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# Role of Basin Physiography on the Statistical Parameters of Peak Flows

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***Author's contribution***

*The sole author designed, analyzed and interpreted and prepared the manuscript.*

***Article Information***

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## ABSTRACT

The objective of this study is to integrate frequency and event based rainfall-runoff models in order to derive some conclusions on the role of basin physiography on the frequency distribution of peak flows. Annual peak flow series of the hypothetical basins with alternating physiographic characteristics, such as drainage area, and length and slope of the main channel are generated through a deterministic rainfall-runoff model. Sample statistics and frequency distributions of the generated annual maximum storms of random effective durations and of the resulting peak flow series are investigated. It was found that the average and the standard deviation peak flow decreases as the length of the main course increases, while the average and standard deviation of peak flow increase as the drainage area and harmonic slope increases. Besides variation coefficients and skewness coefficients of the peak flow samples exhibit a random behavior.

*Keywords: Synthetic rainfall generation; flood probabilities; rainfall-runoff relationship; unit hydrograph; time of distribution storms; abstraction methods.*

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## 1. INTRODUCTION

The planning and design of hydraulic structures for use in ungaged basins suppose some estimate of flood flows and their frequency of occurrence. Sometimes observed and recorded rainfall data may be much longer than corresponding flow observations [1]. If there is no historical streamflow data for these basins, regional analysis, or parametric rainfall-runoff event simulation can be used for the estimation of floods. Existing rainfall data with maximum value are used as input variables in parametric rainfall-runoff models *that* unifies watershed characteristics to estimate flows at any site in the watershed. If both rainfall and runoff data are not present, random input variables are produced by the Monte Carlo method and frequency analysis techniques are utilized to analyze output variables [2,3].

Rainfall-runoff models have been developed by several researchers for the purpose of accurately predicting runoff hydrographs, peak flow rates, as well as times of peak. Early models were structured according to empirical equations. [4] proposed the “unitgraph” or the unit hydrograph method. This was one of the early attempts to predict a hydrograph as a whole, rather than just predicting the peak flow rate and time of peak. Several years later, many researchers attempted to enhance the unit hydrograph technique by using sophisticatedly complex models so as to help build up the hydrograph shape. Some of these proposed methods involved treating the watershed as a cascade of linear reservoirs, with the help of nonlinear reservoirs or different statistical procedures. In the assessment of [5], the method produced mathematically accurate hydrographs, but lacked association with reality and quickly turned into mathematical exercises solved by algebrists.

During the 1960s, researchers attempted to set up models that not only yielded accurate results, but could also be interpreted physically. [5] presents a brief summary of several physically-based rainfall-runoff models structured between the 1960s and 1970s.

With the improvement of computing power, hydrologists have also developed more sophisticated models. Between the 1980s and 1990s, a great number of distributed parameter models were launched. Distributed parameter models have the capability of incorporating information about land use, the spatial variability of soils, topography, as well as all other parameters in the modeling set-up. Several distributed parameter models have numerous input data requirements and need considerable computing power. However, they are capable of modeling processes occurring within the watershed and the outlet as well.

L. K. Sherman first introduced the unit hydrograph in 1932 [6], which is a method for estimating storm runoff. Since then, this technique has been used as a chief concept of measurement. The unit hydograph is described as the watershed response to a unit depth of excess rainfall, evenly distributed over the whole watershed and applied at an invariable rate for a specific period of time. Following the study of watersheds in the Appalachian mountains of the United States in 1938, Snyder presented several relations between a number of key qualities relating to the unit hydrograph, such as peak flow, lag time, base time, and width – in terms of units of time – at 50% and 75% of the peak flow [6]. [7], on the other hand, made a substantial contribution to the theory of unit hydrograph. He introduced a unit hydrograph developed through a specifically pure translation routing process, known as the plug-flow, followed by another process of pure storage routing, which involves a fully stirred tank reactor. Despite the fact that Clark did not use a spatially distributed analysis, the translation phase of the routing is performed according to the time-area diagram of the watershed. The storage phase involves routing the response of the translation using a single-linear reservoir found at the watershed outlet. As a way to reproduce the falling limb of observed hydrographs, the reservoir’s detention time is determined. Note that the actual travel time of a water particle, based on this approach, represents the travel time given by the time-area diagram and the detention time of the reservoir, which is found to be variable to some degree.

A few years later, a unit hydrograph equation was introduced by [8]. This equation is a gamma distribution, which is the response of a cascade of identical linear reservoirs to a unit impulse. It is also worth mentioning that the technique, presented for the first time by Nash, did not structure the watershed itself. In fact, it was merely a fitting method, which performed according to the first and second moments of the measured and observed hydrographs.

The aim of the rainfall-runoff method to transform a rainfall event, specifically a rainfall depth of a given annual exceedance probability (AEP), to flood discharge or flood estimate of the same AEP. The approach that is referred Design Event Method considers the probabilistic nature of rainfall depth but ignores the probabilistic behavior of other model inputs such as rainfall temporal pattern and losses. The Design Event Approach has been the focus of much critique by researchers [9,10,11,12,13,14,2,15,16]. The end result of this process is that assumed AEP of design inputs and parameters can not be confirmed and the actual AEP of the flood peak or flood estimates is never really known.

The other rainfall-runoff methods are developed named as the Joint Probability Approach [17] and the Continuous Simulation vs. Event-based [18], for Australian catchments. [18] used a daily rainfall generation model with disaggregation procedure to provide input to a water balance model. [17] considered the probability-distributed nature of input variables and the dependencies between them to produce probability-distributed flood outputs.

In this study, the proposed model of the peak flow formation process involves the same components as the models most commonly used with the current Design Event Approach but in this study most important concept is generation of synthetic rainfall depth. As generation of rainfall depth, maximum rainfalls of standard durations are used. Mean and standard deviation of the rainfall data are defined as certain smooth functions of rainfall duration.

In content of this study, a Monte-Carlo simulation (Experimental Statistical) which is performed in order to derive some conclusions about the role of basin physiography on statistical parameters of annual peak flow sequences.

In the content, the first objective of this study is to integrate frequency models and event based rainfall-runoff models in order to derive some conclusions on the role of basin physiography on the statistical parameters of peak flows. The second is to explore whether a rainfall-runoff transformation process transfer the statistical and distributional characteristics of rainfall events into the output (peak flows).

It is hoped that these conclusions will be beneficial in areas with significant information on precipitation and limited information on peak flows. In order to achieve these objectives the following studies are performed with below steps:

Step 1: Generation of synthetic rainfall series with random durations and specific time distribution for given population statistics and probability distribution.

Step 2: Determination of flood hydrographs of a hypothetical basin with known physiographic characteristics, such as drainage area (A), length of the main course (L) and slope of the main channel (S). Deterministic rainfall-runoff models such as, synthetic unit hydrograph methods and discrete convolution technique applied to transfer rainfall input into direct runoff.

In Turkey, rainfall and runoff data are seldom adequate to determine unit hydrographs of drainage basins. When it is necessary to determine a unit hydrograph for a basin, one of the synthetic unit hydrograph determination methods is used. Synthetic unit hydrographs can be estimated for ungauged drainage basins by means of relationships between parameters of a characteristic of the drainage basin. The most commonly used methods are the Snyder, the Mockus [19], the State Hydraulic Works (DSI) Synthetic and U.S. Soil Conservation Service (SCS) methods. In this study, Mockus Synthetic Unit Hydrograph Methods is used.

Step 3: Frequency analysis of the generated long peak flow series performed. Seven well-known probability distribution models with method of moment parameters are tested by chi-square goodness of fit tests.

Step 4: The effect of rainfall pattern (time and areal distribution) under given physiographic characteristics are investigated.

Step 5: The effect of basin physiographic characteristics such as drainage area (A), length (L), and slope (S) of the main course which are the principal factors affecting the basin unit graph, on the frequency distribution of the peak flows are investigated.

## 2. GENERATION SYNTHETIC STORMS AND PEAK FLOWS

To determine runoff pattern of a stream it is first necessary to know the amount and the pattern of rainfall. Several strategies have been used to develop rainfall inputs for use in estimating flood probabilities by runoff modeling. Potential methods are classified into three groups, depending on whether they are based on: (1) direct use of actual data, (2) stochastic rainfall models, or (3) synthetic storms. The use of synthetic storms is based on the concept of a storm event for which explicit exceedance probabilities can be estimated. In (1) and (2) methods, exceedance probabilities associated with the rainfall inputs are implicit. An observed rainfall record is assumed to represent a random sample. In the case of synthetic storms, exceedance probabilities are explicitly associated with specific storm events.

Rarely there is a constant rainfall excess over a single time increment. Usually, the rainfall excess varies in accordance to time. Consider a unit hydrograph method that divides a rainfall into successive shorter time events, each of which has constant rainfall excesses and equal times. Each rainfall excess value is multiplied by the unit hydrograph to obtain the resulting ordinate values displayed in time by the start of each rainfall excess. This multiplication is defined in mathematical terms as a convolution. Then, the total runoff hydrograph is the superposition of each hydrograph as initiated by its rainfall excess [6].

The basic premise of the unit hydrograph method is that the individual hydrographs obtained by multiplying the ordinates of the unit hydrograph by the various successive rainfall excess increments, when properly arranged with respect to time, can be added to give the total runoff hydrograph.

A single-event based rainfall-runoff simulation model as shown in Fig. 1 is used in estimating peak flows resulting from a given synthetic storm ($X_D$) of duration D. As there are great numbers of physiographic, morphologic, climatologic, soil and vegetal cover factors of the watershed almost impossible to consider them in the simulation model. Therefore only the principal factors in the following are taken into consideration in the generation algorithm of the synthetic peak flows:

In the first step of the study it is planned to generate synthetic storms of given duration (D) and recurrence interval (T) from a given probability distribution. Extreme Value Type-I (or Gumbel) probability distribution is selected since it is commonly used in modelling observed rainfall frequencies and is easy to use.

Synthetic storm generation procedure is as follows:

Probability distribution of rainfall depth ($X_D$) of given duration (D) may be assumed to follow a unique type of distribution function, for example, the probability of non-exceedance of Extreme Value Type-I distribution is given as [20, 21],

$$F_d(X_D)=\exp[-\exp(-\alpha_D(X_D-\beta_D)] \tag{1}$$

where parameters $\alpha_D$ and $\beta_D$ vary as D varies.

$$\alpha_D = 1.2825/ \sigma_x$$
$$\beta_D = \mu_x - 0.45\, \sigma_x$$

where $\mu_x$ is the population arithmetic mean and $\sigma_x$ population standard deviation. Designating a unit duration by $\Delta t$ the rainfall duration may be represented as multiples of $\Delta t$.

$$D = M.\Delta t \tag{2}$$

where M is the number of $\Delta t$ intervals in D. M is any integer number which is generated by pure chance, for example an integer number following discrete uniform distribution in the range $1 \le M \le M_{max}$ where $M_{max}$ is the maximum number of $\Delta t$ intervals in storm duration.

By generating uniform random number (or probability of non-exceedance) $F_D(X_D)$ in the range

$$0< F_D <1 \tag{3}$$

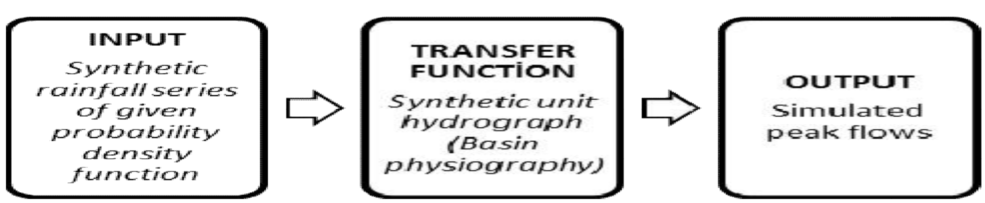


**Fig. 1. Flow chart for rainfall-peak flow simulation**

The synthetic rainfall depth $X_D$ calculated from the postulated probability density function if the parameters (or population statistics, such as the mean and standard deviation of the storms) are known in advance:

$$X_D = \beta_D + \{-\ln[-\ln(F_D(X_D)]\}/ \alpha_D \quad (4)$$

For each generated synthetic rainfall input $X_D$ with duration d incremental rainfall excesses $\Delta R_m$, m=1,2,..., M are calculated from assumed time distribution curve and $\phi$-index (Fig. 2).

$$\Delta R_m = P.\ \Delta f_m - \phi.\Delta t \quad (5)$$

where $\phi$ is the $\phi$-index of the watershed and $\Delta f_m$ is the percent rainfall amount between times (m-1) $\Delta$t and m$\Delta$t.

Rainfall abstractions in the rainfall-runoff model are considered through the $\phi$-Index and SCS curve number methods. The appropriate values of $\phi$ and CN are investigated for the excess rainfall values for a few synthetic storms that are approximately equal. A constant $\phi$ =2 mm/h infiltration rate is assumed throughout the storm durations. As an alternative, the SCS-curve number method with CN=90 is also applied in order to account for the initial abstractions and its role on the ERH and composite hydrographs.

Time distribution curves in Fig. 2 proposed by DSI are commonly used in Turkey in deriving rainfall hyetographs of given design storms. In this study DSI's-A and SCS 6-hour that is the most intense short duration rainfall [22] are used in order to calculate rainfall hyetographs of given synthetic storms. The Soil Conservation Service (SCS) dimensionless cumulative rainfall curves was developed for various storm types, storm durations and regions in the United States [23]. The storm duration was initially selected to be 6 hours. Durations of up to 48 hours have, however, been developed. The rainfall distribution varies, based on duration and location.

DSI's Curve-A that is mostly used in Turkey for hydrologic analysis [24] and SCS 6-hour time distributions [25] are assumed to represent the role of the time distribution of storms on the probability distribution of peak flows.

$$\Delta f_m = (f_m - f_{m-1}) \quad (6)$$

$f_m = X_m / X_D$ values are taken from a curve A, B or C.

The direct runoff hydrograph (DRH) resulting from a given excess rainfall hyetograph (ERH) is calculated using an appropriate synthetic unit hydrograph method. For the sake of simplicity, it is assumed that the Mockus (or triangular) unit hydrograph is a sufficient tool to simulate the rainfall-runoff transformation process. The triangular unit graph [23] of a unit duration $\Delta$t includes the size of the basin drainage area (A), the length of the main channel (L), and slope, (S) because of the relation between time to peak, $t_p$, and time of concentration, $t_c$.

$$t_p = \Delta t/2 + 0.6t_c = f_1(L, S, \Delta t) \quad (7)$$

$$q_p = KA/t_p = KA/f_1(s) = f_2(A, L, S, \Delta t) \quad (8)$$

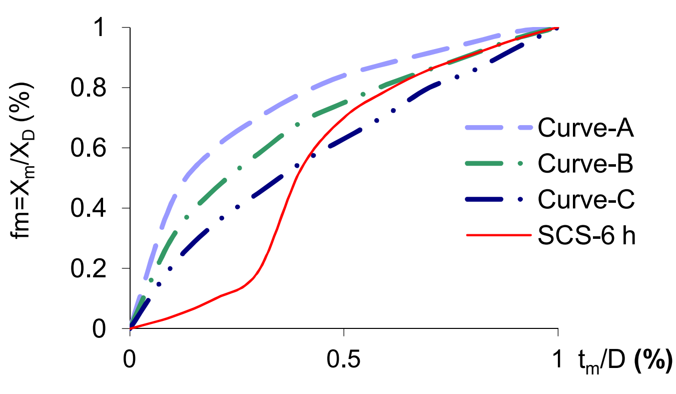


**Fig. 2. Time distribution of cumulative rainfall [23,24,25]**

One of the most important features of a catchment is the time that must pass until the whole area is contributing to runoff at the outflow that is generally called the time of concentration, ($t_c$). The idea of time of concentration is significant in all methods of flood estimation as it can be assumed that the rainfall occurring while the time of concentration is directly related to flow. This time is composed of two parts; (1) The time for overland flow to comprise from a point on the perimeter of the catchment to a natural or synthetic drainage channel. (2) The travel time in the channel to the outflow point of the catchment. It (The time taken for overland flow to reach a conduit or channel) depends on a number of factors that are overland flow length (L), average surface slope (S), surface roughness and depth of overland flow (x).

Ordinates of $\Delta$t-hour triangular unit hydrograph at times $\Delta t$, $2\Delta t$, $3\Delta t$, .... are used in calculating superposed output resulting from given ERH of M number of incremental excess rainfall pulses, $R_1$, $R_2$, .... $R_M$.

$$Q_n = \sum_{m=1}^{n \le M} R_m U_{n-m+1} \tag{9}$$

Synthetic peak flow samples are generated and evaluated for four different cases:

(I) DSI' Curve-A and Φ index abstraction method
(II) DSI' Curve-A and SCS-CN abstraction method
(III) SCS 6-hour curve and Φ index abstraction method
(IV) SCS 6-hour curve and SCS-CN abstraction method

## 2.1 Critical Storm Duration and Unit Graph Duration

In this study, it is assumed that the critical storm duration, D, which creates peak flows, is greater than or equal to the effective storm duration, $D_e$, at a given basin with a concentration time, $t_c$,

$$D_e \le D \le 2D_e \tag{10}$$

where $D_e$ is given by $D_e=2(t_c)^{0.5}$ for $t_c$ <4 h, and is $D_e=t_c$ for $t_c \ge 4$ h.

Durations of synthetic storms conforming basin lag are generated by considering that the length (L) and harmonic slope (S) of the main channel are dominating factors on the time of concentration. The effective storm Duration, $D_e$, is given as [6,23]:

$$D_e=2(t_c)^{0.5} \tag{11}$$

$$t_c=0.00032(L)^{0.77}/S^{0.385} \tag{12}$$

where L is the length of the main course in meters, S is the harmonic slope, $t_c$ is the time of concentration of the watershed and $D_e$ is the effective storm duration, both in hours.

Time of concentration ($t_c$) according to Kirpich's formula Eq.12 for various lengths of main course (L) and harmonic slopes (S) are calculated, (For $t_c \ge 4$ hour, effective storm durations are assumed to be equal to time of concentration ($D_e=t_c$)).

A typical rainfall hyetograph is a composition of M number of discrete pulses of $\Delta$t time increments. Therefore the total rainfall duration, D, generated in a random manner from a uniform distribution in the range $D_e \le D \le 2D_e$ is rounded off as multiples of $\Delta$t (Eq. 2)

In order to simplify calculations of composite hydrograph M is assumed as 5, 6, or 7. This assumption is in accordance with unit graph durations used in hydrologic practice, $0.15t_c \le \Delta t \le 0.20t_c$.

## 2.2 Calculating Composite Hydrograph and Peak Runoff

Synthetic peak flow samples for basin sizes A= 40, 80, 150 km$^2$ are calculated using 12 sets of synthetic storms of different durations.

Calculation of compound hydrograph is repeated as the number of generated synthetic design storms, N. Therefore, we have N number of peak runoff, $Q_{max1}$, $Q_{max2}$,......, $Q_{maxN}$.

Ordinates of $\Delta$t-hour triangular unit hydrograph at times $\Delta t$, $2\Delta t$, $3\Delta t$, .... are used in calculating superposed output resulting from given ERH of M number of incremental excess rainfall pulses, $R_1$, $R_2$, .... $R_M$.

$$Q_n = \sum_{m=1}^{n \le M} R_m U_{n-m+1} \tag{13}$$

Best fit probability distribution model for $Q_{maxi}$ sequences will be investigated according to Chi-square goodness of fit test.

In order to explore the effect of physiographic characteristics of the basin on probability distribution of peak flows, each of physiographic variables drainage area (A), length of main channel (L), and harmonic slope (S) will be changed systematically; and the procedure given above is repeated.

## 3. RESULTS AND DISCUSSION

This study concerns itself with application of a new and simple approach for peak flow estimation, the form of a Monte Carlo Simulation Technique. For doing this, frequency and event-based rainfall-runoff model based on physiographic properties of watershed and annual maximum storm with standard duration as input are integrated in order to derive some outputs on the role of basin physiography (transfer function) on the frequency distribution of peak flows for small ungauged basins (Fig. 1).

In order to use in generating synthetic peak flows of the watersheds with 3 number of harmonic slopes and 4 number of main channel lengths, totally 12 number of synthetic storm samples (each N=100 size) distributed as Gumbel are generated. Relative acceptance frequencies of each model for the 12 synthetic storm samples each N=100 size computed by Eq.15 except that absolute frequencies divided by 12.

Statistical and distributional characteristics of synthetic peak flow samples are estimated for various probability distribution models by method of moments for four cases. These synthetic peak flow series of each in size N=100 are generated for three drainage area 40, 80, and 150 $km^2$ and as a result 36 peak flow series were generated.

In order to compare the probability distribution models (normal (N), lognormal with two and three parameters (LN2 and LN3), Gumbel (GUM), Gamma with two and three parameters (G2 and G3), and loggumbel (LGUM)), most frequently accepted (that is, the goodness of fit test is passed) for the synthetic storm samples (input) and for the peak flows (output), relative acceptance frequencies of each model, $f_O$, computed from Eq. 15, at a significance level α=5% for the chi-square test are presented in Table 1 for four cases. Relative acceptance frequency of a specific model ($f_O$) is defined as:

$$f_O = 100\,(TNCH)/36 \qquad (15)$$

The chi-square test results are given in Table 1. When the probability distribution types of the 12 mixed storms used in the generation of the peak flows are evaluated, LN2, G2, GUM and LN3 distributions being the most suitable distribution according to chi-square method with MOM parameters.

As seen in the Table 1, the chi-square test results reveals that; with MOM parameters; GUM model is the most appropriate for case I; G2 for cases II and III, and LN2, LN3, G3 for case III for peak flows. Although the synthetic storms of different durations have the Gumbel distribution, it has been found that the synthetic peak flows follow different probaility distributions.

In the study, it was found that the average peak flow decreases as the length of the main course increases, while the average peak flow increases as the drainage area and harmonic slope increases (Figs. 3 to 6). The SCS-6 hour time distribution (Fig. 2) assumption gives about 20%-25% greater peak flows in the average than the DSI's curve-A (Fig. 2) assumption in the case Φ=2 mm/h.

**Table 1. Percentage of total sample series of the synthetic storm and peak flows series that passed the chi-square goodness of fit test at 5% level of significance (with MOM Parameters) (The most appropriate distribution or distributions are shown with (*))**

| Probability distributions | | NOR | LN2 | G2 | GUM | LGUM | LN3 | G3 |
|---|---|---|---|---|---|---|---|---|
| Input ( $f_I$) | | 58.3 | 91.7* | 91.7* | 91.7* | 75 | 91.7* | 83.3 |
| Output ( $f_O$) | Case I | 66.7 | 66.7 | 91.7 | 100* | 0 | 83.3 | 83.3 |
| | Case II | 0 | 88.9 | 91.7* | 16.7 | 25.0 | 63.9 | 77.8 |
| | Case III | 33.3 | 86.1* | 83.3 | 83.3 | 52.7 | 86.1* | 86.1* |
| | Case IV | 0 | 69.4 | 75.0* | 8.3 | 16.7 | 47.2 | 61.1 |

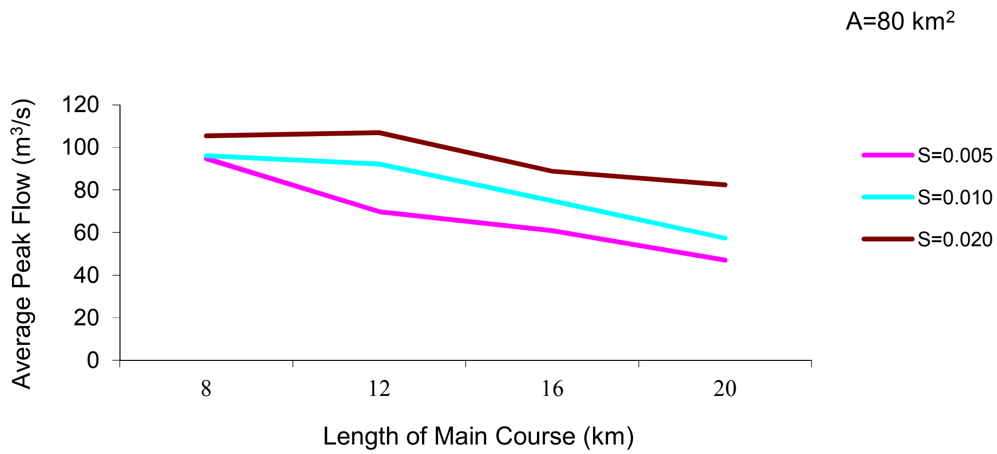


**Fig. 3. Variation of the average peak flow with basin characteristics, A, L and S. (for Case I)**

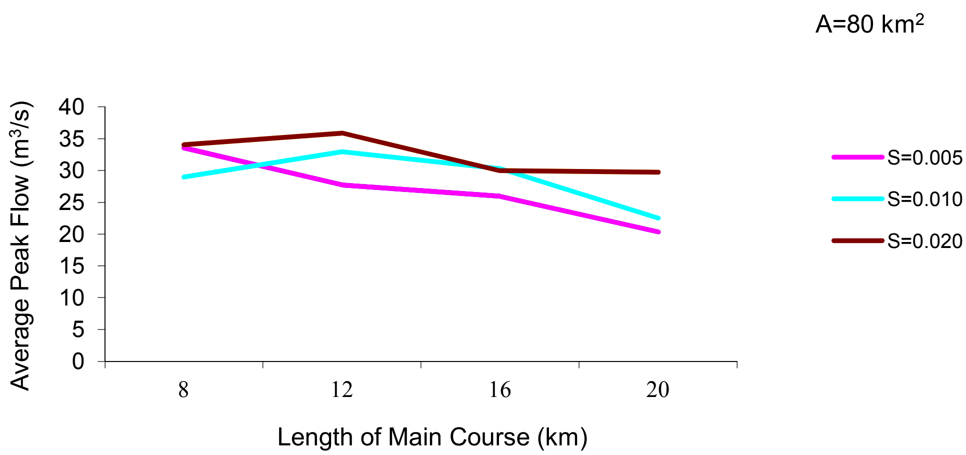


**Fig. 4. Variation of the average peak flow with basin characteristics, A, L and S. (For Case II)**

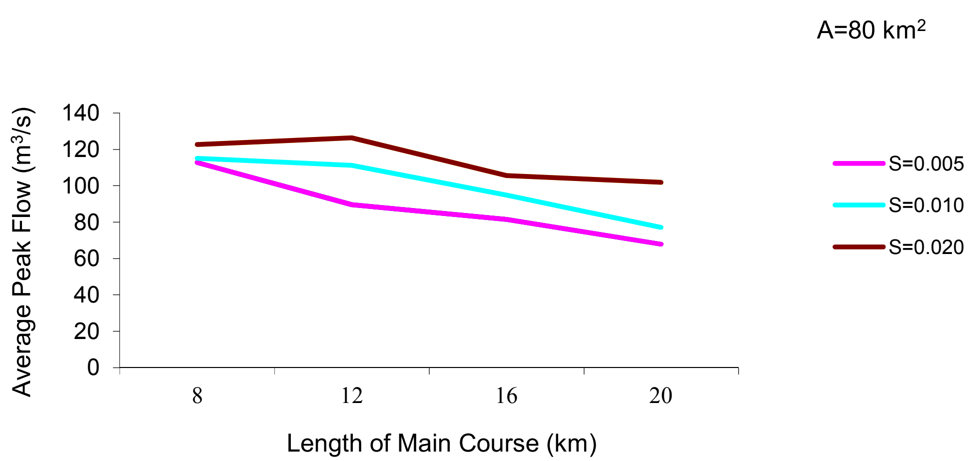


**Fig. 5. Variation of the average peak flow with basin characteristics, A, L and S. (for Case III)**

The standard deviation of the peak flow series decreases as the length of main course increases, while the standard deviation of peak flows increases as the drainage area and harmonic slope of the main channel increases (Figs. 7, 8, 9 and 10). That is, standard deviations of the peak flows are not influenced by the assumptions of time distribution, whereas the standard deviations of the peak flow series estimated by the Φ-index method are about 2 times greater than those estimated by the SCS-curve number method.

Variation coefficients of the peak flow samples exhibit a random behavior within a very narrow band for all situations. Because of the drastic differences between the averages (about 3 times) and standard deviations (about 2 times) the variation coefficients of the peak flow series computed from SCS-curve number method are about 1.5 times greater than those computed by the Φ-index method (Figs. 11 to 14).

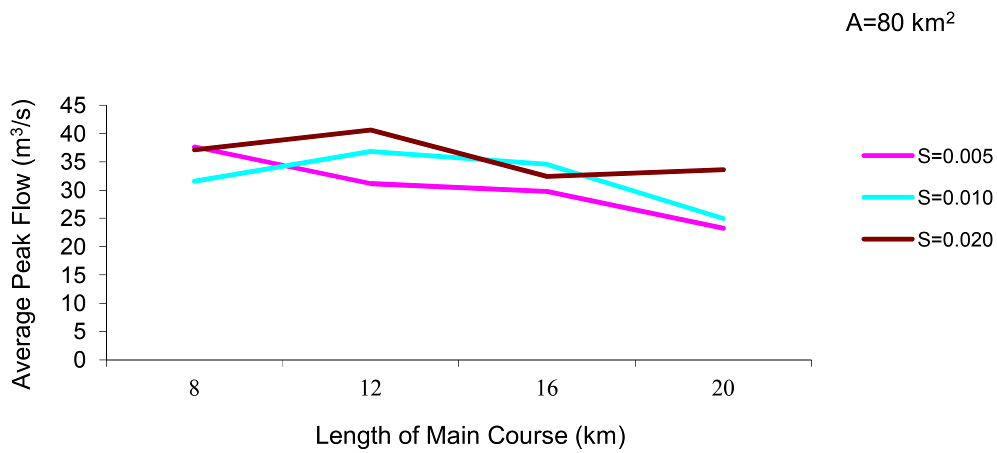


**Fig. 6. Variation of the average peak flow with basin characteristics, A, L and S. (for Case IV)**

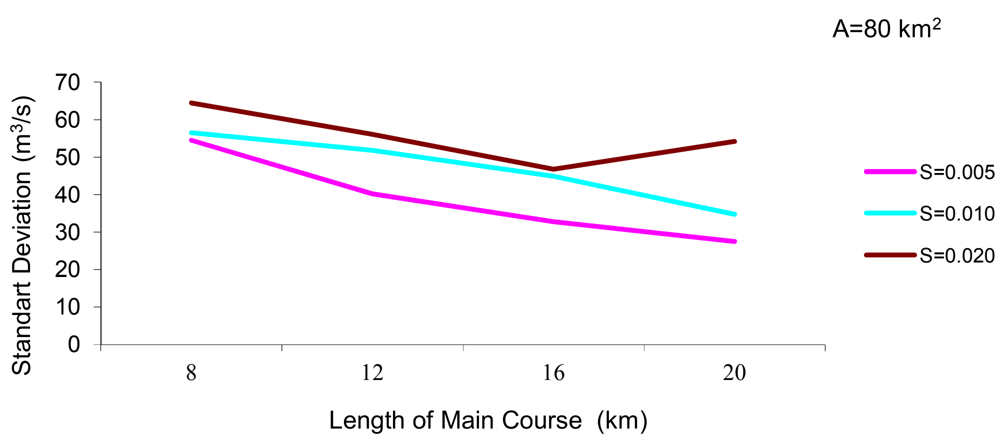


**Fig. 7. Variation of the standart deviation of the peak flows with basin characteristics, A, L, and S (for Case I)**

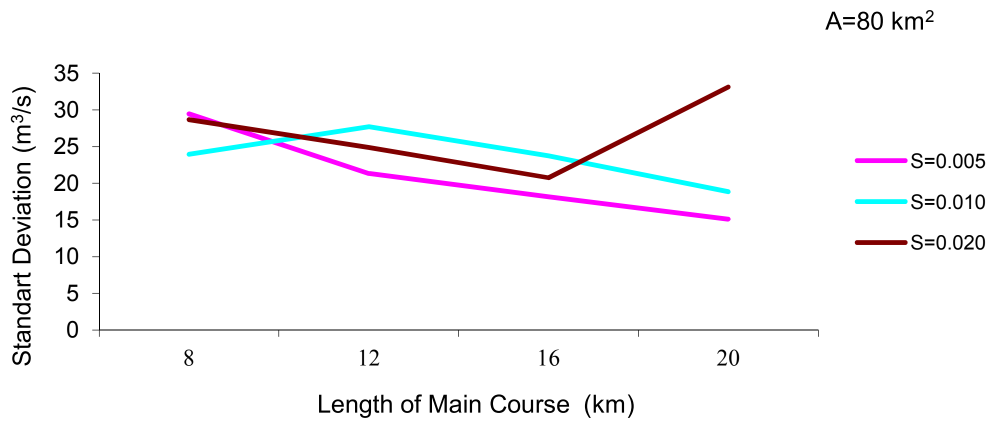


**Fig. 8. Variation of the standart deviation of the peak flows with basin characteristics, A, L, and S (for Case II)**

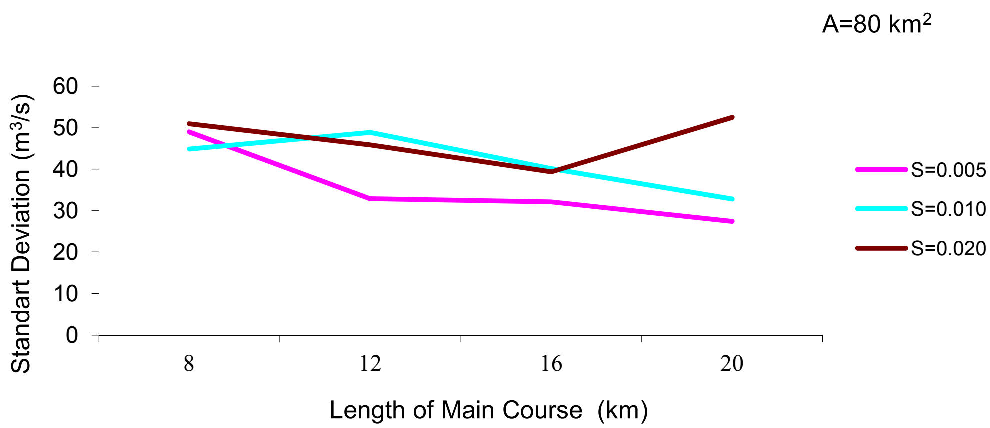


**Fig. 9. Variation of the standart deviation of the peak flows with basin characteristics, A, L, and S (for Case III)**

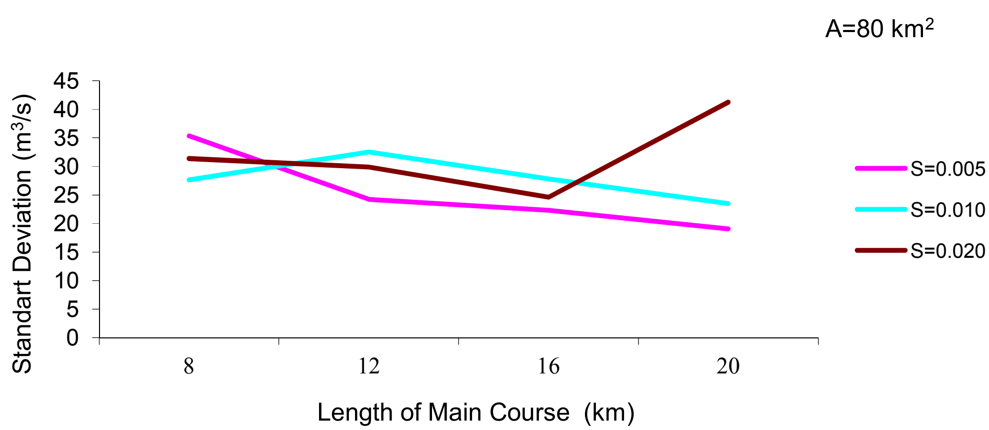


**Fig. 10. Variation of the standart deviation of the peak flows with basin characteristics, A, L, and S (for Case IV)**

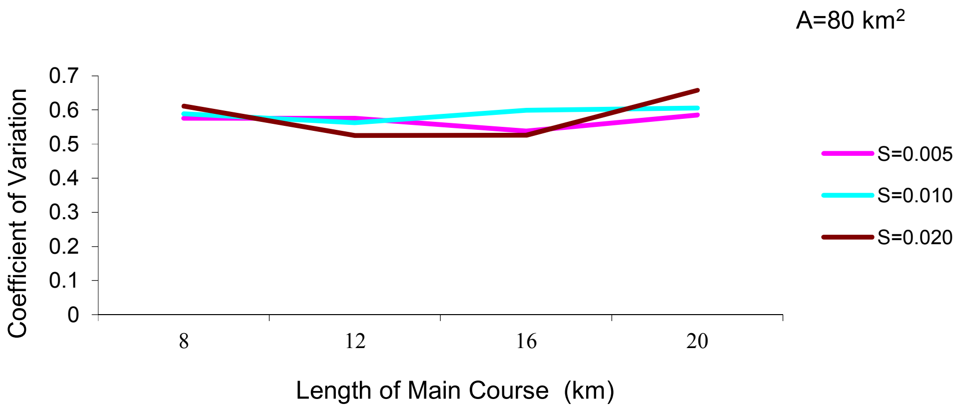


**Fig. 11. Variation of the coefficient of variation with basin characteristics, L and S (for Case I)**

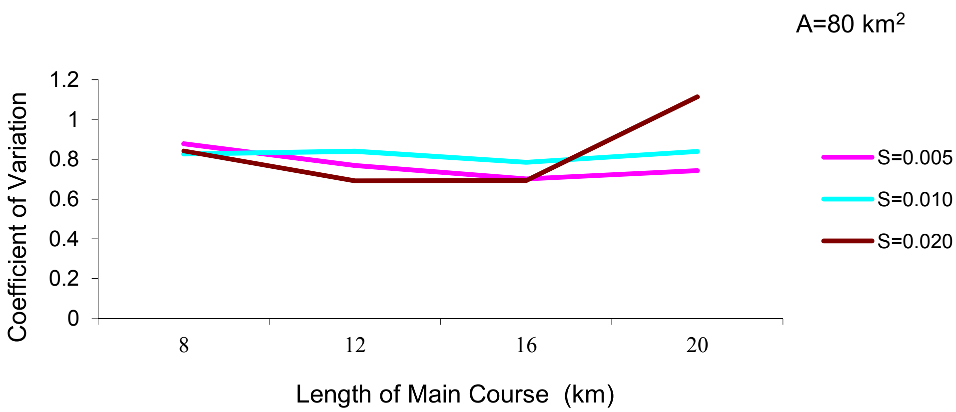


**Fig. 12. Variation of the coefficient of variation with basin characteristics, A, L, and S (for Case II)**

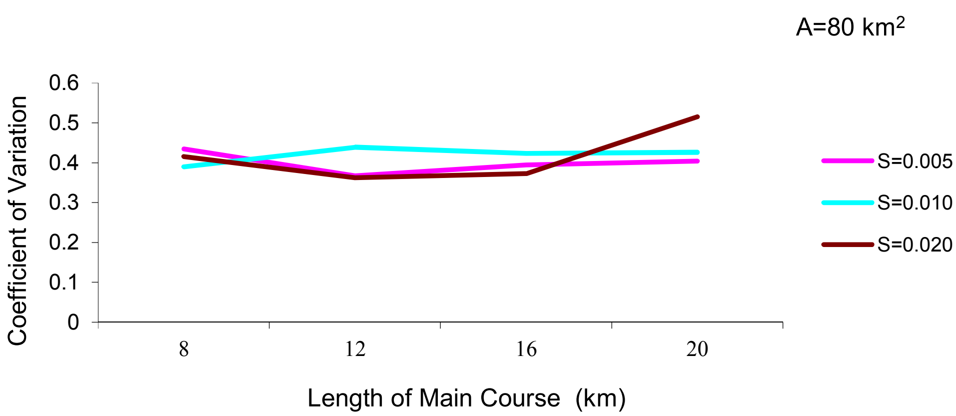


**Fig. 13. Variation of the coefficient of variation with basin characteristics, A, L, and S (for Case III)**

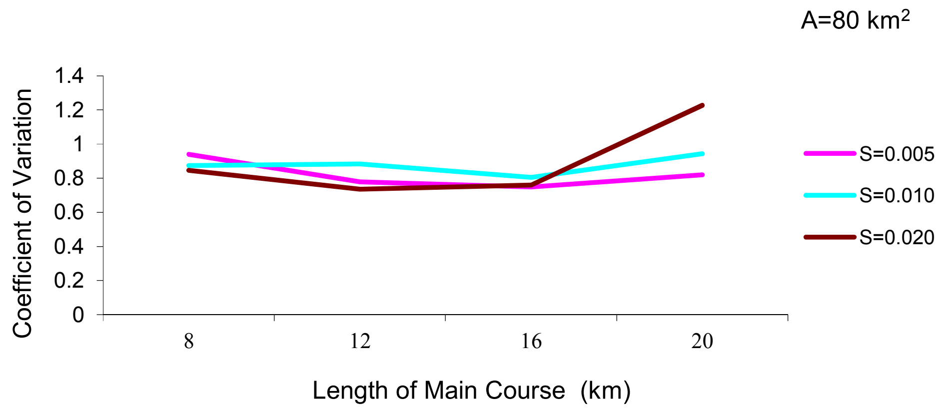


**Fig. 14. Variation of the coefficient of variation with basin characteristics, A, L, and S (for Case IV)**

## 4. CONCLUSION

This study is based on various assumptions and simplifications; therefore the conclusions should be evaluated carefully. These assumptions and simplifications limit the use of the procedures and can ensure results that are less accurate than more detailed methods. However, this study is a simple approach for starting hydraulic and hydrologic analyses at basic level, especially at underdeveloped basins, and will be beneficial in small basins where significant information on precipitations and limited information on peak flows are available.

The synthetic storm series were evaluated with chi-square goodness of fit test, the most suitable distribution with MOM parameters is LN2, G2, GUM and LN3. This means that when the generated synthetic storms distributed as Gumbel are put into a mixed duration series the type of the appropriate distribution may change.

It was found that the average and the standard deviation peak flow decreases as the length of the main course increases, while the average and standard deviation of peak flow increases as the drainage area and harmonic slope increases. Besides variation coefficients of the peak flow samples exhibit a random behaviour. According to these results, the basin physiography can be used to estimate peak flows in small basins that have no recorded streamflow data.

The synthetic peak flow series generated for four different alternatives were tested with goodness of fit tests, the results show that time of distribution of storms and abstraction methods have influence on probability distribution of peak flows.

The other expected conclusion is that the storm events which are responsible for the annual peak flows may be drawn from different populations.

For further studies, different assumptions e.g., different time distributions, rainfall properties, basin properties, vegetation, land management, storage effects and antecedent moisture conditions of the watershed can be taken into consideration. For example, mixed synthetic storms can be generated with different probability distribution or random synthetic storm durations can also be generated for different conditions. Also, different abstraction methods and synthetic hydrographs can be used. Besides calibration should be done using real rainfall and runoff data.

## COMPETING INTERESTS

Author has declared that no competing interests exist.

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