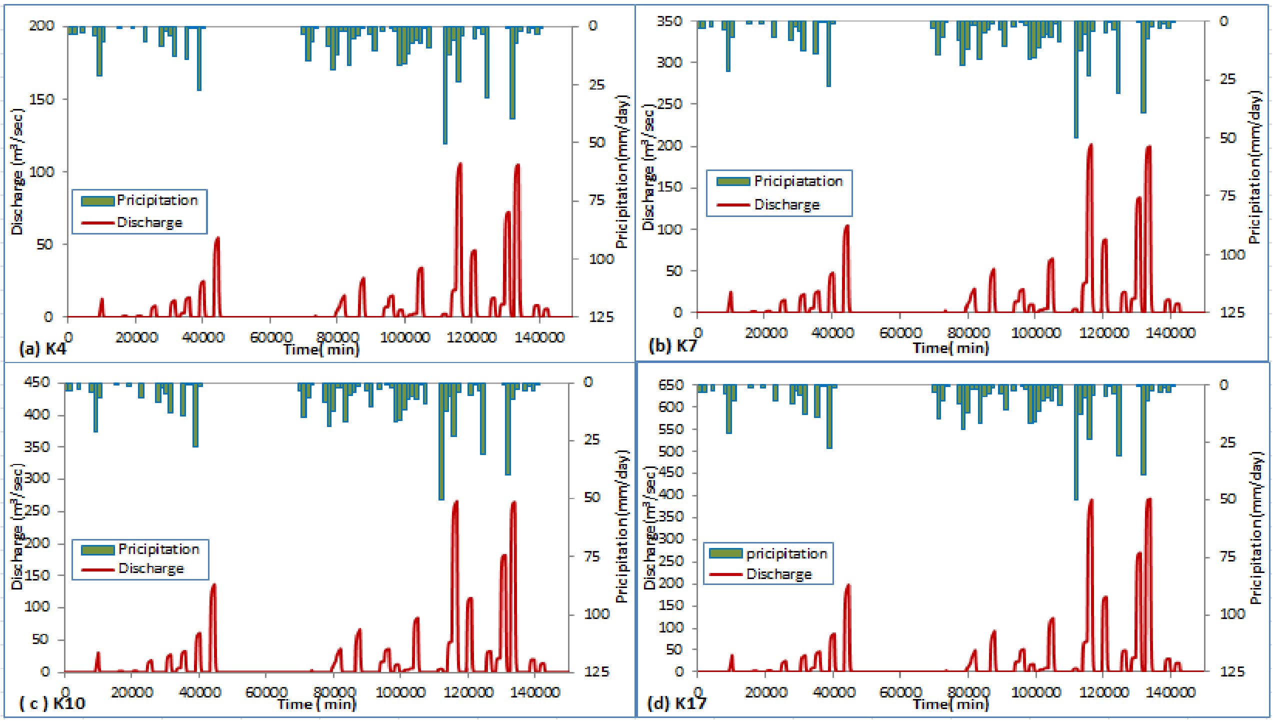

Fig. 8. Simulation of flash flood event of (2002-2003) at four sub-catchment outlets of Wadi AL-kouf: (a) k4, (b) k7, (c) k10, and (d) k17.

Table 3 Simulation results of event (2002-2003) at Wadi AL-Kouf.

Sub Basin	Peak(m³\sec)	Volume (m³)	Sub Basin	Peak(m³\sec)	Volume (m³)
K1	30.8	$15.4x10^6$	K10	266.19	$132.1x10^6$
K2	53.69	$26.9x10^6$	K11	20.34	$8.8x10^6$
K3	25.36	$12.7x10^6$	K12	47.67	$20.6x10^6$
K4	105.72	$52.8x10^6$	K13	62.47	$27x10^6$
K5	144.07	$72.4x10^6$	K14	72.41	$32.2x10^6$
K6	29.07	$14.3x10^6$	K15	28.72	$13x10^6$
K7	202.23	$101.4x10^6$	K16	44.18	$20.1x10^6$
K8	18.66	$9.1x10^6$	K17	393.18	$190.2x10^6$
K9	247.35	$123.6x10^6$			

6. Conclusion

The process of estimating the surface runoff derived from watershed , the important issues in water resources engineering, especially in studies related to water harvesting, so the use of modern methods in the estimation of surface runoff is an important factor, Especially in the valleys unearmarked. This reserch is concideredthe first hydrological study for Wadi Al kouf. Watershed for Wadi AL-kouf is applied on area of 921 km², divided to seventeen sub-basins. The simalated results for rainfall events succesfully coincident followed the measured flow rates at different three measuring stations.

The program was calibrated with measured run-off data from stations Saleh, AL-Ghreqah and Sudan during the two storms (5/2/81)and (22/1/83). The using the rainstorms (2002-2003) has reached to Wadi-ALkouf is required a rainstorm intensity of at least 15 mm in order to initiate surface runoff with a noticeable flood peak at its main outlet. The calculation and results, based on the SCS method. From the fig we see that the average runoff depth for the (2002-2003) storm in Wadi Al-kouf watershed is equal to 24.8 mm.

After hydrological study of the basin of the Wadi AL- Kouf found that is the best sites for weirs on the main stream of the valley at the outlets of sub-basins. The total annual harvested runoff reached about $190.2 \times 10^6 m^3$. The effective quantity of annual runoff that can be stored in the suggested weirs sites can be used for different purposes andsolving the problem of water shortage within the region. In the present project, the methodology for determination of runoff for Wadi Al-kouf watershed using Watershed Modeling System(WMS) and (SCS) method was described. This approach could be applied in other libyan watersheds for planning of various conservations measures.

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