ESTIMATION OF RUNOFF FOR GOIZHA-DABASHAN WATERSHED WITH AID OF REMOTE SENSING TECHNIQUES

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ABSTRACT.

Estimation of runoff volume and peak runoff is necessary for designing and operating the dams. One of the accepted models for estimating the runoff is HEC-1 model. Two methods were used in this study to estimate the runoff in Goizha-Dabashan watershed, 2.02 km^2, Rational method and Soil Conservation Service curve number method (SCS-CN). Satellite image from Landsat-7 (ETM+) was used to develop land use and soil type maps. Watershed was delineated from DEM *(http: //www.emrl.byu. edu/gsdu)* with resolution 10 m with aid of WMS 7.1 software. Runoff coefficient was calculated by inverse the Rational equation. Manual calibration was performed until the Nash-Sutcliffe coefficient gives the best results. Results showed that the runoff coefficient is 0.05 and the curve number value for conditions II and III are 75 and 80.5 respectively after calibration. Also, curve number method is better than Rational method for estimating the peak runoff discharge.

الخلاصة.

تقدير حجم السيح السطحي وذروته ضروري لتصميم وتشغيل السدود. احد اهم النماذج المقبولة لتقدير السيح السطحي هو نموذج (HEC-1) . في هذه الدراسة استُخدمت طريقتان لتقدير السيح السطحي في حوض گويژة-دباشان ،2,02 كم^2، وهما طريقة (Rational) وطريقة (SCS-CN). تم استخدام صورة القمر الصناعي (Landsat-7 ETM+) لانشاء خرائط استخدام الارض و نوع التربة. تم تحديد حوض النهر بواسطة نموذج الارتفاعات الرقمي (DEM) *(http: //www.emrl.byu. edu/gsdu)* وبدقة 10 م وبمساعدة برنامج (WMS 7.1). عامل السيح السطحي تم حسابه بعكس معادلة (Rational). وتم استخدام معايرة يدوية للمعادلات بواسطة معادلة (Nash-Sutcliffe) للحصول على افضل النتائج. نتائج هذه الدراسة اوضحت ان مقدار السيح السطحي لهذا الحوض هو 0,05 و مقدار رقم المنحني (CN) للحالة الثانية والثالثة هو 75 و 80,5 على التوالي. وكذلك، تبين ان طريقة رقم المنحني (CN) هي افضل من طريقة (Rational) في تقدير ذروة السيح السطحي.

INTRODUCTION.

The Estimation of runoff from rainfall is critical for water resource management and hydraulical design. In the recent years, the use of remote sensing and Geographic Information System (GIS) technologies in runoff estimation from watersheds has gained increasing attention, because of a good runoff model has to include spatially variable geomorphologic parameters such as rainfall, soil characteristics, and land use change.

In hydrologic analysis and design, it is often necessary to develop relations between precipitation and runoff, possibly using some of the factors affecting runoff as parameters. The relations between precipitation and runoff differ with the type of precipitation, the considering of the volume or peak or runoff, or the time distribution of runoff *(Chow, 1964).* Hydrologic systems are generally analyzed by using mathematical models. These models may be empirical or statistical, or founded by known physical laws. In this study, SCS curve number model and Rational method were used to estimation the runoff in Goizha-Dabashan watershed.

The purpose of this research is to demonstrate and evaluate the use of satellite imagery for obtaining the watershed and soil parameters, and to comparison these parameters with the measured values. Also, comparison the calculated runoff from SCS curve number with post results calculated by Deterministic optimization model and Artificial NEURAL Network model, and estimated the runoff coefficient value for Goizha-Dabashan watershed.

PREVIOUS STUDIES.

Barzinji, 2003 studied the hydrology, climate, and watershed management for 11 watersheds in Al-Sulymaniah region, namely; Zalim, Chaqan, Chaq-Chaq, Dewana, Basara, Goizha-Dabashan, Smaquli, Halsho, Tanjaro, Shiranish, and Mawakan. He was focused in his study on Goizha-Dabashan watershed. He described it soils by excavated 16 ponds, and he measured the infiltration rate in 15 ponds. Also, he was constructed a gaging station in it to measure the runoff.

Barzinji, 2007 developed a mathematical model (Deterministic Optimization model) to calculate the runoff during 2002 and 2006 for Goizha-Dabashan watershed. His model is based on water balance principles in which, the main input are precipitation, evaporation, base flow, and other requirement to run the optimization program. He was showed a good relation between calculated and observed runoff (correlation factor= 0.91).

Al-Hamawandi, 2009 studied the rainfall-runoff relationship by using Artificial Neural Network, ANN. He built different ANN watershed models (simple and complex) and tried using Walnut Gulch watershed. The instantaneous ANN model was applied also for Goizha-Dabashan. The results indicate the capability of the model to simulate the runoff-rainfall relationship with correlation coefficient 0.95.

3. GOIZHA-DABASHAN WATERSHED.

Goizha-Dabashan watershed located in the north east of Iraq, in the north of Al-Sulymaniah city between 45°27′00" - 45°28′30" E (Longitude) and 35°35′00" - 35°36′00" N (Latitude) as shown in **Fig 1**. The watershed area is about (2.02km²); and its perimeter is 8.436 km. It was selected due to availability of its data such as; rainfall and runoff storms (10 storms), soil properties data, land use data, location of soil samples, location of infiltrometers, and other data.

THEORITICAL BACKGROUND.

SCS curve number model.

The curve number, CN, method for estimating direct runoff response from rainstorms was developed to fill a technological niche in the 1950. Its popularity is rooted in its convenience, its simplicity, its authoritative origins, and its responsiveness to four readily grasped catchment properties: soil type, land use, treatment, surface condition, and antecedent condition *(Ponce and Hawkins, 1996)*. Watersheds have a certain group of soil and fair pasture cover can be classified by various curve numbers. These curves are the relationship obtained between rainfall and runoff, as follows:

$$F/S = Q/P \quad \ldots\ldots\ldots (1)$$

Where F = P - Q: is actual retention.

S: is potential retention.

Q: is actual runoff, and

P: is potential runoff that is total rainfall.

The initial abstraction, I_a, is all losses before runoff begins. It included water retention in surface depression and intercepted by vegetation, infiltration, and evaporation. I_a was approximated by the following equation:

$$I_a = 0.2\ S \quad \ldots\ldots\ldots\ldots (2)$$

By subtracted I_a from rainfall P in equating (1) and solving for Q, yields:

$$Q = \frac{P - 0.2S}{P + 0.8S} \quad \ldots\ldots\ldots (3)$$

Curve number value range from 0 to 100 and determined from the SCS tables, according to land-cover, hydrologic soil group, treatment, and antecedent moisture condition (AMC). Hydrologic soil group is expressed as four groups (A, B, C, and D) according to the soil's minimum infiltration rate *(ASCE, 1996)*. AMC is expressed as three levels, according to rainfall limits for dormant and growing seasons *(Viessman and Lewis, 2003)*. For application the curve number model, the watershed is divided to some areas principally by land-cover based area-weighting of curve numbers.

Rational Method.

The rational method dates from the 1850 in Ireland and called the Lloyd-Davies method in Great Britain. It represents the relation between rainfall and peak runoff. This formula is called rational because the units of the quantities involving are numerical consistent approximately *(Suresh, 2005)*. The Rational formula is:

$$Q_P = 0.277\ C\ I\ A \quad \ldots\ldots.. (4)$$

Where Q_P: is the peak flow in m^3/s.

C: is the runoff coefficient varies from 0 to 1.

I: is the rainfall intensity in mm/hr.

A: is the watershed area in km^2.

Estimates of the runoff coefficient are based on very limited data, but several studies have shown that is depends on the infiltration rate, surface cover, channel and surface storage and intensity of rainfall *(Schwab, et al, 1966).* The coefficient of runoff varies for different storms on the same catchment, and thus, using an average value C, only a crude estimate of Q_P is obtain , that may have wide margins of error *(Shaw, 1983).*

WMS 7.1 Software.

Watershed Modeling System, WMS, is a comprehensive environment for hydrologic analysis. It was developed by the Environmental Modeling Research Laboratory of Brigham Young University in cooperation with the U.S. Army Corps of Engineers Waterways Experiment Station. The current version, 7.1, is built at March 10 2005. The distinguishing difference between WMS and other applications designed for setting up hydrologic models like HEC-1 and TR-20 is its unique ability to take advantage of digital terrain data for hydrologic model development. WMS uses three primary data sources for model development: Geographic Information Systems (GIS) Vector Data, Digital Elevation Models (DEM), and Triangulated Irregular Networks (TIN).

HEC-1 Model.

The HEC-1, Flood Hydrograph Package, computer program was designed to simulate the surface runoff response of a watershed to precipitation by representing the basin as an interconnected system of hydrologic and hydraulic components. Each component models an aspect of the precipitation-runoff process within a portion of the basin, commonly referred to as a subbasin.

The model components function based on simple mathematical relationships which are intended to represent individual meteorologic, hydrologic and hydraulic processes that comprise the precipitation-runoff process. These processes are separated into precipitation, interception and infiltration, transformation of precipitation excess to subbasin outflow, addition of base flow and flood hydrograph routing.

WATERSHED DELINEATING.

WMS software provides a powerful tool to delineate the boundary of any watershed. DEM file represents the base layer to delineate the watershed. It was obtained from website *(http: //www.emrl.byu. edu/gsdu)* with resolution (10m) and treated with aid of Global Mapper 8 program. The first step to delineate the Goizha-Dabashan watershed is pinpointing the location of the outlet, thus; the Global Position System tool, GPS, was used to obtain the coordinates of the watershed outlet and its boundary. After that, the direction of water entering through the watershed was drowned. This step was accomplished by creating a flow direction file, with aid of WMS Software. This software examines each cell in the DEM file and determines the direction of flow for that particular cell based on the elevations of the eight neighboring cells. The watershed was delineated by assigning the outlet cell in the stream flow file. The WMS Software examines the flow direction file to determine which cells will eventually flow through the outlet cell, as shown in **fig. 2**.

The watershed characteristics such as basin area, basin perimeter, basin slope, max flow distance, basin shape factor, elongation ratio, and etc. were calculated from the DEM file and with aid of WMS Software after delineating the watershed boundary. However, the time of concentration was computed by using Kirpich equation and as follows:

$$T_c = 0.02\, L^{0.77}\, Y^{-0.385} \quad \ldots\ldots\ldots\ldots\ldots (5)$$

Where T_c: is the time of concentration in min.

L; is the maximum length of flow in m, and

Y: is the watershed gradient in meter per meters, or the difference in elevation between the outlet and the most remote point divided by the length, L.

REMOTE SENSING WORKS.

Generally, the remote sensing works can be summarized as follows:

- Selecting the satellite image.
- Layer stack.
- Image subset.
- Image classifying.

The satellite image for Al-Sulymaniah city was obtained from sensors Landsat-7 Enhanced Thematic Mapper Plus (ETM+). It contained nine bands with resolution equal to 14.25m. Layer stack is combining the bands together of an image to obtain a combination image and to facilitate the analyzing it. The satellite image for al-Sulymaniah city was very large and includes area outside the Goizha-Dabashan watershed. Therefore, the subset operation was used to reduce the image size file.

The process of categorizing pixels into broader groups is known as Image classification. The advantage of classification is to allow cost-effective mapping of the spatial distribution of similar objects (i.e. tree types in forest scenes); a subsequent statistical analysis can then follow *(Walsh, 2003).*

IMPLEMENTATION OF SCS MODEL PARAMETERS.

SCS Curve number model depends only on one parameter, because the other parameters, initial abstraction and potential maximum retention, are related directly with the curve number. To determine the curve number values, information about the soil types, land use, land treatment, and hydrologic condition must be known. Soil types were determined according to its basic infiltration rates which result from the infiltrometers. Musgrave (1955) was given the following values of basic infiltration in cm per hour for the four hydrologic soil groups: A, more than 0.76; B, 0.38 to 0.76; C, 0.13 to 0.38; D, 0.13 or less. Land use description, treatment, and the hydrologic condition were taken from Barzinji study in 2003. The study area was divided to 15 regions utilizing remote sensing results. Each region has individual curve number value, the composite curve number was calculating as:

$$CN_c = \sum CN_j\, A_j' \quad \ldots\ldots\ldots\ldots (6)$$

Where CN_c: is the composite curve number.

CN_j: is the curve number value for region j, and

A_j': is the weighted area for the same region.

COMPUTATION OF RUNOFF.

Rainfall distribution is representing the first step for HEC-1 model to identifying the rainfall as hyetograph. Rainfall distribution was constructed for each rainfall storm by plotting accumulative rainfall depth against time and dividing it by the total depth. Land surface interception, depression storage and infiltration are referred to in the HEC-1 model as precipitation losses. The precipitation loss calculation can be used with either the unit hydrograph method or kinematic wave method. In this study, the unit hydrograph method was used. The average precipitation loss was determined for each time interval and subtracted from the rainfall hyetograph as. The resulting precipitation excess was used to compute an outflow hydrograph for the watershed. The required parameters for SCS curve number methods in HEC-1 mode are:

- I_a: Initial rainfall abstraction. If value is 0, then it will be computed as 5080/CN – 50.8.
- CN: SCS curve number value for overall watershed (composite value).
- RTIMP - Percentage of drainage basin that is impervious. In the study area, there is no impervious area.

The volume of runoff which calculated in the previous step was transformed to hydrograph by using the unit hydrograph method. SCS dimensionless unit hydrograph method was used in this study. HEC-1 model automatically sets the duration of unit excess equal to the computation interval selected for watershed simulation. Input data for the SCS dimensionless unit hydrograph method in HEC-1 Model consists of a single parameter, T_{PEAK}, which is equal to the lag between the beginning of runoff and the peak of the unit hydrograph. Peak flow is computed as:

$$QP = 2.08 \times A / T_{PEAK} \quad \ldots\ldots\ldots (7)$$

Where, T_{PEAK} is the time to peak of unit hydrograph in hours, Q_P is the peak flow of unit hydrograph in $m^3/s/cm$, and A is the watershed area in km^2.

ESTIMATION OF RUNOFF COEFFICIENT.

The default procedure for calculating the runoff coefficient cannot be used, because there are only 10 storms, and its return period is unknown and cannot calculated. Therefore, the runoff coefficient was calculated by inverse the Rational method, where the maximum intensity was used in this formula with duration equal or greater than time of concentration. This procedure was used to calculate the runoff coefficient for 20 storms; each storm has an individual value according to its return period. The average value of it was obtained, and supposed as the runoff coefficient for the Goizha-Dabashan watershed.

VERIFICATION AND VALIDATION

Model validation includes initial data collection and subsequent model calibration. Sufficient data must be collected and analyzed to define the characteristics of the model domain (e.g., flows, pressures, precipitation, runoff coefficients, etc.). Model validation includes the comparison of the model results with a data set different from the calibration data set and, if the comparison is not satisfactory, the recalibration of the model using both sets of data *(Adrien, 2004)*. For SCS curve number model, it was used for the curve number value to obtain the best fit of the calculated hydrograph as comparison with observed hydrograph. The curve number value (composite value) for the conditions II and III were changed to give the best results. For Rational method, this process was used to verifying the runoff coefficient. The storms number nine and two was neglected in the verifying because it was assumed as extreme value. Nash model was used to test the fitting of the results as follows:

$$\text{Nash} = \sqrt{1 - \frac{\Sigma(Q_c - Q_o)^2}{\Sigma(Q_o - Q'_o)^2}} \qquad \text{….. (8)}$$

Where Q_c: is the calculated value.

Q_o: is the observed value, and

Q'_o: is the mean of observed values.

RESULTS AND DISCUSSION.

Watershed properties (watershed characteristics) involved area, shape, slope, etc. and the watershed morphology which consists of elongation ration, circulation ratio, etc. These parameters were computed to comparison the DEM results and field results (Barzinji, 2003) which calculated by taken GPS coordinates and measuring the area by the planimeter, while he was measured the perimeter and channels length by chartometer, as shown in **table 1**. It is notice from this table; all error is not excess 10%, excepted the average watershed slope and centroid stream distance. So, the DEM with resolution 5 m gives accepted results by comparison with field results.

On the other hand, supervised classification was used to classify the land use and soil type of the study area, as shown in figures (3) and (4). It is notice from figures (3); the range land is covering most the watershed (44%) as opposite of the vine grape land (16%). However, figure (5) shows the comparison between Remote sensing results and field (Barzinji, 2003) results. It is obvious from this figure; there is no high difference in the two results for land use and soil texture excepted in range land (10.1%).

Table 2 shows the value of curve number for the 15 regions. The value of curve number depends on four factors; hydrologic soil group, treatment, land use, and hydrologic condition. The distribution of land used and soil type was obtained from the satellite image by using supervised classification as shown in **Fig. 3** and **Fig. 4.** The soil type was computed according to its basic infiltration rate. So the watershed area was divided to 15 regions which equal the number of infiltrometers.

Runoff Hydrograph and Runoff Coefficient.

Runoff of Goizha-Dabashan watershed was computed with aid of HEC-1 model. The data required to the model are, distribution and depth of rainfall, base flow, loss method parameters, and unit hydrograph parameters. Figures (1 to 10) in Appendix A show the runoff hydrograph for storm number 1 to storm 10. However, Runoff coefficient was calculated for 10 storms by inversed the rational formula. Each model has individual runoff coefficient due to the return period of the storm, as shown in table 3.

The calculated runoff by using SCS-CN method showed an error in it; also, runoff coefficient resulted from Rational method showed there is a fluctuation in values of runoff coefficient for the ten storms, so optimization process is used to reduce this error.

CALIBRATION AND VERIFICATION.

Calibration process was used to one parameter in each model trial and error method. For SCS curve number model, the optimum value for condition II and condition III were obtained from the first 6 storms and verified for the last 4 storms. Condition III was used if the last storm not exceeded ten days. The value of runoff coefficient is 0.05 after calibration and verification. Storm number nine was neglected from the verification process because it was assumed as extreme value or it return period is high (runoff coefficient increase with increasing the return period and vice versa).

CONCLUSIONS.

- In the light of this study, the following steps can be concluded:
- The difference between DEM results (with 10m resolution) and field results for the watershed properties are not excess 10%, excepted average watershed slope (14.03 %) and centroid stream distance (19.10%).
- There is no high difference between remote sensing results and field results for land use, excepted in range land (the difference is 10.1%).
- The calculated composite values of curve numbers for Goizha-Dabashan watershed are 50.2, 69.5, and 83.3 for conditions I, II, and III respectively. While, the optimum values for conditions II and III are 75 and 80.5 respectively. Also, the optimum runoff coefficient is 0.05.
- If the SCS curve number model is used without optimized its parameters values, it may cause some error in runoff.
- SCS curve number model is better than Rational method in estimation of peak runoff discharge.
- The Values of Nash model for SCS-CN, Barzinji (2007), and ANN models are 0.909, 0.907 and 0.964 respectively, therefore; ANN is the best with 1 storm failed. And SCS-CN model is better than Barzinji model.

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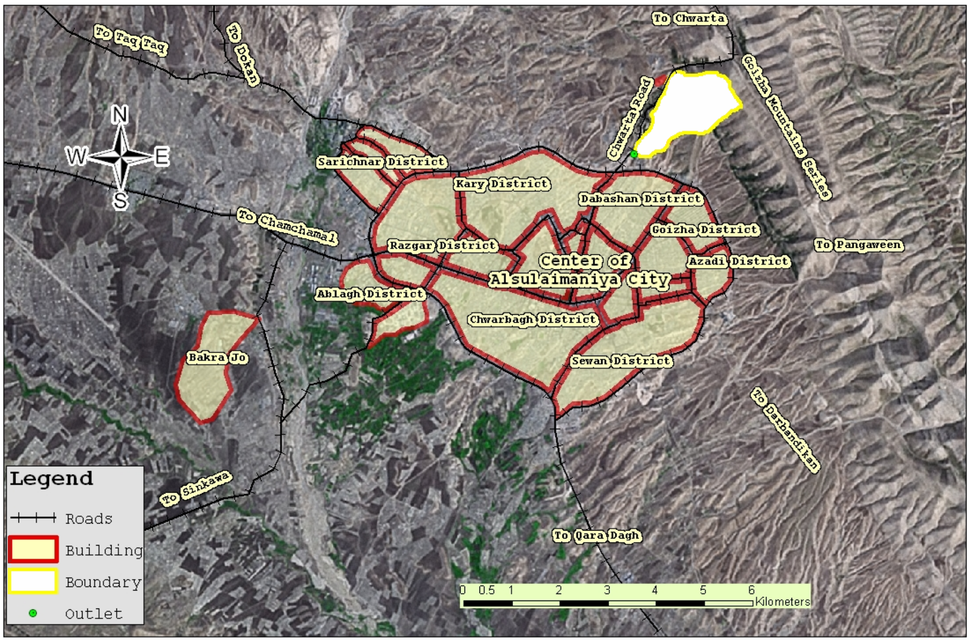


Fig. 1: Location of Goizha-Dabashan watershed in Al-Sulymaniah city.

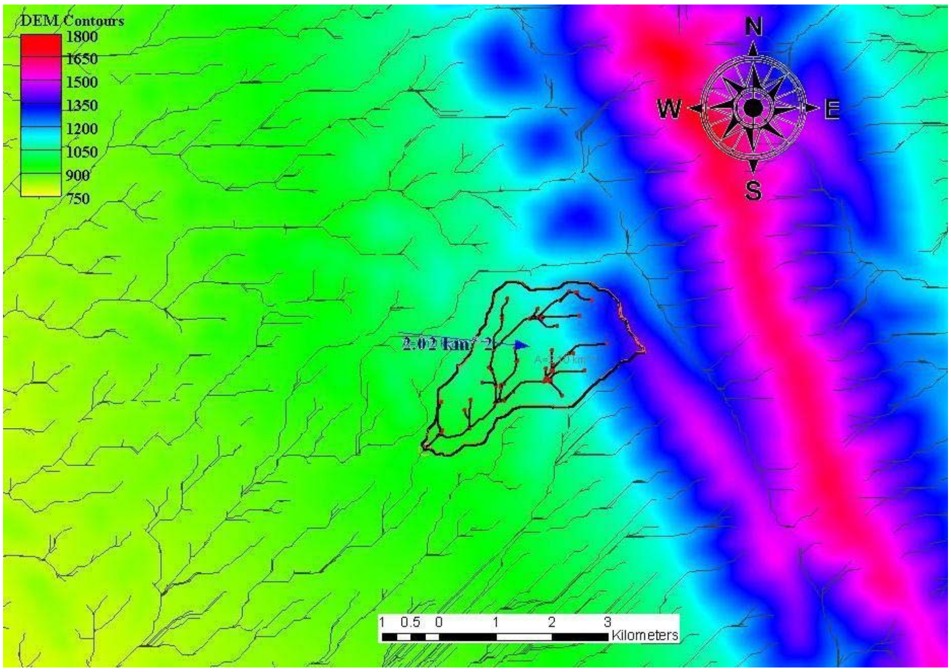


Fig. 2: Streams flow and boundary of the watershed.

Table 1: Comparison for the watershed properties results.

Parameter Name	DEM Results	Field Results	Unit	Percent of Error	Equation
Area	2.02	2.014	km2	0.3	-
Average Basin Slope	0.126	0.11	m/m	14.03	-
Max Flow Distance	3.2	3	km	6.67	-
Centroid Stream Distance	1.44	1.78	km	19.1	-
Watershed Length	2.47	2.43	km	1.89	-
Watershed Perimeter	6.75	6.63	km	1.81	-
Elongation ratio	0.65	0.65	-	0	$= (4\,A / \pi)^{0.5} / L$
Circulation ratio	0.55	0.56	-	1.79	$= A / A_c$
Compactness ratio	1.34	1.31	-	2.29	$= P_b / (2\sqrt{\pi A})$
Form factor	0.32	0.34	-	3.52	$= A / L^2$
Maximum Elevation Difference	452	482	m	6.22	-
Relief ratio	0.182	0.198	-	8.08	$\Delta H/L$
Time of Concentration	21.6	24	min	10	$= 0.02\,L^{0.77}\,Y^{-0.385}$

* Percent error = $|R_{DEM} - R_{Barjinji}| / R_{Barjinji} \times 100$ %
* A: watershed area.
* L: the maximum watershed length.
* A_c: the area of a circle has the same perimeter.
* P_b: is the perimeter of the watershed.
* Y: is the watershed gradient.

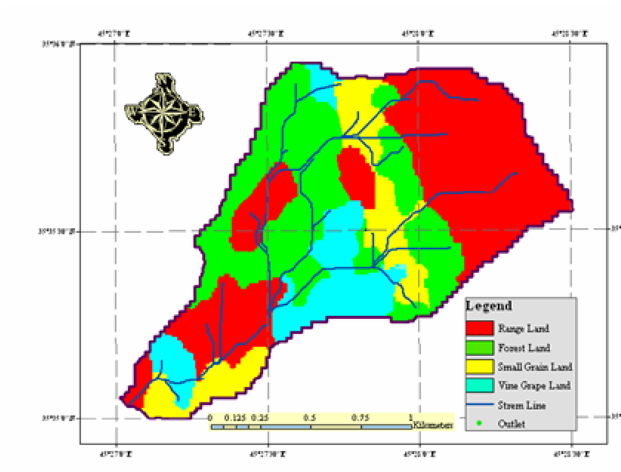


Fig. 3: Land use map.

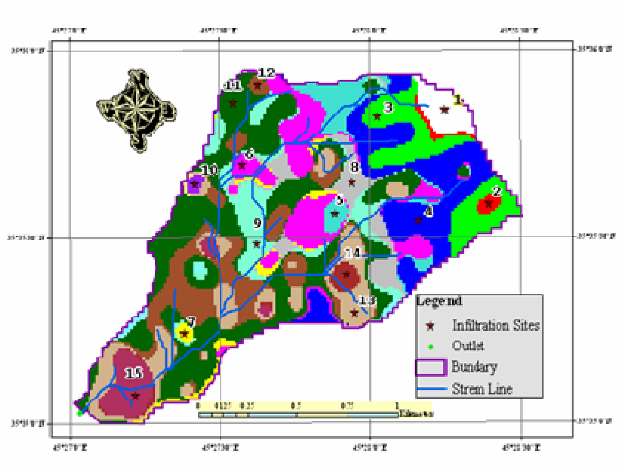


Fig. 4: Soil type map.

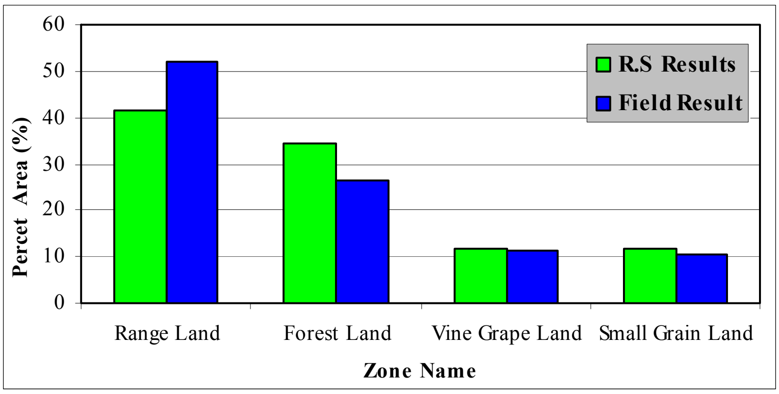


Fig. 5: Percent and total area of land use for Goizha-Dabashan watershed.

Table 2: Curve number values for the study area.

Zone No.	Land use	Area (ha.)	Weighted Area	Soil Type	Condition	Treatment	CN II	CN I	CN III
1	Range	6.158	0.03	D	Good	-	71	50.7	84.9
2	Range	2.803	0.014	D	Good	-	71	50.7	84.9
3	Range	14.151	0.07	D	Good	-	71	50.7	84.9
4	Range	29.881	0.148	D	Good	-	71	50.7	84.9
5	Range	11.486	0.057	D	Good	-	71	50.7	84.9
6	Range	18.217	0.09	C	Fair	-	73	53.2	86.1
7	Range	6.276	0.031	D	Poor	-	89	77.3	94.9
8	Forest	6.434	0.032	B	Good	Contoured	58	36.7	76.1
9	Forest	9.927	0.049	A	Good	Contoured	32	16.5	52
10	Forest	4.993	0.025	C	Good	Contoured	72	51.9	85.5
11	Forest	24.651	0.122	B	Good	Contoured	58	36.7	76.1
12	Small Grain	12.532	0.062	B	Poor	Contoured	74	54.4	86.7
13	Small Grain	21.848	0.108	C	Poor	Contoured	82	65.7	91.3
14	Vine Grape	7.401	0.037	B	Poor	Contoured	73	53.2	86.1
15	Vine Grape	25.243	0.125	B	Poor	Contoured	73	53.2	86.1

Table 3: Nash model Values for the three models, and rainfall depth for each storm.

Storm No	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**Mean**
CN Model	0.918	0.95	0.958	0.93	0.7	0.88	0.98	0.988	0.83	0.957	**0.909**
Barzinji, 2007 Model	0.786	0.702	0.954	0.911	0.936	0.964	0.927	0.982	0.951	0.964	0.907
ANN Model	0.938	0.968	0.95	0.985	0.844	0.994	1	1	1	Failed	0.964
Rainfall Depth (mm)	21.4	18.9	19.65	13.9	16.4	22	14.8	30.3	40	18	

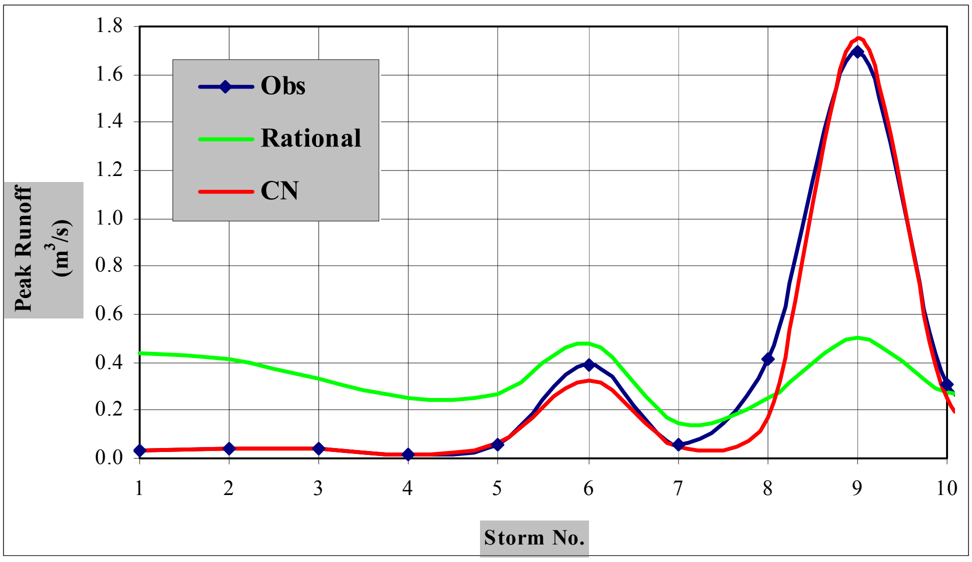
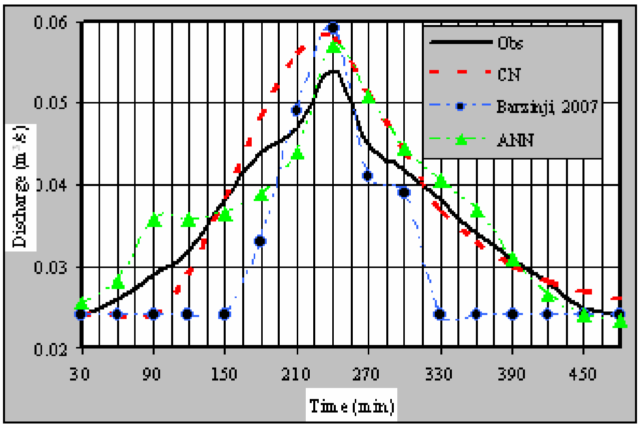


Fig. 6: Observed and calculated peak runoff.

APPENDIX A: RUNOFF HYDROGRAPHS.



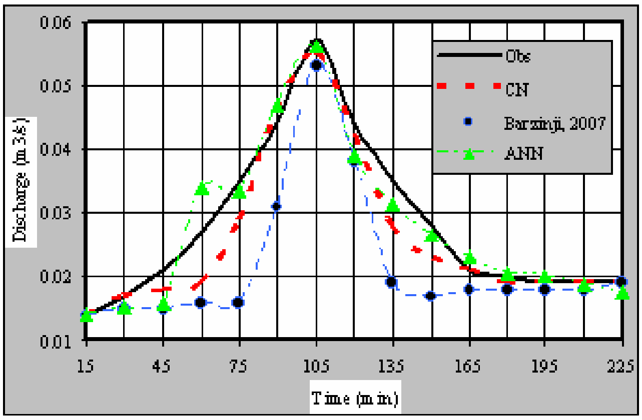


Fig. 1: Observed and calculated runoff for storm Fig. 2: Observed and calculated runoff for storm 2

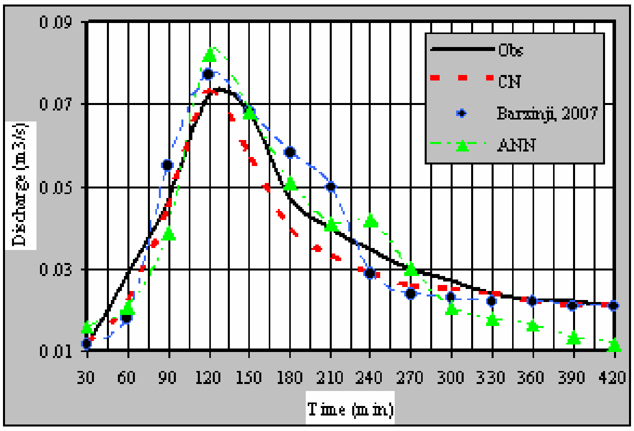


Fig. 3: Observed and calculated runoff for storm 3

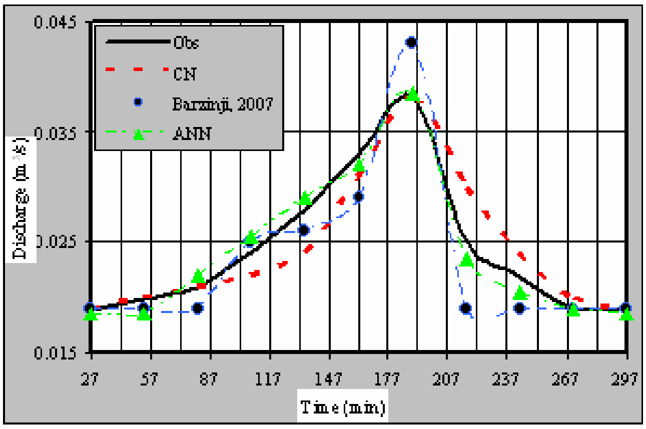


Fig. 4: Observed and calculated runoff for storm 4

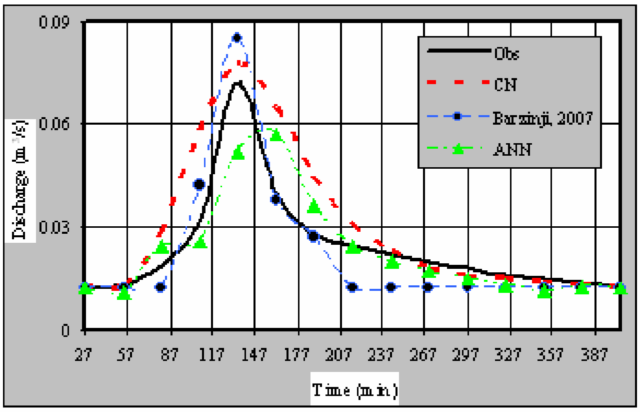


Fig. 5: Observed and calculated runoff for storm 5

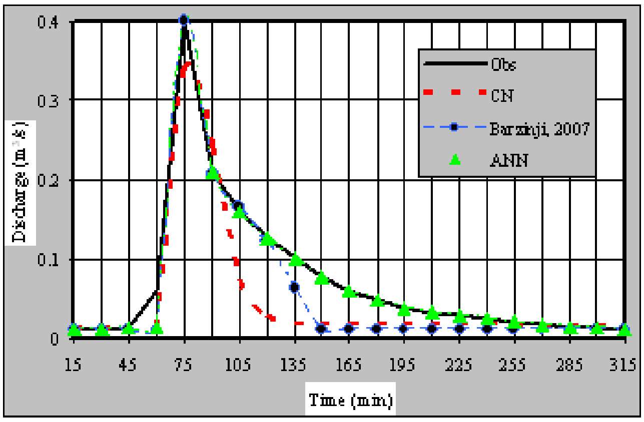


Fig. 6: Observed and calculated runoff for storm 6

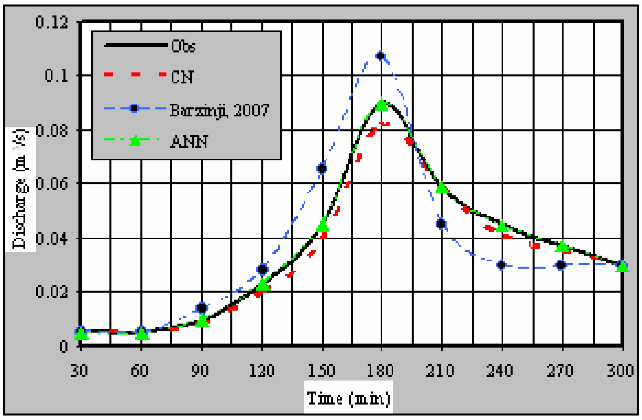


Fig. 7: Observed and calculated runoff for storm 7

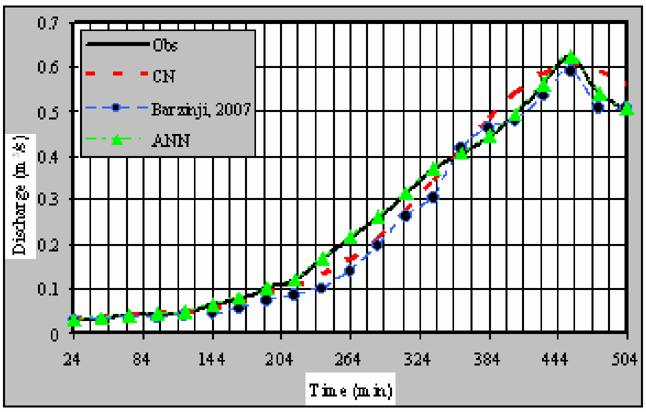
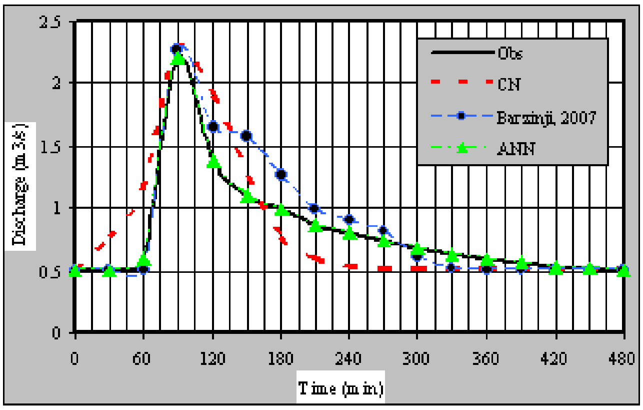


Fig. 8: Observed and calculated runoff for storm 8



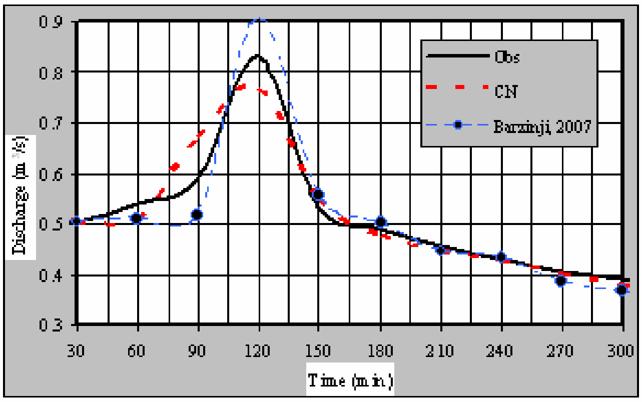


Fig. 9: Observed and calculated runoff for storm 9 Fig. 10: Observed and calculated runoff for storm10