Comparison Study of Two Methods Used to Estimate Surface Runoff Hydrograph for Small Basins

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Abstract

In this study Rainstorm hydrograph peak discharge and unit-hydrograph peak discharge in small basins were calculated and evaluated using various methods for peak discharge assessment applying 6-hour storm rainfall duration. Rainfall-runoff models: HEC-1 option of the WMS software based on American Soil Conservation Service (SCS) Curve Number (CN) Method and Mockus Method were used to compute runoff hydrograph peak discharge, and time to peak discharge in Khazir river basin near the Mosul city North Iraq for dry, normal and wet soil cases. The aim of this study was to assess the ability of these two methods to predict design peak discharge in comparison with the observed data obtained. The results demonstrate that the peak discharges computed by HEC-1 in WMS software method are mostly closest to the data observed. And dry state of soil at CN=66 showed the best agreement with the observed data.

Key words: peak discharge, Curve Number, hydrograph, WMS, Mockus.

دراسة مقارنة اداء طريقتين لتقدير السيح السطحي للاحواض الثانوية الصغيرة

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الخلاصة :

في هذا البحث تم استخدام طرق تقدير وتقييم تصريف الذروة لهيدروكراف الموجة المطرية والهيدروكراف القياسي في الاحواض الصغيرة ولاستدامة 6 ساعات. تم استخدام نموذج HEC-1 في برنامج WMS الذي يستند على طريقة خدمة حفظ التربة الامريكية (SCS) رقم المنحني (CN) وطريقة (Mockus) في حساب قيمة تصريف الذروة وزمن الوصول اليه في حوض نهر الخازر الواقع قرب مدينة الموصل شمال العراق ولحالات التربة الجافة والطبيعية

والرطبة. الهدف من هذه الدراسة هو لتقييم قابلية هاتان الطريقتان في تقدير تصريف الذروة بالمقارنة مع البيانات المرصودة. اظهرت النتائج انه قيمة تصريف الذروة المحسوبة بطريقة HEC-1 في برنامج WMS تكون اقرب الى البيانات الحقيقية المرصودة. كما بينت النتائج ان حالة التربة الجافة عند CN=66 اظهرت تقارباً جيداً مع البيانات المرصودة.

الكلمات الدالة: نهر الخازر، تصريف الذروة، الاحواض الصغيرة، خدمة حفظ التربة الامريكية.

Introduction:

The surface runoff mean the flow of the results runoff from a storm rainfall through a stream in the catchment, when precipitation fall the part of its goes as losses such as evaporation, infiltration and surface reservation all this losses are subtract from the total amount of rainfall before runoff begins to happen. Then the increase in precipitation will moves on the surface of the ground until it reaches the small canals and this part of the runoff called (Overland flow), this several small channels linked together to form the large channels, this runoff called surface runoff.

For the planning and projection of soil and water conservation structures in small catchment, it is necessary to know the relation between rainfall and runoff. Knowing the amount of runoff from the catchments is important especially for planning and design of the hydraulic structures such as culverts, bridges and the erosion control measures. One of the most important objectives of hydrological engineers is to calculate water yield of the catchment and the other is to determine the flood flows for planning the water storage structures. American Soil Conservation Service (SCS) Curve Number (CN) Method is one of the most widely used techniques for estimating surface runoff depths from storm rainfall.

Several studies for estimating hydrograph peak discharge have been made in the past, Sorman (1995) applied the geomorphologic instantaneous unit hydrograph GIUH model to estimate the peak discharges resulting from various rainfall events for watersheds in Saudi Arabia [1]. Ponce and Hawkins identified the CN method as one of the most popular tools for calculating runoff depth [2]. Jain et al. derived the peak discharge of runoff and time to peak using the GIUH formulas for rivers in western India [3]. Zhan and Huang applied Arc CN Runoff tool (an extension of ESRI's ArcGIS software) to determine CNs and to calculate runoff or infiltration from a rainfall event for a watershed in Lyon County and Osage County, USA [4]. Jain et al. developed an enhanced version of the SCS CN-based Mishra-Singh model incorporating the storm duration and a nonlinear relation for initial abstraction [5]. Bhadra et al, (2010) adopt the Soil Conservation Service's (SCS) Curve Number (CN) and Muskingum methods to route surface runoffs from different sub-basin outlet points up to the outlet point of the catchment [6]. Bhunya et al, present a Critical Review of the synthetic unit hydrograph methods available in hydrologic literature [7] .Vassova evaluate the Design discharges in a small catchment using various methods for peak discharge assessment applying 24-h storm rainfalls reduced to short duration.[8]

The hydrograph is one form of expression of the relationship between the precipitation and the surface runoff, the hydrograph is the discharge curve results from specific rainfall storm within a period of time. the runoff hydrograph gives discharge rate in all the points of the storm during the period of rainfall on the catchment, and the hydrologists depends on the measured or calculated hydrographs to estimate or to get the value of the peak discharge which is very important in the design process security for hydraulic structures, The area under the hydrograph between any two points of time give the total volume of water flowing between the two points over a period of certain time, so in addition to getting the peak value of the discharge and the time to reach the peak discharge the hydrograph gives the volume of runoff that is very necessary for the designer to estimate the sizes of dams and water reservoirs and other hydraulic structures.

The objective of this study:

The objective of this study is to estimate the flood discharge from the accurate calculations of morphological and hydrological characteristics of the river basin under study. These estimated values are used to draw the hydrograph of the Khazir basin and the sub basins by using the method of watershed Modeling System WMS version 7.1. [9] And dimensionless standard hydrograph method according to Mockus 1957.[10]

Study Area and Basin Description:

The Khazir river basin with a length of 96.5 km and a catchment area of about 3280 km^2 is selected as the study region. The Khazir basin is located in the north-eastern of the Mosul city north of Iraq with longitude and latitude of 43º 10'–44º 07'E and 36º 04'–37º 05'N respectively. All of the catchment area is within Iraqi boundaries. The maximum rainfall depth recorded for a single storm falling over the catchment area is 50mm. Khazir river is the main tributary of Greater- Zab river. The main basin divided into 12-sub basin as illustrated in figure -1- which be easily subjected to the hydrological studies. The morphological properties of these sub basins are calculated and tabulated in **Table (1).**

Table .(1) Morphological property of sub basins within Khazir basin*

Basin name	Area (Km^2)	Slope	Perimeter (Km)	Length (Km)	Shape factor	Sinuosity factor	Elevation (m)
1B	194.6	0.1862	79.963	15.849	1.29	1.25	1025.8
2B	298.49	0.2149	119.79	36.767	4.53	1.08	1190
3B	386.19	0.2299	149.93	22.509	1.31	1.17	1033.8
4B	217.69	0.1598	104.94	20.894	2.01	1.13	911.23
5B	213.61	0.1346	95.871	22.803	2.43	1.38	684.42
6B	272.44	0.108	125.91	30.601	3.44	1.09	603.92
7B	147.61	0.0256	78.538	26.059	4.6	0.94	484.39
8B	303.02	0.0693	114.63	34.725	3.98	1.18	515.66
9B	306.52	0.0341	110.21	30.794	3.09	1.06	414.78
10B	141.2	0.0174	83.726	24.857	4.38	0.99	380.13
11B	424.13	0.043	209.73	50.638	6.05	1.4	444.82
12B	374.85	0.0268	128.26	33.907	3.07	1.34	323.91
Total	3280.34	0.1061	432.85	96.589	2.84	1.48	665.12

***from analyzing the (DEM) of study area by using WMS software.

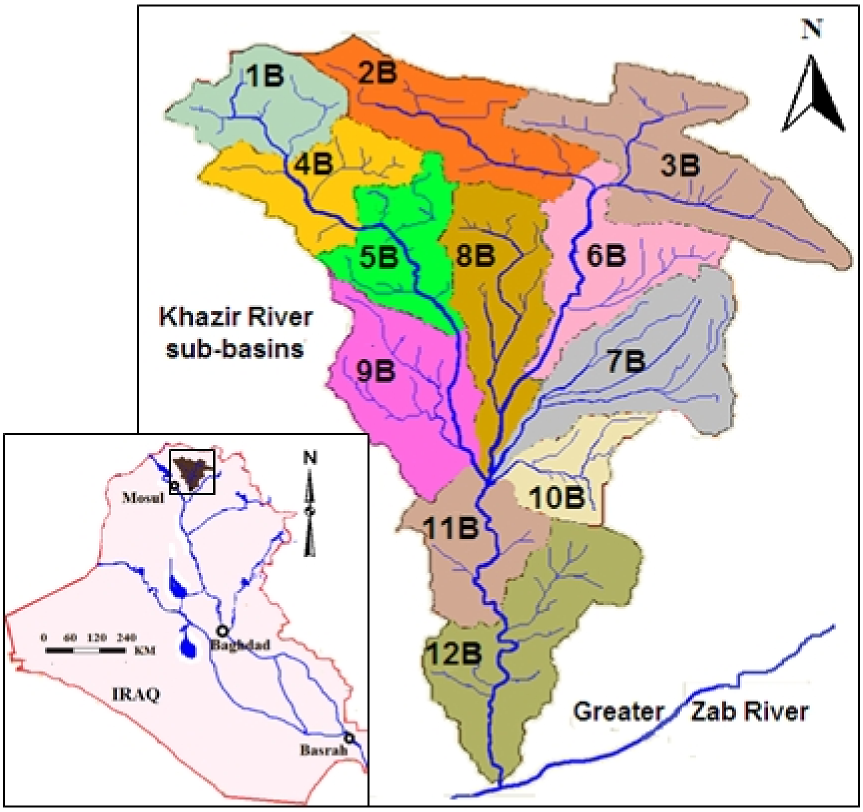


Fig .(1) Khazir River Basin

Curve Number (CN) for Khazir Basin:

The CN represents a soils hydrologic group and cover treatment, and is used to determine the net amount of runoff from the basin. To find the Curve Number (CN) for the Khazir basin in natural state we subdivided the study area to three equal areas **A**, **B** and **C** then the hydrological soil group were determined based on various soil factors such as vegetation cover, land use and soil texture. The land use is considered pasture and according to the soil texture, it classified to three types as follows:

A- Sandy loam and Silty loam whose Curve Number is **74**

B- Silty Clay loam whose Curve Number is **82**

C- Silty clay whose Curve Number is **91**

The average Curve Number for the entire of the Khazir River is **82**. This was adopted as study area CN for natural state CN2=**82**.

Depending on the standard tables, the curve number not be stay in its natural state, where changes from time to time by soil moisture for this reason the following equations are used to find the curve number for study area in dry and wet cases depending on the CN2 for the natural state[8]:

$$CN1 = \frac{4.2\ CN2}{10 - 0.058\ CN2} \qquad \text{……………………… (1)}$$

$$CN3 = \frac{23\ CN2}{10 + 0.13\ CN2} \qquad \text{……………………… (2)}$$

Where:

CN2: curve number in the natural state of soil. (Where reached **82**).

CN1: curve number in the dry state of the soil. (Where reached **66**).

CN3: curve number in the wet state of the soil. (Where reached **91**).

The runoff and draw of the hydrograph for Khazir basin and sub-basins were calculated using three values for curve number and them **66**, **82**, and **91** for dry, natural and wet cases respectively:

Methods for peak discharge assessment

Surface runoff peak discharge, volume of runoff and the runoff hydrograph for Khazir river basin and its sub basins are carried out and compared by using the following two methods:

First method: Watershed Modeling System WMS model

A composite, Soil Conservation Service (SCS) curve number (CN) method using the HEC-1 model in Watershed Modeling System WMS software [Version 7.1] [9] was chosen to calculate surface runoff hydrograph for each Khazir river sub- basins. WMS software is one of the more specialized and integrated programs in the field of water resources systems and digital hydrological. Simulation of surface runoff and draw the runoff hydrograph included by the following steps:

1. Declaration form of the study area was converted into digital elevation model [DEM] with the ability of spatial discrimination 30*30 meters per cell using Global Mapper program so as to facilitate the possibility of dealing with this digital data with other software.
2. The digital data [DEM] were used as input data to WMS program which deals with the river basins in digital form to delimitation Khazir main basin and its sub basins. The importance of this program lies in the analysis, treatment of the characteristics of water basins, get integrated information about the basins limits and derive all required hydrological information and documenting it in form of maps and tables. Digital elevation model considered as the main axis to derive the geomorphological information which form the main basis to conclude of morphologic and hydrological properties.
3. Use the model of Hydrologic Engineering Center [HEC-1] to find the hydrographs for all sub-basins and trace the beginning of the wave and even downstream reaches of the Tigris River. The required information's are:

A- CN values for the three previous cases, which relied on soil texture, soil classification, the use of soil and vegetation cover.

B- The total depth of the rainfall storm was assumed to be equal to 50 mm, represents the maximum depth of the rainfall from Meteorological station records.

C- Basin area of each sub-basin and other information.

D- Rainfall storm duration selected was 6 hours the most appropriate and closest to durations of these basins.

4. The program processes the data, carrying out simulations for the runoff, and then draws the runoff hydrograph of the Basin.

The results of peak discharge and total volume of runoff for Khazir basin and its sub-basins for the three values of Curve Number are tabulated in **Tables 2, 3 And 4** respectively:

Table .(2) Results of peak discharge and total volume of runoff by using WMS for Dry state

Basin name	Peak discharge Qp (m^3 / sec)	Time to peak Tp (minute)	Volume of discharge (m^3)
1B	39.78	515	714409.8
2B	41	625	1095864.6
3B	73.21	530	1417846.8
4B	37.61	555	799221
5B	28.26	640	784244.1
6B	31.08	695	1000191.9
7B	10.94	965	541894.2
8B	24.57	885	1112463
9B	21.9	1005	1125311.1
10B	9.24	1180	518359.2
11B	28.17	1420	1557099.6
12B	24.27	1300	1376178.3
Basin	225.61	585	12043089.9

Table .(3) Results of peak discharge and total volume of runoff by using WMS for Natural state

Basin name	Peak discharge Qp (m^3 / sec)	Time to peak Tp (minute)	Volume of discharge (m^3)
1B	199.66	420	3104289.3
2B	239.59	480	4671797.7
3B	380.32	430	6160873.2
4B	203.03	445	3472797.3
5B	166.82	485	3407709.9
6B	189.67	520	4346064.9
7B	66.36	690	2354657.4
8B	152.19	640	4833905.4
9B	130.82	713	4889741.4
10B	50.93	815	2252397.3
11B	131.31	965	6765967.8
12B	124.21	890	5979809.1
Basin	1564.93	465	52330009.8

Table .(4) Results of peak discharge and total volume of runoff by using WMS for Wet state

Basin name	Peak discharge Qp (m^3 / sec)	Time to peak Tp (minute)	Volume of discharge (m^3)
1B	345.77	385	5615406
2B	467.25	420	8613714.6
3B	673.53	390	11144529
4B	369.75	395	6282018
5B	329.02	425	6164280.9
6B	390.59	445	7861684.5
7B	152.38	550	4259386.5
8B	343.46	520	8744146.5
9B	301.99	570	8845150.8
10B	117.81	640	4074408.3
11B	294.12	745	12239098.5
12B	283.98	695	10816997.1
Basin	3352.97	420	94660820.4

Second method: Mockus Method:

The non–dimensional unit hydrograph has been developed by U.S. Soil Conservation Service (USSCS) and it expressed by Q_n .[10] where:

$$Q_n = \frac{Q_t}{Q_p} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

Where:

Q_t = discharge at any time t.

Q_p = peak discharge.

And non – dimensional time is expressed *by* T_n where

$$T_n = \frac{t}{T_P} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots. (4)$$

Where:

t = time at any instant.

T_p= time of the peak discharge.

The non–dimensional unit hydrograph given by Mockus 1957 tabulated in **Table (5):**

Table .(5) Non – dimensional unit hydrograph vs. Non – dimensional time

T_n	0	0.25	0.5	0.75	1.0	1.25	1.5	1.75	2.0	2.25	2.5
Q_n	0	0.12	0.43	0.83	1.0	0.88	0.66	0.45	0.32	0.22	0.12
T_n	2.75	3.0	3.25	3.5	3.75	4.0	4.25	4.5	4.75	5.0	
Q_n	0.105	0.075	0.053	0.036	0.026	0.018	0.012	0.009	0.006	0.004	

The peak discharge has been calculated as follows:

$$Q_p = \frac{5.36A}{t_p} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.(5)$$

Where:

Q_p = peak discharge (m^3 / s).

A = basin area (km^2).

t_p= time of the peak discharge (hr.) and has been calculated as follows:

$$t_p = \frac{D}{2} + tlr \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(6)$$

Where:

D = duration of rainfall (hr.).

tlr = average time in (hr.) and calculated as follows:

$$tlr = tl + 0.25\,(D - tr) \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.(7)$$

Where:

tl = time from the middle of the sustainability wave to peak discharge (h).

$tr = original\ sustainability = 5.5\ /\ tl.$ [11]

$$tl = \frac{L^{0,8}(SR + 1)^{0.7}}{1900Y^{0,5}} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(8)$$

Where:

L = length of basin (ft.).

Y = % slope of basin.

SR= the potential maximum retention.

$$SR = \left[\frac{1000}{CN} - 10\right] \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(9)$$

The depth of direct runoff is calculated as follows: [11]

$$QD = \frac{(P-0.25SR)^2}{(P+0.8SR)} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.(10)$$

Where:
QD = Direct runoff (in).
P = total depth of rainfall (in).

To find the real values of hydrograph for Khazir basins the value of direct runoff (QD) is multiplied by the values of discharge obtained from UH of Mockus method, where the value of direct runoff for Khazir basin of the dry state is **0.2107** cm, and for the normal state is **1.4243** cm, and for the wet state is **2.794** cm by using total depth of rainfall 50 mm, The results of this method are tabulated in the **Tables 6, 7 And 8.**

Table .(6) Results of peak discharge by using Mockus method for dry state.

Basin name	Peak discharge (Qp) (UH) (m^3 / sec)	Time to peak (Tp) (minute)	Peak discharge (Qp) (m^3 / sec)
1B	149.86	417	31.5755
2B	178	539	37.5046
3B	278	446	58.5746
4B	149.35	468	31.46805
5B	136.76	502	28.81533
6B	146.5	598	30.86755
7B	55	863	11.5885
8B	134.76	723	28.39393
9B	115	857	24.2305
10B	47.2	962	9.94504
11B	130.16	1048	27.42471
12B	122.4	985	25.78968
Total	958.865	1100	202.0329

Table .(7) Results of peak discharge by using Mockus method for Natural state

Basin name	Peak discharge (Qp) (UH) (m^3 / sec)	Time to peak (Tp) (minute)	Peak discharge (Qp) (m^3 / sec)
1B	172.25	363	245.3357
2B	218	440	310.4974
3B	325.8	381	464.0369
4B	176.9	396	251.9587
5B	164.79	417	234.7104
6B	183.5	477	261.3591
7B	73.6	644	104.8285
8B	175.1	556	249.3949
9B	153.77	641	219.0146
10B	64.17	708	91.39733
11B	179	762	254.9497
12B	167	722	237.8581
Total	1327.1	795	1890.189

Table .(8) Results of peak discharge by using Mockus method for Wet state

Basin name	Peak discharge (Qp) (UH) (m^3 / sec)	Time to peak (Tp) (minute)	Peak discharge(Qp) (m^3 / sec)
1B	185.7	337	518.8458
2B	244.74	392	683.8036
3B	355	350	991.87
4B	194.36	360	543.0418
5B	183	375	511.302
6B	209.17	419	584.421
7B	88	539	245.872
8B	204	475	569.976
9B	183.8	536	513.5372
10B	77.74	584	217.2056
11B	218.94	623	611.7184
12B	202.8	594	566.6232
Total	1631.23	647	4557.657

Results and Discussion

For the purpose of a comparison between the WMS and Mockus methods and then stand on the best way with CN values obtained from previous calculations the results of two rainfall-runoff models cited earlier were compared with the one established on recorded data, it was included the peak discharge results from some depths of single rainfall storm recorded as 50, 45, 38, and 35 mm. The analysis has shown that peak discharge estimated with the use of WMS has been the closest one to observed peak discharge for different depths of single rainfall storm recorded. Therefore, this method could be useful to estimate and predict flood flows in ungauged catchments in situation of limited information.

The results obtained from these models were compared with observed peak discharge based on two performance criteria, namely ME, and R^2. [12] [13],[14] as shown in **(Table 9 and Figure 2):**

Model Efficiency ME:

$$ME = \left(1 - \frac{\sum\left(Q_{po} - Q_{pc}\right)^2}{\sum\left(Q_{po} - \overline{Q_{po}}\right)^2}\right) \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (11)$$

Where

ME: The model efficiency (%). its range lies between 1.0 (perfect fit) and $-\infty$.

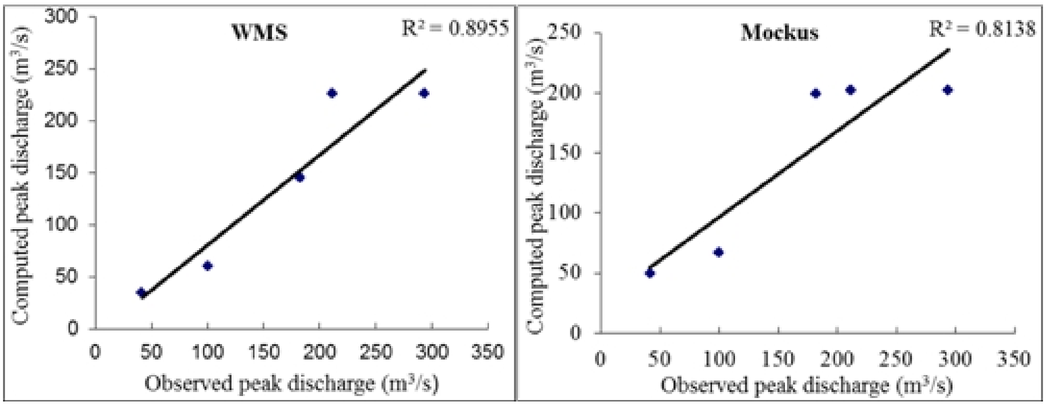
Q_{PO}: Observed peak discharge (m^3/s).

$\overline{Q_{PO}}$: Average of the observed Peak discharges (m^3/s).

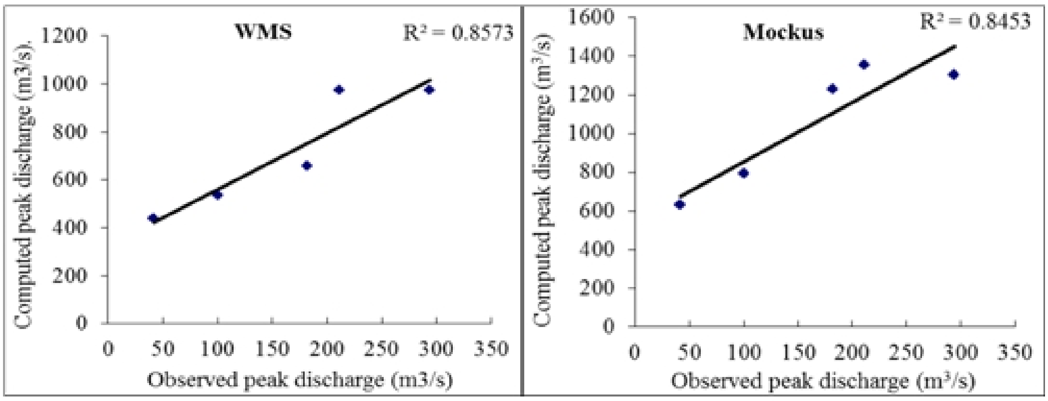
Q_{PC}: Computed peak discharge (m^3/s).

Where the values of the ME were 0.8, -0.41, -0.31 for dry, Natural and Wet states respectively for WMS model, and for Mockus method were 0.74, -0.10, -0.83 for dry, Natural and Wet states respectively.

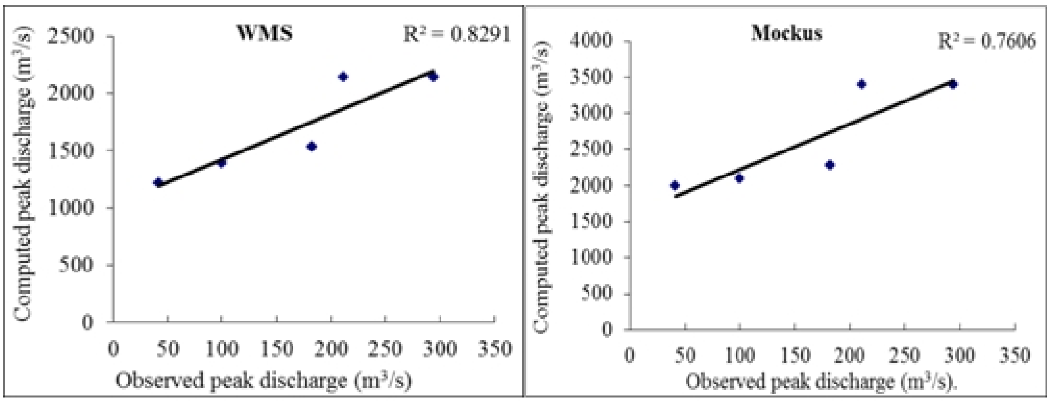
Figure 2 shows the values of Determination Coefficient R^2 and Scatter plots of observed and computed peak discharge for Dry, Natural and Wet states.



(a)



(b)



(c)

Fig .(2) Scatter plots of observed and computed peak discharge for (a) Dry state, (b) Natural state and (c) Wet state.

Figure (3) shows comparison between times to peak discharges for computed hydrographs by WMS and Mockus models for Dry soil state, the value of time to peak discharge computed by WMS method less than value of time to peak discharge computed by Mockus method, because the WMS method simulates surface runoff based on the reality of the study region topography represented by DEM, while the Mockus method not take the topography of the basin into consideration, for this reason WMS method recommend to estimate the time to peak discharge for safety purpose.

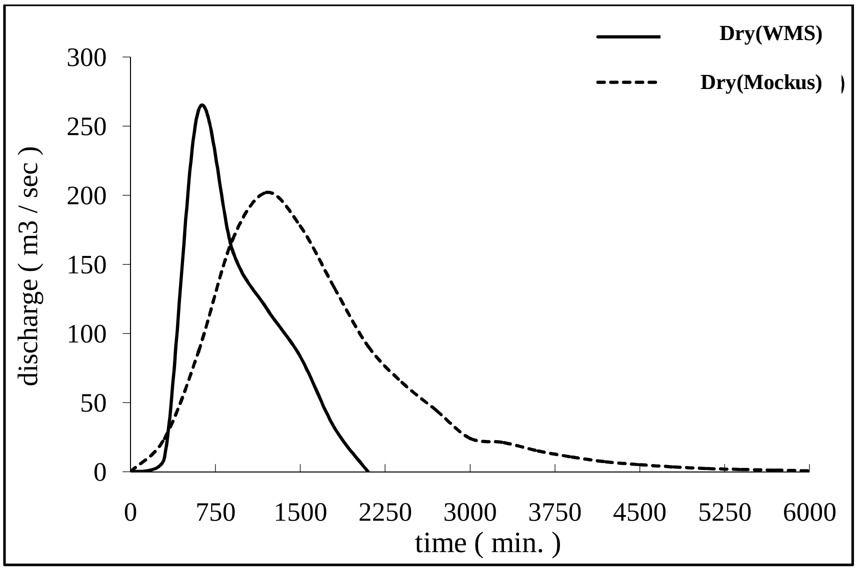


Fig .(3) comparison between times to peak discharges of hydrographs by using WMS and Mockus models for Dry soil state for 50 mm storm

Conclusions

1. The land use of Khazir river basin is pasture and the soil texture classified to Sandy loam, Silty loam, Silty Clay loam and Silty clay.
2. The curve number values of Khazir basin were **66**, **82**, and **91** for dry, natural and wet cases respectively.
3. The performance of WMS model is found more accurate from Mockus method, because the WMS model simulates surface runoff based on the reality of the study region topography represented by DEM, while the Mockus method not take the topography of the basin into consideration.
4. From the results shown in **Figure 2** and calculated from equation (11) it was found that the best state of the study area soil is the Dry state at CN=66, which gave the best values for Determination Coefficient R^2 and Models Efficiency ME as Compared with the observed values.

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