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Evaluation of the Storms Direct Runoff Prediction Methods used for Goizha-Dabashan Watershed

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Abstract: The Momentum and Aron & White evaluating methods have been adopted to estimate the Nash Instantaneous Hydrograph parameters (IUH), while the two methods of excess rainfall (Φ-index and Natural Resources Conservation Service (NRCS) were applied in a model using a developed computer program in MATLAB to predict the direct runoff hydrograph for Goizha-Dabashan watershed located in the northeast of Iraq. In the verification stage, both Nash IUH optimal parameters of the storms and the average optimal values of the same parameters estimated in the calibration stage were applied and compared. The statistical tests showed a preference for the NRCS method with the momentum method in estimating direct runoff hydrograph (the average Nash-Sutcliffe Efficiency (NSE) was equal to 0.815 and 0.77 using optimal parameters verification storms and the average calibrated IUH parameters values, respectively). Also, satisfactory results (NSE was equal to 0.77 and 0.76 using storm parameters and the average calibrated IUH parameters values, respectively) were obtained by applying Aron & White with the NRCS methods, which indicated the ability of both methods for estimating direct runoff hydrograph.

تقييم طرق التنبؤ بهايدروغراف السيح السطحي المباشر للعواصف المطرية لحوض كويزة – داباشان

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الخلاصة

اعتمدت طريقتي الزخم و Aron & White لتقييم هايدروغراف السيح السطحي للعواصف المطرية لتقدير معلمات هايدروغراف Nash القياسي اللحظي، بينما استخدمت طريقتين لحساب المطر المؤثر (مؤشر فاي وخدمة حفظ التربة). وضع نموذج رياضي اعد له برنامج حاسوبي (MATLAB) للتنبؤ بهايدروغراف السيح السطحي المباشر لحوض كويزة - داباشان الواقع في شمال شرق العراق. في مرحلة التحقق لعاصفتين مرصودتين لم تعتمدا في مرحلة المعايرة تم تطبيق كل من المعلمات المثلى للعاصفتين ومتوسط القيم المثلى للمعلمات المحسوبة في مرحلة المعايرة. أظهرت نتائج الاختبارات الإحصائية تفضيل طريقة خدمات حفظ التربة مع طريقة الزخم في تقدير هايدروغراف الجريان السطحي المباشر (متوسط كفاءة Nash-Sutcliffe يساوي 0.815 و0.77) باستخدام المعلمات المثلى للعاصفتين في مرحلة التحقق ومتوسط قيم معلمات IUH لمرحلة المعايرة على التوالي. تم الحصول على نتائج مرضية (متوسط كفاءة Nash-Sutcliffe تساوي 0.77 و0.76) باستخدام معلمات العاصفتين ومتوسط قيم معلمات IUH لمرحلة المعايرة على التوالي) من خلال استخدام طريقة Aron & White مع طريقة خدمة حفظ التربة، والتي تشير إلى قدرة كلتا الطريقتين على تقدير هايدروغراف الجريان السطحي المباشر للحوض المختار.

الكلمات الدالة: جابية، السيح السطحي، عاصفة مطرية، الهايدروراف القياسي اللحظي.

1.INTRODUCTION

Watershed runoff plays an important role in planning and designing hydraulic structures, controlling soil erosion, and assessing the water yield potential of the watershed [1]. Significant problems may arise in predicting the direct runoff hydrograph resulting from storms occurring over ungauged watersheds. In such situations, conceptual models meet the conditions and therefore are often used. The watershed acts as a hydrological system transforming the input hyetograph into an output hydrograph. The transfer function contains a process of mathematical characterization that relates the inputs and outputs. Based on this system's transformation approach, numerous conceptual rainfall-runoff models have been developed to simulate the rainfall-runoff process of transformation [2]. Such models have limited parameters that can be derived from recorded data or empirical equations. Nash´s model of the Instantaneous Unit Hydrograph (IUH) is one of the conceptual rainfall-runoff model forms used to predict direct runoff in these types of watersheds[3]. This model uses a concept of a watershed described as a cascade of linear reservoirs of number (n), each with a storage constant (k). The derivation of the Nash Instantaneous Unit Hydrograph has been addressed by many researchers [4-12]. According to the Nash model parameters' significant importance in estimating the instantaneous unit hydrograph, various researchers studied its effect and proposed different relationships for estimating [13-18]. Recently, researches have been intensified towards using empirical and geomorphologic methods for estimating the instantaneous unit hydrograph (IUH) coupled with a conceptual model's approach for direct runoff prediction from ungauged watersheds. The object of the present work is to estimate the storm's direct runoff hydrograph from the instantaneous unit hydrograph for the Goizha-Dabashan watershed and focus on evaluating the two methods used in determining Nash IUH parameters in addition to evaluating the two methods used for estimating the excess storm rainfall and adopting adjusted CN relations of both initial abstraction coefficient and watershed slope for improving the performance of NRCS method. The methods' accuracies were evaluated and compared by applying different statistical tests. WMS model was used firstly to delineate the boundary of the watershed understudy and then to classify and identify both land use and soil types using satellite imagery for the study area. A developed mathematical model was prepared and applied for estimating the instantaneous unit hydrograph (IUH) and its two parameters and direct runoff hydrograph (DRH) resulting from the storm rainfall occurring over the study area. Goizha-Dabashan watershed has been selected as a study area because of the availability of its recorded rainfall and runoff data for some storms for the years 2002 and 2006. A gauging station was constructed at the outlet of the watershed by Barzinji to measure the runoff flow induced by rainfall storms using the digital current meter model Slap Bologna [19].

2. DESCRIPTION OF THE STUDY AREA

Goizha-Dabashan watershed is located in the north of Iraq, in the north of Al-Sulymaniah city in the Kurdistan region. Geographically, the Goizha-Dabashan watershed is confined between 45°27´00" - 45°28´30" E (Longitude) and 35°35´00" - 35°36´00" N (Latitude). A digital elevation model (DEM) with a resolution of 10 m was downloaded from the site ASTER GDEM to delineate the boundary of the watershed and derive its characteristics, see

Fig. 1. The watershed characteristics, such as area, perimeter, and slope, were calculated, as shown in Table 1, from the DEM file and with the aid of WMS version 10.1 Software after delineating the watershed boundary. The watershed area is estimated to be 2.02 km², with its elevation varying from 1490 m to 947 m above mean sea level. Geologically the study area is located within a high folded zone [20]. The upper part of the watershed is the Komitant Formation (which consists of limestone); however, the lower parts consist of the Tanjaro Formation, which is composed of sandstone and green marl, and the Shiranish Formation (bluish marl and marl limestone). Generally, Shiranish and some parts of Tanjaro formations are covered by soil or alluvial deposits (colluvium). The average soil porosity =0.57, and the actual infiltration capacity ranges from 0.3 to 1.68 mm/day [19]. Based on meteorological data from 1991 to 2019 obtained from the Directorate of Meteorology and Seismology of Al-Sulymaniah, the study area has a mean annual rainfall of 719 mm and a mean daily temperature of 19°C. The highest rainfall occurs throughout December, January, and February, while the lowest rainfall is observed throughout May and October, and there is no rainfall in June, July, August, and September.

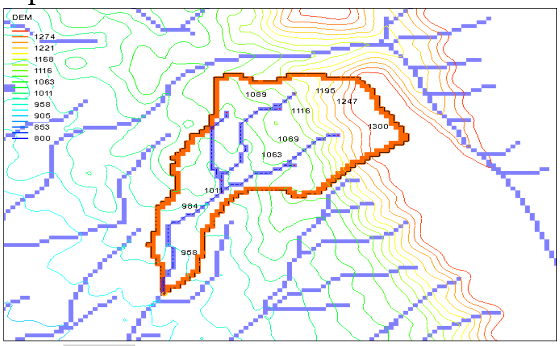

Fig. 1 Location of Goizha-Dabashan Watershed.

Table 1. Goizha-Dabashan Watershed Characteristics

Watershed characteristics							
Area (km²)	Perimeter Slope (Km)	Watershed Length (km)	Max elevation difference (m)	Max flow distance (km)	Centroid stream distance (km)	Shape factor	Area (km²)
2.02	6.72	0.125	2.45	543	3.2	1.62	0.32

3. THEORETICAL BACKGROUND

3.1. *Temporal Distribution of Storm Excess Rainfall*

The excess rainfall temporal distribution for each storm event is estimated in this research using two methods, namely the Phi-index and the NRCS.

3.1.1. Φ-index Method

The Φ-index for a watershed can be subtracted from the storm rainfall hyetograph. The total excess rainfall depth or the resulting runoff depth of the storm can be estimated from the relation [21]:

$$\mathrm{ER} = \sum_{i=1}^{n} \mathrm{ER_i} = \sum_{i=1}^{n} (\mathrm{P_i} - \Phi \cdot \mathrm{t_e}) \quad \textbf{(1)}$$

where:

ER= Total excess rainfall depth or the resulted runoff depth of the storm(mm)

$\mathrm{ER_i}$ = Excess rainfall depth over the time interval i (mm).

$\mathrm{P_i}$ = Recorded rainfall over the time interval i (mm).

ϕ = Average rate of infiltration (mm/hr).

t_e = Duration of excess rainfall (The recorded rainfall > ϕ-index in hours).

n = Number of non-zero-time intervals of excess rainfall.

3.1.2. Natural Resources Conservation Services Method (NRCS)

This method is known formally as soil conservation service (SCS), and it is considered a popular method for computing excess rainfall (direct runoff) in watersheds whose sizes are small to medium [22]. Natural Resources Conservation Services Method (NRCS) is based on a hypothesis that equates the ratio of two actual components to the two potential components, Eq. (2), in addition to the continuity equation Eq. (3) [23]:

$$\frac{F_a}{S} = \frac{(P - I_a)}{P - I_a + S} \quad \textbf{(2)}$$

$$P = I_a + F_a + ER \quad \textbf{(3)}$$

Solving Eqs. (2, 3) for F_a, the storm time distribution of the accumulated abstraction depth in the watershed (F_a) can be estimated at each time interval using the following relationships [1, 23]:

$$F_a = \frac{S \cdot (P - I_a)}{P - I_a + S} \qquad P \geq I_a \qquad \textbf{(4)}$$

$$S = \frac{25400}{CN} - 254 \qquad \textbf{(5)}$$

$$I_a = \lambda . S \qquad \textbf{(6)}$$

where:

P= Accumulated rainfall depth in mm

S= Potential maximum retention (mm)

I_a= Initial abstraction in mm

λ= Initial abstraction coefficient

ER= Excess rainfall (mm)

F_a = Accumulated abstraction depth (mm)

To standardize and conveniently use potential retention (S), it was expressed in terms of dimensionless curve number (CN). The CN value is influenced by the hydrologic soil group, cover type, and antecedent moisture condition [23]. Antecedent moisture condition (AMC) of the storm refers to the amount of moisture content found in the soil at the beginning of the storm. Both initial abstraction and infiltration are governed by AMC [22]. In the growing season, if the summation of the rainfall for the previous five days was less than 35.6 mm, the dry condition of the soil will be assumed; however, if the summation of rainfall was greater than 53.3mm, then the wet soil condition will be assumed; otherwise, the normal condition will be assumed. In contrast, in the dormant season, if the summation of rainfall for the previous five days was less than 12.7 mm; the dry soil condition will be assumed; however, if the summation of rainfall was greater than 27.9 mm; then the wet soil condition will be assumed; otherwise, the normal condition will be assumed. The value of CN under dry conditions (CN_I) and wet conditions (CN_{III}) can be estimated from CN under normal conditions using Eqs. (7, 8) [1]:

$$CN_I = \frac{4.2\ CN_{II}}{10-0.058\ CN_{II}} \quad \textbf{(7)}$$

$$CN_{III} = \frac{23\ CN_{II}}{10+0.13\ CN_{II}} \quad \textbf{(8)}$$

The accumulated excess rainfall (direct runoff) for each time interval of the storm duration can be estimated by subtracting the accumulative abstraction depth and initial losses from the accumulated rainfall (P) at that interval. The excess rainfall (direct runoff) at any time interval of the storm duration can be estimated as the difference between the accumulated excess rainfall at the end and the accumulated excess rainfall at its beginning [23]. Different cases of the adjusted composite CN values can be adopted and applied to choose the most suitable composite CN value for the watershed (after comparing it with the calibrated optimal CN value) for estimating the direct storm runoff hydrograph [24, 25]. These different cases can be selected by studying the effect of the initial abstraction coefficient (λ) and watershed slope (α)in adjusting and modifying the tabulated CN value used for estimating the excess rainfall.

a- Effect of the Initial Abstraction Coefficient

The value of threshold λ= 0.2 used by NRCS is still being actively debated by several studies, which have shown considerable differences between handbook-tabulated CN values based on land cover/use and those estimated from watershed observations rainfall-runoff storms [26, 27]. These studies found that λ of value 0.05 or 0.01 were much more representative than λ=0.2. Nevertheless, essentially all handbook CN table values correspond to λ= 0.2. The corresponding S and then CN for λ= 0.05 differs from that for λ= 0.2; hence, the resulting runoff values differ. The adjustment of CN value from λ= 0.2 to λ= 0.05 has been adopted by the Task Group on Curve Number Hydrology, which recommended a new relation of the form [27]:

$$S_{0.05} = 1.42 S_{0.2} \quad \textbf{(9)}$$

and leads to:

$$CN_{0.05} = \frac{100}{1.42-0.0042 CN_{0.2}} \quad \textbf{(10)}$$

b- Effect of the Watershed Slope

The approach of Ajmal et al. (2012) for the slope-adjusted CN values calculation was used to estimate the effect of the slope of the watershed in adjusting the tabulated CN values [28]. The approach relation takes the form:

$$CN_{II\propto} = \left[\frac{CN_{II}(50-0.5CN_{II})}{CN_{II}+75.43}\right] x\left[1-e^{-7.125(\propto-0.05)}\right] + CN_{II} \quad \textbf{(11)}$$

where:

$CN_{II\alpha}$= slope adjusted CN value for normal conditions

α= the average slope of the watershed varying between 7.50% and 53.53%

The approach of (Ajmal et al., 2012) [28] has two advantages over other suggested approaches [29-31], where this approach has only one parameter compared to two or three in the other approaches. Also, this approach works within the theoretical limits (i.e., 0 to 100), unlike the others.

3.2. Nash Instantaneous Unit Hydrograph and Methods of Estimating its Two Parameters

(Nash, 1957) developed a conceptual model based on identical linear reservoirs in series to derivate a natural watershed's instantaneous unit hydrograph (IUH) [3]. Nash IUH model has two parameters: (n) the number of reservoirs and (k) the storage coefficient [5, 32]. The final form of the Nash IUH model is:

$$IUH(t) = \frac{1}{k.\Gamma(n)}\left(\frac{t}{k}\right)^{n-1} e^{-t/k} \quad \textbf{(12)}$$

where:

IUH(t) = Instantaneous unit hydrograph ordinate at time t in m^3/sec.

t = Time in hr.

Γ(n) = Gamma function.

Gamma Function (Γn) developed by [33] was used in this research. The equation takes the following form:

$$\Gamma(n) = \sqrt{\frac{2\Pi}{n}}\left(\frac{n}{e}\right)^n\left(1+\frac{1}{15n^2}\right)^{\frac{5}{4}n} \quad \textbf{(13)}$$

where n is any positive real number (dimensionless).

Eq. 13 is used for estimating Γ(n) rather than the related tabulated values because of its capability to find Γ(n) for any real value n directly without requiring some additional steps to find Γ(n) for real values n as in the related table. In this research, the Nash model parameters (n and k) were estimated for the storms by the following two methods:

3.2.1. Momentum Method

Nash found a relationship between the parameters n, k, and the moments for the storms of the recorded excess rainfall hyetograph (ERH) and direct runoff hydrograph (DRH) [23,34]. These relationships are:

$$k = MQ_1 - MI_1 \quad \textbf{(14)}$$

$$n \cdot (n+1) \cdot k^2 + 2 \cdot n \cdot k \cdot MI_1 = MQ_2 - MI_2 \quad \textbf{(15)}$$

where:

MI_1 = ERH first momentum about the time origin divided by the total excess rainfall

MI_2 = ERH second momentum about the time origin divided by the total excess rainfall.

MQ_1 = DRH first momentum about the time origin divided by the total direct runoff.

MQ_2 = DRH second momentum about the time origin divided by the total direct runoff.

The moments of the ERH and DRH are determined as follows:

$$MI_1 = \frac{\Delta T}{2} \cdot \frac{\sum_{t=1}^{nr}(2t-1)\cdot ER(t)}{\sum_{t=1}^{nr} ER(t)} \quad \textbf{(16)}$$

$$MI_2 = \frac{\Delta T^2}{4} \cdot \frac{\sum_{t=1}^{nr}(2t-1)^2\cdot ER(t)}{\sum_{t=1}^{nr} ER(t)} \quad \textbf{(17)}$$

$$MQ_1 = \frac{\Delta T}{2} \cdot \frac{\sum_{t=1}^{nq}(2t-1)\cdot \frac{Q_t+Q_{t+1}}{2}}{\sum_{t=1}^{nq} \frac{Q_t+Q_{t+1}}{2}} \quad \textbf{(18)}$$

$$MQ_2 = \frac{\Delta T^2}{4} \cdot \frac{\sum_{t=1}^{nq}(2t-1)^2\cdot \frac{Q_t+Q_{t+1}}{2}}{\sum_{t=1}^{nr} \frac{Q_t+Q_{t+1}}{2}} \quad \textbf{(19)}$$

where:

Q_t = The direct runoff hydrograph ordinate at $time(t) = 1, nq$ in m3/sec

$ER(t)$ = Excess rainfall depth throughout the interval (ΔT) between

the ordinates t and $t + 1$ in mm/hr.

nr = Number of excess rainfall interval duration.

nq= Number of Direct runoff hydrograph ordinates.

The amounts of first momentum (MI_1 and MQ_1) and second momentum (MI_2 and MQ_2) can be estimated by Eqs. (14- 19). Then the n and k can be calculated for a given storm of recorded direct runoff hydrograph (DRH) and excess rainfall hyetograph (ERH). The excess rainfall hyetograph (ERH) has been estimated by one of the applied excess rainfall methods.

3.2.2. Aron and White Empirical Method

Aron and White's empirical method was employed in this research to estimate the two parameters of Nash IUH depending on the unit hydrograph and watershed characteristics. This method was developed by Croley II in 1980. Aron and White in 1982 [4, 35, 36] described the following equations to calculate the two parameters:

$$n = 1.045 + 0.5f + 5.6f^2 + 0.3f^3 \quad \textbf{(20)}$$

$$k = \frac{T_p}{n-1} \quad \textbf{(21)}$$

in which

$$f = \frac{Q_p \cdot T_p}{A} \quad \textbf{(22)}$$

where:

Q_p = peak discharge in ft3/sec

T_p = Time to peak in hr

A = area of the watershed in acres

The n parameter is dimensionless, while the k parameter is in hours. The amounts of Q_P and T_P in the Aron and White method were estimated using the dimensionless unit hydrograph method [37]. This unit hydrograph has a point of inflection approximately 1.67 times the time to the peak, while the time to the peak is about 0.2 of the time base. The peak discharge is calculated by the English system using the following equations:

$$Q_P = \frac{484.A}{T_P} \quad \textbf{(23)}$$

$$T_P = \frac{D}{2} + T_{Lag} \quad \textbf{(24)}$$

$$T_{Lag} = 0.6 T_C \quad \textbf{(25)}$$

where:

Q_p= peak discharge in ft3/sec

A = watershed area in mile2

D= Duration of excess rainfall in hr

T_{Lag} = Watershed lags time in hr

T_c = Time of concentration in hr

The concentration-time (T_c in minutes) was calculated using the Kirpich relation in the two methods for estimating the excess rainfall. In the case of applying the NRCS method for estimating the excess rainfall, the watershed lag time is calculated [38, 1]:

$$T_{Lag} = \frac{0.0057\,(L)^{0.8}\left(\frac{1000}{CN}-9\right)^{0.7}}{\propto^{0.5}} \quad \textbf{(26)}$$

where:

L= The mainstream length in m

$\propto$= Average slope of the watershed

3.3. Estimating the Direct Runoff Hydrograph

The ordinate of Direct Runoff Hydrograph (DRH) at any time can be estimated by employing the D-hr UH and excess rainfall hyetograph in the de-convolution method [21].

$$Q_t = \sum_{i=1}^{m} ER_i \cdot UH_{(t-(i-1)\cdot D)} \quad \textbf{(27)}$$

where:

m = value equal to the lesser one of both t and No. of storm effective-rainfall blocks for each value of t.

The ordinates of any D-hr UH can be estimated from 1hr- UH by the S-Curve method [23] , where the derivation of 1hr- UH from IUH is conducted using the equation [21]:

$$(1\text{-}hr\ UH)_t = \frac{1}{2}[(IUH)_t + (IUH)_{t-1}] \quad \textbf{(28)}$$

4. STATISTICAL METHODS TO EVALUATE THE MODEL'S ACCURACY

To evaluate the performance and accuracy of different methods applied in this research, three statistical tests were used to demonstrate the agreement between recorded and estimated direct runoff hydrographs of each storm. These tests are:

4.1. The Root of Mean Square Error (RMSE)

RMSE is calculated as [6]:

$$RMSE = \sqrt{(1/N)\sum_{i=1}^{nq}(Q_r - Q_e)^2} \quad \textbf{(29)}$$

4.2.Relative Mean Error (RME)

RME is calculated as [32]:

$$RME = (1/nq)\sum_{i=1}^{nq}\frac{(Q_r - Q_e)}{Q_r} \quad \textbf{(30)}$$

4.3.Nash-Sutcliffe Efficiency Test (NSE)

NSE is calculated from [39]:

$$NSE = 1 - \frac{\sum_1^{nq}(Q_r - Q_e)}{\sum_i^{nq}(Q_r - Q_{avr})} \quad \textbf{(31)}$$

where:

Q_r = Recorded value of direct runoff hydrograph ordinates in m3/sec

Q_e = Estimated value of direct runoff hydrograph ordinates from the IUH models in m3/sec

Q_{avr}= Average of the recorded runoff data in m^3/sec
nq= Number of the direct runoff hydrograph ordinates

Nash–Sutcliffe efficiency (NSE) can range from 0 to 1. NSE is equal to 1 corresponds to a perfect match of the modeled direct runoff to the recorded data. NSE equals 0 indicates that the model predictions are as accurate as the average of the recorded data, whereas an efficiency less than zero (NSE < 0) occurs when the recorded average is a better predictor than the model, in other words, when the residual variance (described by the numerator in the expression above) is larger than the data variance (described by the denominator). Essentially, the closer the model efficiency to 1, the more accurate the [32, 39]. The root mean square error (RMSE) statistical test estimates how the recorded and predicted values may differ from the average, which helps in results analysis. The RMSE value is vital for determining the plausibility of the phenomenon understudy compared with the model's predicted value [32]. If the average value of the recorded data is significantly different from the predicted data of the model, then the predicted data obtained or the method of predicting them should be rechecked. The zero values indicate a perfect match between the predicted and recorded data. The relative mean error (RME) statistical test gives the overall relative estimating bias. According to the above notes, the best method to be chosen for the first test will be the one that has the efficiency value maximum outcome, and the best method to be chosen for the last two tests (RMSE and RME) will be the one that has the test's most negligible outcome value.

5. THE APPLIED MODEL

A computer program in MATLAB was prepared according to the following procedure steps for estimating the Instantaneous Unit Hydrograph (IUH) and its two parameters and Direct Runoff Hydrograph (DRH) resulting from the occurring storm rainfall over the watershed:

1. Delineate the Watershed and estimate its characteristics and curve number related to soil type, land use, area, slope, and maximum water length using the Hydrologic Modeling Wizard tool in WMS 10.1 using Digital Elevation Model (DEM) as spatial data input.
2. Estimate the excess rainfall from the storm recorded rainfall hyetograph by the selected one of the two methods mentioned in paragraph (3), taking into account the extent to which the performance of the NRCS method be improved by adopting the adjusted CN relations of both initial abstraction coefficient and watershed slope.
3. Estimating the gamma function using the method developed by Nemes [33].
4. Estimate the n and k parameter values using either the momentum equations or one of the two empirical methods.
5. Estimate the storm IUH ordinates by employing the Nash model, then estimate the ordinates of 1-hr UH, D-hr UH, and DRH by the methods mentioned in paragraph (3).
6. Analysis of accuracy from the estimated DRH with the recorded one by applying the tests mentioned in paragraph (4).

The flow chart in Fig. 2 shows the different steps in executing the model.

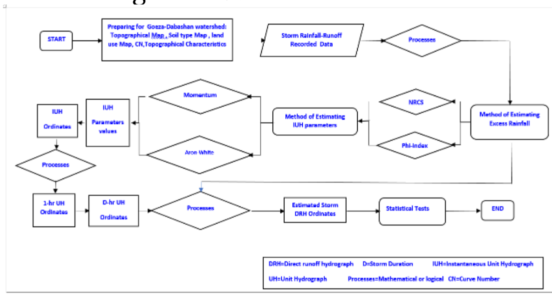

Fig. 2 General Flow Chart of the Developed Mathematical Model.

6. APPLICATION OF THE MODEL AND RESULTS

6.1. Estimation of the Composite Curve Number

The CN can be calculated from the readily available tables and curves; however, this traditional method is very tedious and consumes a significant portion of hydrologic modeling time. In contrast, using the watershed modeling system (WMS) integrated with a specific hydrological tool and program considerably reduced the cost and time with high reliability and accuracy over the traditional method. The CN represents a soil hydrologic group and cover treatment and is used to estimate the excess rainfall (direct runoff) from the watershed at any time interval of storm duration. The thematic maps for the watershed boundary, land use map, and soil type map are required to get information about the soil type, land use, land treatment, and hydrologic condition for the watershed, which must be known to determine the curve number values. Landsat satellite imagery, with a resolution of 10 m downloaded from the Landsat-7 ETM+, was used to develop the study area's land use map and soil type maps. Digital Elevation Map (DEM) and Watershed Modeling System (WMS) version 10.1 software were used to build, manage, and generate various layers and maps, as presented in Figs. (3, 4), respectively.

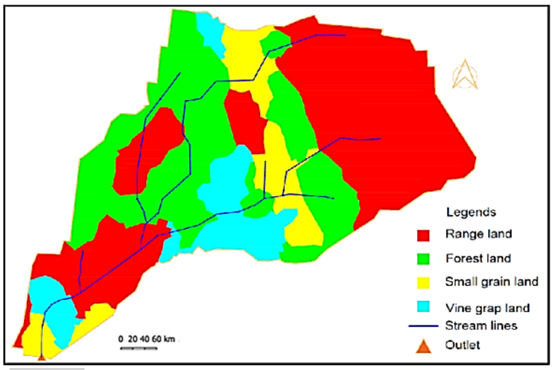

Fig. 3 Land use Map of the Goizha-Dabashan Watershed.

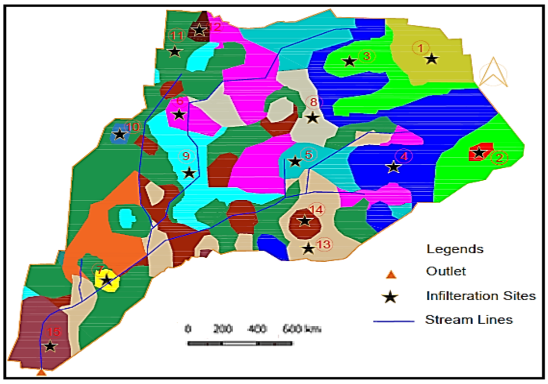

Fig. 4 Soil-Type Map of the Goizha-Dabashan Watershed.

Different types of soil texture and land use were found in the study area. The percentage area of soil types A, B, C, and D out of the total area of the watershed is equal to 5, 37, 22, and 36, respectively. The mountainous part of the watershed is characterized by very shallow to moderate soil depths and silt clay texture and has a very steep slope. The hilly area has a soil of moderate to deep, silt clay structure, while the plane lands are characterized by a soil of moderate to deep depth, silt, and clay structure. The watershed area is divided into four sub-areas according to the variation in vegetation types, land use, and topography. Therefore, it was divided according to the range, forest, vine grape, and small grain land of percentage area out of the total area of the watershed equal to 45%, 22%, 17 %, and 15%, respectively. The weighted curve number value for the 14 zones depends on the hydrologic soil group, land use, and hydrologic condition. With the aid of (WMS) software, land use and soil type maps, as shown in Figs. (3, 4) were conformed to obtain a unified map to find the weighted CN values for the 14 watershed zones, as shown in Table 2. The composite curve number for the watershed was equal to 48.32, 69.1, and 83.72 for moisture conditions I, II, and III, respectively. The composite curve number for natural moisture conditions was calculated as follows:

$$CN = \sum_{j=1}^{m} \frac{CN_j A_j}{A} \qquad \textbf{(32)}$$

where:
CN = The composite curve number for the watershed.
CN_j=The weight curve number value for subarea j.
A_j = The weighted area for the subarea j.
Four different NRCS method cases were applied. The composite curve number CN_{II} and CN_{III} have been adjusted for initial abstraction (λ) and watershed slope (α) individually and for both, applying relations 10 and 11. The adjusted composite CN values for these different cases are shown in Table 3.

Table 2 Weighted Curve Number Values of the Goizha-Dabashan Watershed.

Zone	Hydrological Soil group	Land use	Percentage of sub area (%)	CN_{II}	Zone	Hydrological Soil group	Land use	Percentage of sub area (%)	CN_{II}
1	D	Ranged	1.4	71	8	A	Forest	4.8	32
2	D	Ranged	7.1	71	9	C	Forest	2.5	72
3	D	Ranged	12.0	71	10	B	For	12.1	58
4	D	Ranged	5.3	71	11	B	Small grain	6.0	74
5	C	Ranged	9	73	12	C	Small grain	10.5	82
6	D	Ranged	3.1	89	13	B	Vine grape	3.5	73
7	B	Forest	3.3	58	14	B	Vine grape	12.7	73

Table 3 Watershed Composite Curve Number (CN) for Different Cases of Initial Abstraction and Watershed Slope Adjusting.

Values of Composite Curve Number (CN) for different application cases							
CN_{II}				CN_{III}			
CN_{II} without adjusting (λ=0.2)	CN_{II} adjusted for λ=0.05	CN_{II} adjusted for slope (α) and λ=0.2	CN_{II} adjusted for slope (α) and λ=0.05	CN_{III} without adjusting (λ=0.2)	CN_{III} adjusted for λ=0.05	CN_{II} adjusted for slope (α) and λ=0.2	CN_{II} adjusted for slope (α) and λ=0.05
69.1	88.52	72.16	93.65	83.72	94.66	85.63	97.14

7. APPLICATION AND RESULTS

To apply the developed model for different cases and determine Nash IUH parameters, the available data of nine recorded rainfall-runoff storms, which were recorded by Barzinji in 2002 and 2006 at the outlet of the Goizha-Dabashan watershed [19], were used. The applied storms covered a wide range of rainfall intensity, where Storms 6 and 9 had high intensity (>7.5mm/hr), while the others fell in mediate intensity between 2.5 and 7.4 mm/hr. The rainfall depth for storms 1 to 9 were 18.9, 18.5, 13.9, 16.4, 21,15.8, 16.8, 14.2, and 15.2 mm, respectively. The other related data; such as watershed area, slope, max flow distance, soil type, land use, and composite curve number; were first estimated, as shown in a previous paragraph. The application and reassessment of the different methods and application cases were divided into two stages: the calibration stage and the verification stage. Storms 1 to 7 were used for calibration, and storms 8 and 9 were used to verify the methods and case accuracy. The calibration process was first performed for the CN parameter by trial-and-error method using the recorded rainfall and direct runoff data for each storm until obtaining the optimal calibrated CN value according to the statistical tests results. The values of optimal parameters, i.e., n and k, and their average for the storms, were obtained by applying the three methods of estimating IUH parameters using both methods of the excess rainfall estimation, as shown in Table 4.

From the calibration stage, it was found that:

a- The optimal calibrated curve number (CN_{III}=78) and the parameters values of storm number 5 by applying the momentum method with both NRCS and Φ-Index methods were assumed as extreme values as compared with the parameter's values of the other storms (Table 4) and its composite CN_{III} values besides the composite CN_{III} values for the mentioned wet condition in Table 3. The same can be seen for the Aron and White empirical method, as shown in Table 4.

b- The estimated direct runoff hydrographs for each of the seven storms were tested using Nash-Sutcliffe Efficiency, the root mean square error, and relative mean error tests. Table 5 shows the statistical test results between the recorded and estimated direct runoff hydrograph. The average of calibrated optimal values of n and k parameters (Table 4) was estimated after neglecting storm number 5.

c- The average rainfall and the average recorded runoff coefficient for the rest six storms (after neglecting extreme storm number 5) equaled 17.74mm and 0.056, respectively. The runoff coefficient for estimated excess rainfall by Φ-index and NRCS methods equaled 0.066 and 0.055, respectively.

d- It was also found, after neglecting extreme storm number 5, that only storm number 1 of natural antecedent moisture condition had an optimal calibrated curve number CN_{II} =75.8, where the adjusted slope(α) CN_{II} of value=72.16 was closer to it more than the other composite values in Table 3. The rest storms had closed values of optimal calibrated curve number CN_{III}, of an average equaled 80.6, where the composite CN_{III}, i.e., without adjusting, of value= 83.72, was closer to it than the other adjusted composite values in Table 3. The values of n and k estimated by the momentum method (Table 4) were not close to each other compared to those estimated by the Aron-White method, indicating the high sensitivity of the momentum method to the excess rainfall of the storm and its resulting direct runoff as compared to Aron-White method. The mean values of n and k using the Φ index method were higher than those estimated using the NRCS method. Table 5 shows the results of the statistical tests between the recorded and estimated direct runoff hydrograph.

e- The optimal calibrated curve number (CN_{III}=78) and the parameters values of storm number 5 by applying the momentum method with both NRCS and Φ-Index methods were assumed as extreme values compared to the parameter values of the other storms (Table 4) and its composite CN_{III} values besides the composite CN_{III} values for the mentioned wet condition in Table 3. The same can be seen for the Aron and White empirical method, as shown in Table 4.

The verification stage included applying and comparing the model results with a data set not entered in the calibration [40]. The model was applied firstly using the available recorded data for storms 8 and 9 to estimate the optimal n and k by applying momentum and Aron and White empirical method and secondly using the average optimal values of the parameters estimated in the calibration stage (using the adjusted value of slope (α) for tabulated CN_{II} and tabulated composite CN value without any adjusting for CN_{III} in case of NRCS method) to estimate the direct runoff hydrograph for each of these two storms. Table 6 shows the storms' characteristics of verification stages. The average optimal calibrated curve number CN_{III} for storms 8 and 9 was equal to 80. The composite CN_{III} (i.e., without adjusting) value=83.72 was closer to it (as in the calibration stage) than the other adjusted composite values in Table 3. Table 7 shows the optimal estimated values of the Parameters for storms 8 and 9 and their average in the verification stage. Figs. 5 - 8 show the degree of agreement between the recorded and estimated direct runoff hydrographs for storms 8 and 9 using different methods in the verification stage. Table 8 shows the statistical tests results from applying the model in the verification stage.

Table 4 IUH Parameters (n and k) Resulted from Using Φ-Index and NRCS Methods for Estimating Excess Rainfall for Calibration Stage.

Method of Excess Rainfall	Type of Parameter	Method of Estimating IUH Parameters	IUH Parameters (n and k) Values Storm Number and Date (1) 13/2/2002	(2) 13/3/2002	(3) 30/3/2002	(4) 12/4/2002	(5) 2/4/2006	(6) 3/4/2006	(7) 6/4/2006	Average
Φ-Index	n	Momentum	3.147	2.208	4.030	3.476	5.211	2.093	4.110	3.177
		Aron and White	2.031	2.023	2.039	2.036	2.050	2.021	2.042	2.032
	k	Momentum	0.434	1.335	0.400	0.527	0.3801	0.634	0.394	0.621
		Aron and White	0.689	0.692	0.684	0.687	0.669	0.701	0.676	0.688
NRCS	n	Momentum	3.147	2.857	2.056	3.476	5.220	2.031	4.110	2.946
		Aron and White	2.035	2.032	2.024	2.038	2.050	2.022	2.041	2.032
	k	Momentum	0.434	0.757	0.456	0.527	0.2521	0.738	0.394	0.551
		Aron and White	0.688	0.691	0.694	0.681	0.670	0.696	0.679	0.688

Table 5 The Statistical Tests Results Between the Recorded and Estimated Direct Runoff Hydrograph for Calibration Stage

Type of Test	Method of excess rainfall	Statistical Test Results for Storms 1 *	1 **	2 *	2 **	3 *	3 **	4 *	4 **	5 *	5 **	6 *	6 **	7 *	7 **
NSE	Φ-index	0.86	0.75	0.84	0.54	0.89	0.76	0.73	0.70	0.73	0.58	0.74	0.77	0.79	0.70
	NRCS	0.91	0.84	0.83	0.79	0.96	0.45	0.64	0.70	0.71	0.56	0.76	0.74	0.81	0.73
RMSE	Φ-index	004	0.06	0.07	0.12	0.02	0.02	0.08	0.09	0.24	0.3	0.55	0.56	0.14	0.17
	NRCS	0.04	0.05	0.07	0.08	0.01	0.03	0. 09	0.09	0.25	0.3	0.65	0.60	0.14	0.16
RME	Φ-index	0.11	0.25	0.07	0.04	0.08	0.31	-0.02	0.43	-0.28	0.63	0.25	0.48	-0.24	0.18
	NRCS	-0.07	0.09	0.03	0.03	-0.01	-0.01	-0.05	-0.09	-0.23	0.70	0.21	0.07	-0.03	0.05

* Applying parameters of the Momentum method ** Applying parameters of the Aron and White Empirical method

Table 6 Storms Characteristics of Verification Stages

Method of excess rainfall	Storm No.	Storms characteristics of verification stage Rainfall mm	Recorded DR mm	Average recorded DR coefficient	Estimated DR mm	Average Estimated DR coefficient	Lag Time hr	Average Lag time hr	Optimal CN	∅ index
Φ -index	8	14.2	0.064	0.046	0.06	0.04	1.24	1.21	-	0.94
	9	15.2	0.028		0.02		1.21		-	0.92
NRCS	8	14.2	0.064	0.046	0.06	0.044	1.25	1.23	81	-
	9	15.2	0.028		0.028		1.21		79	-

Table 7 Estimating Optimal Values of N and K Parameters for Storms 8 and 9 in the Verification Stage and their Average.

Method of Excess Rainfall	Type of Parameters	Method of Estimating IUH Parameters	Parameters n and k Values Storm No. and Date (8) 5/ 5/2006	(9) 6/5/2006	Optimal average of Verification Stage
Φ-Index	n	Momentum	1.921	4.277	3.099
		Aron and White	2.020	2.045	2.033
	k	Momentum	0.644	0.282	0.463
		Aron and White	0.702	0.681	0.692
NRCS	n	Momentum	1.924	4.274	3.099
		Aron and White	2.025	2.042	2.033
	k	Momentum	0.649	0.283	0.466
		Aron and White	0.696	0.682	0.689

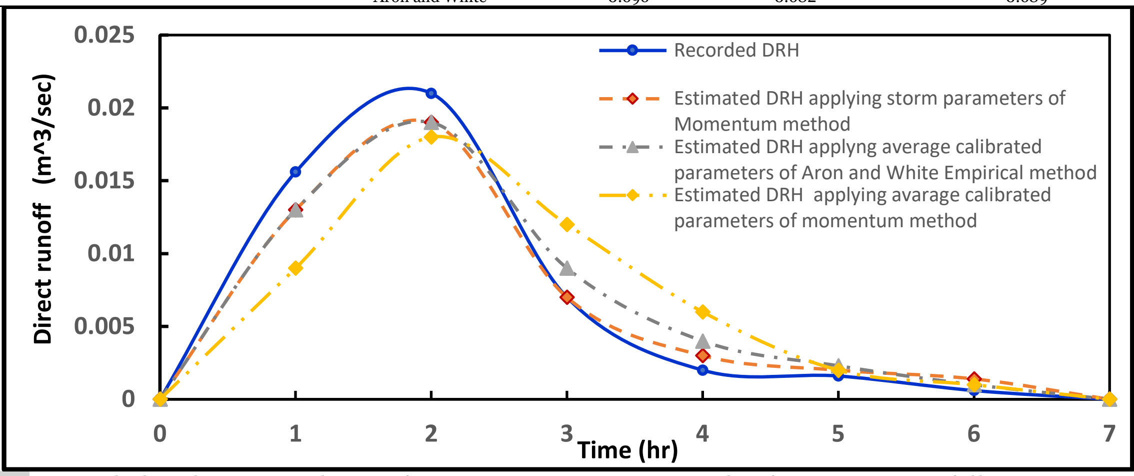

Fig. 5 Recorded and Estimated DRH for Storm No. 8 using ф-Index for Excess Rainfall Estimation.

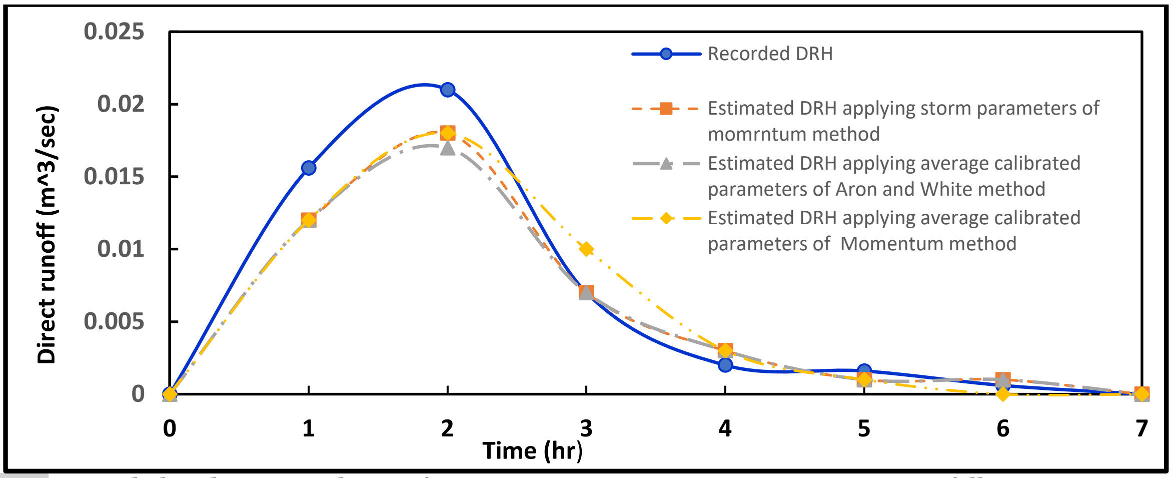

Fig. 6 Recorded and Estimated DRH for Storm No. 8 using NRCS For Excess Rainfall Estimation.

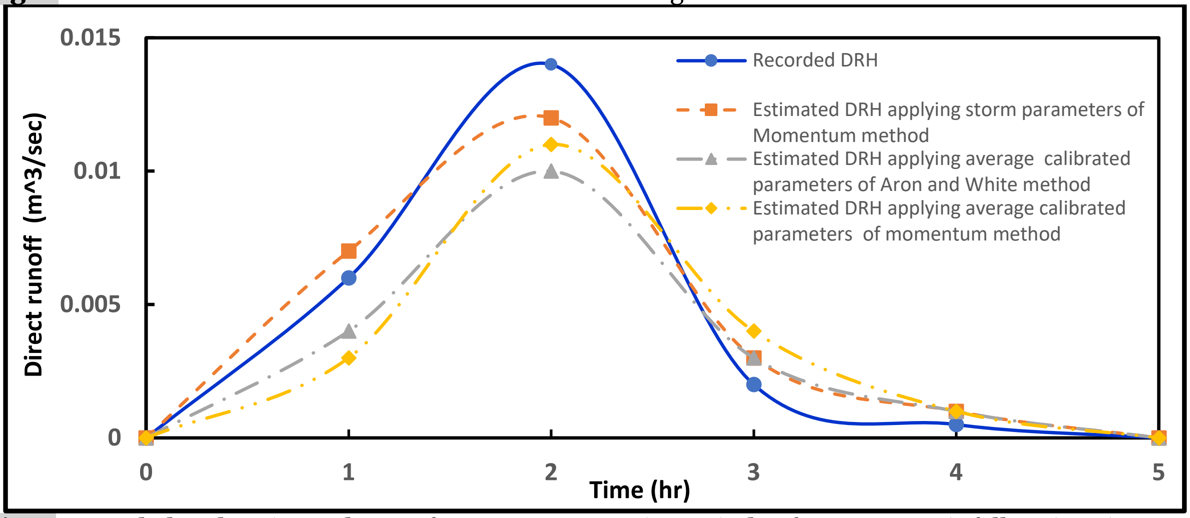

Fig. 7 Recorded and Estimated DRH for Storm No. 9 using Φ-index for Excess Rainfall Estimation.

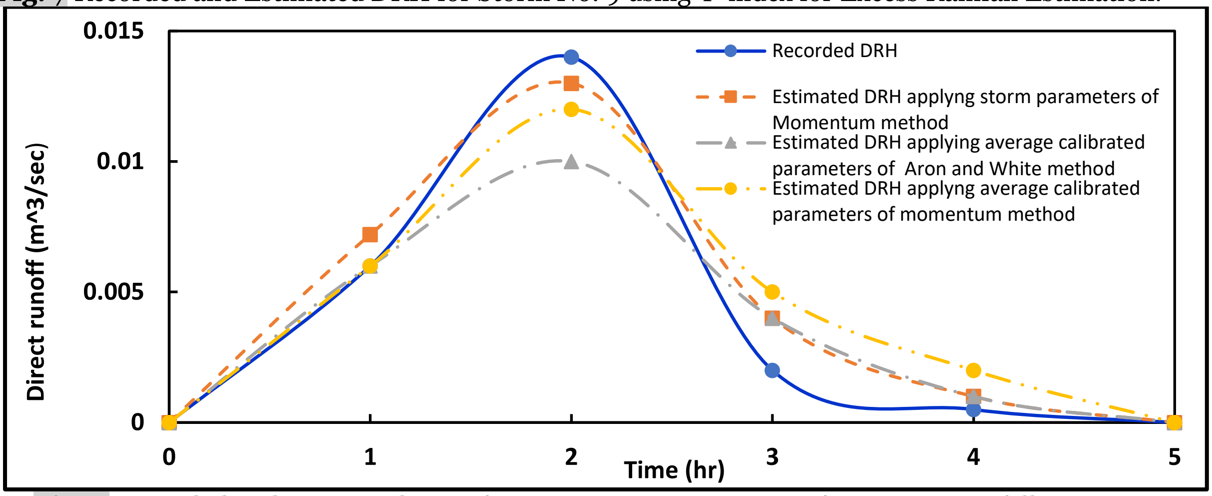

Fig. 8 Recorded and Estimated DRH for Storm No. 9 using NRCS for Excess Rainfall Estimation.

Table 8 Results of the Statistical Tests between the Recorded and Estimated Direct Runoff Hydrograph for the Verification Stage Applying the Estimated and Average Calibration N and K Parameters.

Type of Test	Method of excess rainfall	Statistical Test Values of Verification Stage							
		Tests values of Storm No. 8				Tests values of Storm No. 9			
		Optimal Storm parameters		Average calibration parameters		Optimal Storm parameters		Average calibration parameters	
		*	**	*	**	*	**	*	**
NSE	Φ-index	0.83	0.81	0.63	0.81	0.77	0.60	0.54	0.59
	NRCS	0.82	0.80	0.79	0.80	0.81	0.74	0.75	0.73
RMSE	Φ-index	0.004	0.004	0.006	0.004	0.003	0.004	0.007	0.006
	NRCS	0.004	0.004	0.004	0.004	0.002	0.006	0.006	0.006
RME	Φ-index	0.05	-0.07	-0.35	-0.07	0.003	0.16	0.050	0.160
	NRCS	0.08	-0.05	-0.21	-0.05	0.002	- 0.02	-0.28	-0.18

* Applying n and k of the Momentum method ** Applying the Aron and White Empirical method parameters

Table 9 Average Nash-Sutcliffe Efficiency Test (NSE) Values for Calibration and Verification Stages.

Method of excess rainfall	Average Nash-Sutcliffe Efficiency Test (NSE)					
	Calibration Stage applying		Verification Stage Applying			
	Average Optimal Parameters		Average of parameters of Storms		Average optimal parameters calibration stage	
	*	**	*	**	*	**
Φ-index	0.81	0.70	0.80	0.705	0.585	0.700
NRCS	0.82	0.71	0.815	0.770	0.770	0.765

*Applying Momentum method ** Applying the Aron and White Empirical method

8. DISCUSSIONS

The calibration results show that the NRCS method should identify the initial abstraction coefficient required to estimate the initial losses and the watershed slope adjusting for watershed composite curve number value to get more correct results to calculate the excess rainfall of the storm. For the watersheds under study, the calibration process showed that there was no need to correct the initial abstraction factor (0.2) due to the small size of the watershed besides its soil types and land use characteristics; however, the adjusting curve number for the slope was necessary in the natural antecedent moisture condition case at the beginning of the storm, while there was no need to correct the tabulated CN for slope in the saturated antecedent moisture condition case, which indicates that the low slope (0.125) of the watershed, which was nearest to the minimum slope limit (0.05) in relation No. (2) increased the storms' direct runoff in normal conditions; however, it insignificantly affected the wet condition. As cited by (Ajmal M.) [28], there was no handbook convention on the effect of slope watersheds on CN and runoff estimation; however, intuitively, higher sloped watersheds should have higher CN values. The runoff coefficient estimated by the NRCS method for the calibration and verification storms was closer to the recorded runoff coefficient than that estimated by the Φ-index method. The NRCS method showed better results Tables (4, 7, 8) than that of Φ- index method for both applications, with the two methods of estimating IUH parameters for most cases in the calibration and verification stages. The reason is that the Φ-index was set to the constant infiltration rate, which gave an overestimate of excess rainfall at the beginning and an underestimate at the storm's end. In contrast, in the NRCS method, the recorded rainfall data were used besides other watershed characteristics, so the variance in the results became obvious for these reasons. In the calibration stage, the values of n and k parameters, which were estimated by the two empirical methods for each one of the seven storms (Table 4), were very close to each other and showed that the hydrograph characteristics significantly affected the IUH parameters values compared to storm excess rainfall depth. The momentum method gave better results than the Aron and White empirical method in the calibration and verification stages, as shown in Tables (5, 8), as a result of deriving its parameters from the recorded data, which was unavailable for most of the watersheds. Table 9 shows the average values of Nash-Sutcliffe Efficiency in both calibration and verification stages. The average of Nash-Sutcliffe Efficiency values in the calibration stage using the NRCS and Φ-index methods were equal to 0.82 and 0.81, respectively, by applying the momentum method and 0.71 and 0.70 by applying Aron and White empirical method respectively. The average of Nash-Sutcliffe Efficiency values in the verification stage using optimal storms parameters resulted from applying NRCS and Φ-index methods were equal to 0.815 and 0.80 by applying the momentum method respectively and 0.77 and 0.705, respectively, by applying Aron and White empirical method respectively. Table 9 also shows that the average of Nash-Sutcliffe Efficiency values in the verification stage using average calibrated parameters for NRCS and Φ-index methods were equal to 0.77 and 0.585, respectively, by applying momentum method and 0.76 and 0.70, respectively, by applying Aron and White empirical method. For most cases, the momentum method resulted in a minimum value of RMSE and MRE tests compared to that of the Aron and White empirical method. The reason is that the empirical method depends on the constant effect of both unit hydrograph and watershed characteristics (like time to peak and time of concentration). The results show the importance and effect of the method selected and used for estimating the excess rainfall and the effect of CN slope adjusting in predicting IUH and direct runoff hydrograph. The momentum method resulted in better results Tables (5, 8, 9) than Aron and White empirical method for both methods of estimating excess rainfall in case of using the storm recorded data, while the Aron and White empirical methodesulted in equivalent. to slightly better results in the case of applied average calibrated n and k parameters values. The results show that if the adjusted composite CN was used rather than the optimized CN and parameters values, it produced close results. The resulting direct runoff hydrographs shown in Figs. (5- 8) emphasize the results of the statistical tests. In the Aron and White empirical method, the difference between the average calibration values of n and k parameters and that estimated from the recorded data for storms 7 and 8 were very small. Hence, the resulting direct run hydrographs were identical, as shown in Figs. (5- 8).

9. CONCLUSION

Based on the model application and obtained results, the following noticeable findings can be concluded:

a- The effects of watershed and hydrograph characteristics were more on the IUH parameters than the storm excess rainfall depth (storm characteristics).
b- Based on the recorded hydrograph, the momentum method had better efficiency by applying it with NRCS to estimate direct runoff hydrograph for gauged watersheds. While the Aron and White empirical method, based on the watershed's physiographic characteristics, had higher efficiency when applied with the NRCS method for estimating direct runoff hydrograph of any storm that occurs over the watershed understudy or any other ungauged watershed that had no hydrometric station.
c- The Aron and White empirical method was more appropriate to estimate Nash parameters for ungauged watersheds and the Nash method for gauged watersheds to get more accurate results.
d- The limitations of the application of the model were within the limitations of the instantaneous unit hydrograph, unit hydrograph, and Natural Resources Conservation Services (NRCS) method.
e- Adopting the adjusted CN relations of the initial abstraction coefficient and watershed slope in the calibration process was necessary to improve the NRCS method results.
f- For future research, a study could be carried out for other watersheds with different runoff potential and watershed characteristics and adopt other percentages of initial abstraction coefficient relation rather than 0.2 and 0.5 in the NRCS method besides other developed methods for estimating Nash model parameters. Also, a specific empirical relation for estimating Nash parameters can be developed as a function of watershed characteristics for the region under study or any other region if more gaging watersheds are available within the same region.

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