ICIWRM – 2000, Proceedings of International Conference on Integrated Water Resources Management for Sustainable Development, 19 – 21 December, 2000, New Delhi, India

Rainfall-runoff relationship model for Amameh watershed in Iran

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Abstract

The Amameh catchment in Iran that covers 3712 ha in area is one of the mountainous sub basins of Jajroud River over which the Latian dam has been constructed. There the mean annual precipitation is 848.4 mm. The mean annual runoff of the river is about 18.735 million m^3, with an average discharge of 0.55 m^3/s.

Since the rainfall-runoff relationship is one of the fundamental investigations in the field of hydrometeorology studies, therefore an applicable model has to be defined for each of the case study area. While in some of the studies the equations, which have been developed under different conditions of the case study area, are being directly used and show large differences in between the predicted and the real data. To develop and select the appropriate model for the study watershed, 15 storms have been selected for which all of the characteristics of the storm viz., duration, intensity, amount, related runoff volume and peak, and time of incident are available for the analysis.

An attempt has been made in this paper to apply and observe the relative applicability of some of the available basic equations defining the relationship between rainfall and runoff. The SCS Curve Number method is being used for the development of the model.

Different types of statistical models, viz., bivariable and multivariable linear models as well as their polynomial, power, logarithmic and exponential are being checked. The best model will be selected based on the optimization approach and the statistical criteria. The result of the present study has shown that the models, which have been developed in other countries, are not reliable and their calibration for application on other watersheds are necessary for more accuracy.

INTRODUCTION

Applicability of rainfall-runoff models is watershed specific and great care has to be exercised before applying them on other watersheds. In some cases, the relationships that have been developed under different agroclimatic conditions as compared to the present

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study area, when applied directly were found to show large differences between predicted values and observed data.

The SCS curve number technique, pioneered and developed by the US Soil Conservation Service, which is now identified as Natural Resources Conservation Service (NRCS), is a simple method for the estimation of direct runoff depth from storm rainfall depth (Chunale et al., 1999). It has been found that this model needs calibration for application on other agroclimatic areas (Anonymous, 1972; SCS, 1972; Smith and Eggert, 1978; Hawkins 1978; Hjelmfelt et al., 1982; Bosznay, 1989; Hauser and Jones, 1991; Steenhuis et al, 1995, and many others).

In the present study, an attempt has been made to suitably apply the SCS Curve Number method on the Amemeh watershed in Iran by adjusting its parameters to the condition the study area.

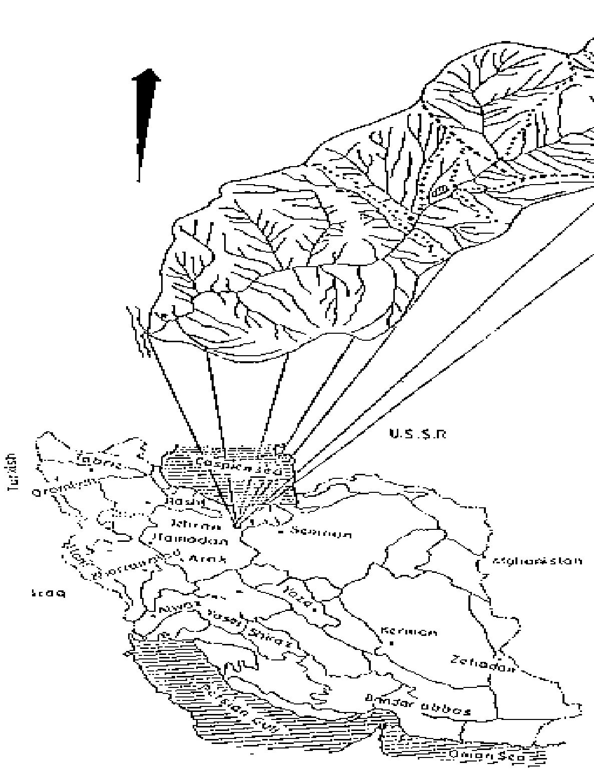

Figure 1. General view and the location of the Amameh watershed in Iran.

THE STUDY AREA

The Amameh catchment in Iran is located about 40 km from the capital of Iran, (Tehran) and covers 37.12 km^2 in area, is one of the mountainous sub basins of Jajroud River. It lies between 35°-51′-00″ to 35°-75′-00″ N latitude and 51°-32′-30″ to 51°-38′-30″ E longitude as is shown in fig.1. It is located in the southern skirt of the Albourz mountain range with quite complex characteristics. Some of the other geometric characteristics of the watershed are summarized in table 1.

Table 1. Geometric factors of the Amameh catchment.

Mean elevation (m)	2620
The most top point elevation (m)	3868
Outlet elevation above sea level (m)	1800
Watershed perimeter (km)	29.5
Drainage density (km/km^2)	3.39
Average slope (%)	28.5
Weighed average slope of main river (%)	14.7
Average slope of main river (%)	13.8
Length of the main river (km)	13.5
Circularity ratio	1.33
Bifurcation ratio	5.8
Length &width of equivalent rectangle (km)	L=18.98, W=3.57
Length between the centroid and the outlet (km)	6.5

The geological formation, through which the Amameh River passes, belongs mainly to the third geologic era with 11-13 km thickness stratography. There are two very important aspects, which influence the modelling effort. Firstly, most parts of the catchment is covered by deep Limstone layers, therefore, keeping track of hydrodynamic processes will be difficult. Secondly, there are variety of geomorphological faces in the catchment such as, various forms of Karstic, Outcrops, Faults, Joints, and rock cracks. Therefore, they can trap the water, most of which is account of snowmelt, thereby affecting the model performance (Gholami, 2000). The area is formed by thick stone layers such as Conglomerate, Marls, Shale Marls, Schist, Limestone, Tuff shale and Bad land (Hezar Darreh formation) that in some cases are seen alternatively in a severely folded form. There is also the Quaternary formation, but it is only to a limited extent in the collovial and alluvial areas.

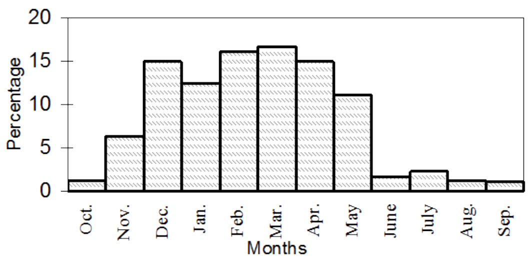

Figure 2. Monthly distribution of precipitation on the Amameh catchment.

There are twelve rainfall stations located over the entire watershed including ten storage and two recording types. Out of these recording raingauges, one of them is situated at the outlet and the other at the center of the watershed. Another recording raingauge is also available just outside the watershed, which was used for climatological analysis.

The mean annual precipitation calculated by the Thiessen method and the runoff are found to be 848.4 and 504 mm respectively. About 45 percent of the precipitation falls during the winter season, i.e., from January to March. The rest of the amount is distributed within other seasons. The monthly distribution of annual precipitation is shown in fig.2. It may be seen that most of the precipitation i.e. almost 73 percent falls during the winter and spring seasons (December to May).

The annual mean temperature in the area is 8.6°C whereas the absolute maximum and minimum temperature are 35 and -24°C respectively. The annual average of evaporation is about 130 mm whereas the least and the highest values of evaporation occur during the months of February and July respectively. According to the Demarten classification, a very humid climate is dominant over the watershed. Humid and semi humid climates are found in the lower portions of the area.

There are two hydrometery stations, one of which is located at the outlet and the other at the middle of the watershed over the main stream, named as Kamarkhani and Baghtangeh respectively. Both the stations are equipped with scale, limnograph (recorder) and a bridge since about 30 years back. The average long-term discharge at Kamakhani station, measured by broad crested weirs and the available stage-discharge relationship, is 0.575 m^3/s (WRRO, Iran, 1996). The maximum and the minimum of observed discharges are 21.2 and 0.01 m^3/s respectively. The months of April and September are the wettest and the driest months during the year respectively. The area is identified as a wet catchment and the average annual runoff is equal to 503.6 mm, which is almost 59 percent of the yearly precipitation.

The Amameh catchment is mainly covered by mountainous rangelands. The distribution of different land uses has been shown in table 2 as below:

Table 2. Land use distribution in the Amameh catchment.

Land uses	Area (ha)	Percentage
Orchards	242	6.5
Rangelands		
-Fair	1603	43.2
-Good	1139	30.7
-Excellent	292	7.9
Others (Rural area, roads, …)	436	11.7

MATERIALS AND METHODS

The available hydrograph and hyetograph of the last many years, having the same time coincidence, were collected and analyzed to develop the relationship between precipitation and runoff for the Amemeh catchment in Iran. Fifteen number of storms have been selected for which all of the characteristics of the storm viz. duration, intensity, amount, volume and peak of runoff and time of incident were available for the analysis as shown in table 3.

Table 3. Selected storms and their specifications on the Amameh catchment.

Serial No.	Storm (Date)	Vol. of discharge (m^3)	Peak discharge (m^3/s)	Precipitation (mm)	Duration (hr)	Max. I30 (mm/hr)
1	April 23,70	13680	0.857	9.050	3.00	12.00
2	April 14,71	95580	8.552	19.050	6.50	18.60
3	Aug. 2,72	11466	0.890	7.500	2.00	11.60
4	Nov. 3,72	64350	3.400	9.550	2.25	29.60
5	July 18,74	27540	4.000	13.150	1.75	51.00
6	April 23,75	66600	6.800	14.000	5.00	9.60
7	July 22,76	64440	10.440	21.250	5.00	29.00
8	April 29,80	97065	4.148	11.000	4.00	13.70
9	April 25,83	68634	3.432	20.350	6.50	30.00
10	May 5,84	8712	1.381	6.860	2.50	8.12
11	July 25,88	32040	2.149	4.000	2.00	10.40
12	Nov. 18,88	16353	0.816	9.500	4.00	35.00
13	Mar. 13,89	80064	1.800	16.360	2.50	80.00
14	Oct. 28,90	7578	0.908	11.375	1.50	52.00
15	April 6,97	35656	2.005	9.200	7.25	9.60

SCS Curve Number method

The SCS curve number was initially investigated for its applicability, from which a set of recessive equations for application of SCS curve number was developed for application on the watershed. The concept of the technique is presented as following and the result will be given latter.

The CN method (1964, USDA) is a conceptual lumped model, which is also called as infiltration loss model because of its lumping nature. It is used to estimate runoff volume from single event storms on small agricultural watersheds. The popularity of the Curve Number (CN) method as a runoff prediction tool lies in the fact that it is simple to use, does not require calibration and is purported to give reliable results. It is often the preferred option because disaggregated daily rainfall data are not required (Hawkins, 1978). A major limitation of the CN method is that rainfall intensity and duration are not taken account, but only the total volume is considered.

It has been found that the simplicity, predictability, stability, reliance on only one parameter (potential maximum retention) and responsiveness to major runoff producing watershed properties are the perceived advantages of the CN method. Whereas, the marked sensitivity to choice of the Curve Number, absence of clear guidance on how to vary the antecedent condition, varying accuracy for different biomass, absence of an explicit provision for spatial scale effects, fixing of initial abstraction ratio at 0.2 and not taking the drainage area into account are the recognizable disadvantages of the CN method (Ponce, V.M. et al., 1996).

The method has been observed to work best in agricultural sites, fair in range sites and poor in forest sites (Hawkins, 1973 and 1984). It is better suited for stream with a negligible base flow i.e. in first and second order streams in sub-humid and humid region and ephemeral streams in arid and semi arid zones (Chunale et al., 1999).

The CN method assumes that, before the commencement of runoff through the watershed, the initial losses viz. infiltration, evapotranspiration, interception and depression storage, must be satisfied. It was assumed that the ratio of direct runoff to the rainfall depth minus initial losses (potential runoff) is equal to the ratio of actual retention to the potential maximum retention. If I_a, Q, P and S are initial abstraction, direct runoff, rainfall depth and maximum storage coefficient of the soil respectively, then the precipitation-runoff relationship is expressed as following:

$$\frac{Q}{P-I_a} = \frac{P-Q-I_a}{S} \qquad (1)$$

For American agroclimatic condition, it has been found that I_a is 0.2S, then for this case equation (1) gets reduced to:

$$Q = \frac{(P-0.2S)^2}{(P+0.8S)} \qquad \text{subject to } P \geq 0.2S \qquad (2)$$

The potential maximum retention (S) is predicted by using a dimensionless number, called as Curve Number (CN), which varies from 0 to 100 based on antecedent moisture condition (AMC), hydrological group of soil (A, B, C and D), hydrological surface conditions (Poor, fair and good) and three major types of land-uses (Agriculture, Rangeland and Forest). The United States Department of Agriculture (USDA) presented the following equation to determine the value of S in mm:

$$S = \frac{25400}{CN} - 254 \qquad (3)$$

When the value of CN is 100, it means an impervious watershed equivalent to the concrete surface that is where P=Q whereas when CN is 0, it means that runoff is zero because in that case S tends to its theoretical maximum value. According to the capability of soil to generate runoff due to previous precipitation, AMC can be classified into three groups viz. I, II and III (Dry, Average and Wet) based on summation of previous 5 days rainfall and vegetation cover circumstances (Growth and Dormant seasons). It has been reported that the sensitivity of the model is very high to any variation in the value of CN (Hawkins, 1972; Bondelid, 1982; Wood and Blackburn, 1984 and Sadeghi, 1993).

RESULTS AND DISCUSSION

Since the performance of the original CN method in defining the governed situation in the study area was found to be weak, appropriate modifications were required in the CN technique. To calibrate the CN method for accurate prediction of runoff on the Amameh catchment, either the attributed value of the Curve Number (CN) or the amount of

Maximum Storage Index Coefficient (MSIC) of 0.2 needs to be checked for its applicability.

To determine appropriate value of MSIC, the following equation was derived from equation (2).

$$MSIC = \frac{(2P-R)+\sqrt{(R-2P)^2-4\{P^2-R[P+(\frac{25400}{CN}-254)]\}}}{2(\frac{25400}{CN}-254)} \qquad (4)$$

Values for CN were selected based on the soil hydrological group, summation of previous 5 days precipitation to get AMC, vegetation cover and their hydrological situation obtained from the available manuals. The value of MSIC was calculated for each of the precipitation-runoff pairs by applying equation (4). It was found that the MSIC value ranged from 0.09 to 0.28 and had an average value of 0.185. This average value was then applied on equation (5) to check the applicability of the model. However, it was found that it did not match the measured value. Then, as the next step, an attempt was made to determine more appropriate values of CN based on the actual condition of soil moisture. Since the AMC is closely related to the summation of previous 5 days rainfall and the season, an attempt was made to apply the concepts of interpolation to determine the more expedient values of CN. It was observed that all the considered cases were falling within the AMCI (dry condition) while the values of the past 5 days rainfall were changing within a wide range i.e. from 0 to 13 mm. Therefore, the values of CN were then interpolated according to 5 days antecedent precipitation. The calculated values of MSIC were found to be between 0.10 to 0.57 with an average of 0.24. The calculated values of MSIC were then again used on equation (2), but the estimated runoff values satisfied the measured data in a few cases only. Probably this was due to the type of precipitation in the area, as mostly there is snowfall during winter and early spring. Another attempt was then made to develop a series of equations by using the same variables to get the most applicable relationship for calculation of runoff parameters.

A correlation matrix was developed to recognize the interrelationship between each pair of parameters to obtain a set of "Recessive series equation", as shown in table 4.

Table 4. Correlation matrix for the studied parameters.

Variable	Volume (m^3)	Peak (m^3/s)	CN	Precipitation (mm)	Duration (hr)	Max I30 (mm/hr)	MSIC
Volume	1.00	0.65*	0.47	0.63*	0.49	0.11	0.77*
Peak		1.00	0.00	0.71*	0.49	-0.11	0.45
CN			1.00	0.48	0.19	0.38	0.82*
Precipitation				1.00	0.53*	0.38	0.82*
Duration					1.00	-0.32	0.54*
Max I30						1.00	0.30
MSIC							1.00

*Marked correlation coefficients are significant at P<0.05 level.

A close relationship was observed between MSIC, CN and depth of precipitation. Each pair, as well as, all variables were regressed separately by using bivariable and multiple regression equations separately, and were found to have the following forms:

$$MSIC=-1.1536+0.0194CN \quad (r=0.819) \quad (5)$$
$$MSIC=-0.0273+0.0219P \quad (r=0.820) \quad (6)$$
$$MSIC=-0.8807+0.0131CN+0.0148P \quad (r=0.952) \quad (7)$$

The statistical results of equation (7) has been presented in table 5.

Table 5. Regression summery for MSIC, CN and Precipitation relationship.

N=15	BETA	St. Err. of BETA	B	St. Err. of B	T(12)	P-Level
Intercept			-0.880739	0.158021	-5.57356	0.000121
CN	0.552181	0.100269	0.013118	0.002382	5.50702	0.000135
P (mm)	0.555059	0.100269	0.014843	0.002681	5.53572	0.000129

Dependent variable: MSIC Independent variables: CN and Precipitation depth (mm)
R=0.95243550 R^2=0.90713338 Adjusted R^2=0.89165560
F(1,13)=58.609 P<0.000001 Std. Error of Estimate=0.04524
Standard deviation of Runoff=0.8660 (mm), Standard deviation of Precipitation=5.1399(mm)

Then, the volume of runoff was related to the MSIC by using all the different types of regression equations viz. linear, polynomial, power, exponential and logarithmic, out of which following models were the most reasonable and found to also have the highest correlation coefficients.

$$V=123988+49746.1935Ln(MSIC) \quad (r=0.821) \quad (8)$$

where V is the volume of runoff in m^3. Since MSIC is directly related to the depth of precipitation, no relationship was developed between the volume of runoff and the depth of precipitation. It was modified by using the subjective optimization technique, which reduced the error of estimation of runoff volume through more adjustment of regression coefficients.

The peak rate of runoff is also a very important parameter in hydrology, therefore, a set of equations were developed as a relationship between the peak flow rate and the relevant parameters as they are shown below:

$$Q_p=0.0009V^{0.7627} \quad (r=0.803) \quad (9)$$

$$Q_p=7.930+1.2262P \quad (r=0.711) \quad (10)$$

where Q_p is the peak of runoff in m^3/s and P is the depth of precipitation in mm. Equation (9) is the most logical relationship to estimate peak of runoff by virtue of having the highest correlation coefficient.

Model verification

Six other storms, which did not contribute in the development of model, were used for the verification and evaluation of the developed models. The error of estimation for all the predicted variables i.e. MSIC, volume and peak of runoff were found to be very small, except for small storms. The error for results of verification was also found to be very small and within the acceptable range of below 30 percent.

It was found that the developed technique is not very accurate in case of small discharges that were caused probably due to snow melt or interflow feeding. The direction of layer bending of the geological formations may also be one of the other reasons for that low efficiency in case of small storms, because a greater part of the initiated runoff may be interred into the ground surface and joined to the sub-layer flows.

CONCLUSION

In spite of popularity of SCS Curve Number method, its applicability is limited under different agroclimatic conditions, as compared to the USA where it was originally developed. The problem is more obvious in cases of those models, in which dummy variables are used, because determination of such parameters not only is very tedious and difficult but also varies from expert to expert. The Curve Number method can also be categorized among these types of models in which determination of CN values need high care.

The assigned coefficient for the potential storage in the CN method was found to be not applicable on small storms in the case study area and due to this, the method could not be used directly. The same parameters applied in the CN method were utilized to develop a series of recessive equations to calculate the Maximum Storage Index Coefficient, the volume and the peak of runoff. The recessive equations showed a very high degree of agreement between the studied parameters, and their accuracy for prediction of unknown variables was found to be acceptable. The developed procedure can be applied on other watersheds having different types of geographical characteristics.

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