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Case Study

A Case Study on the Estimation of Flood Flows in Rivers with Different Methods

Akarsulardaki Taşkın Debilerinin Farklı Yöntemlerle Tahmini Üzerine bir Durum Çalışması

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Abstract

The estimation of the flood discharges of rivers that do not have streamflow measurements is one of the important issues in hydraulic engineering. For the safety of the structures to be built on these rivers, it is necessary to accurately estimate the possible flood discharges for some periods. Many methods have been developed on this subject. With the methods developed based on the catchment and rainfall characteristics, it is possible to make accurate estimations about the catchment without flow measurement. In this study, an evaluation was made on the estimation success of the methods by trying to determine the flood discharges of a river flowing through a 336 km^2 catchment area with indirect and direct methods based on rainfall. Compared rainfall-runoff estimation methods showed that Synthetic Method was the least reliable one among all other estimations. On the other hand, with the discharges of Q_{10} = 77 m^3/s, Q_{100} = 193 m^3/s and Q_{500} = 273 m^3/s, Mockus emerged as the most consistent one through all evaluated peak flow discharges methods. It is also intended that this study will be a guide for those who work on the subject.
Keywords: *flood discharge estimation, rainfall-runoff relationship, runoff estimations, probability distributions*

Öz

Akım ölçüm verileri bulunmayan akarsuların taşkın debilerinin tahmin edilmesi su mühendisliğinin önemli konularından biridir. Bu akarsular üzerinde yapılacak yapıların güvenliği için belirli periyotlarda gelmesi muhtemel taşkın debilerinin doğru bir şekilde tahmin edilmesi gerekir. Bu konuda birçok yöntem geliştirilmiştir. Havza ve yağış özelliklerine bağlı olarak geliştirilen bu yöntemler sayesinde akış verileri olmadan havza hakkında doğru tahminler yapmak mümkündür. Bu çalışmada, 336 km^2'lik bir havza alanı içerisinden akan bir akarsuya ait taşkın debileri çeşitli dolaylı yöntemler ve akış verilerine dayalı doğrudan yöntemlerle belirlenmeye çalışılarak yöntemlerin tahmin başarısı üzerinde değerlendirme yapılmıştır. Karşılaştırılan yağış-akış tahmin yöntemleri, Sentetik Yöntemin yapılan tahminler arasında en az güvenilir olanı olduğunu göstermektedir. Diğer yandan, Q_{10} = 77 m^3/s, Q_{100} = 193 m^3/s ve Q_{500} = 273 m^3/s'lik debi değerleri ile Mockus Yöntemi, değerlendirilen yöntemler arasından en güvenilir yöntem olarak belirlenmiştir. Bu çalışmanın konuyla ilgili uygulamada çalışanlar için bir rehber olması da amaçlanmıştır.
Anahtar sözcükler: *taşkın debisi tahmini, yağış-akış ilişkisi, akış tahminleri, olasılık dağılımları*

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Introduction

Floods seen in streams after heavy rains are among the most common natural disasters in Türkiye and the province of Bitlis, where the study area is located (Ekinci et al., 2020; Işık & Özlük, 2012). Especially considering the current topographic situation of the province, the study area is among the provinces with the highest flood damage (Kadıoğlu, 2008). In this context, the region is in a very vulnerable position in terms of natural disasters. A catchment is a system which the surface waters are collected in the form of a network and the direction of the greatest slope, and are also transferred to sea or lake as the main branch such as a stream, creek or river. In other words, it can be considered as an operator that converts rainfall into runoff. The neighboring catchments are separated from each other by borders called drainage divides, water divides, divides, ridgelines, watersheds, or water partings. The flood risk is strictly related to the characteristics of the catchments. Features such as a catchment area, average slope of the catchment, shape factor and bifurcation rate are important parameters that characterize a catchment. Additionally, vegetation, soil structure, rainfall intensity and flood-frequency in a catchment are foremost factors in creating floods. It is required to determine the peak flood discharge brought by a river for the calculation and design of dam reservoir operations, waterpower facilities, streamflow arrangements and flood control structures. While the highest discharge value observed over the years may be accepted as the design flow for some planning activities, it is desirable to know the return period of discharges that will not be possible to measure in the most engineering designs where flood controls are momentous. These discharges can be determined by various statistical methods and/or empirical equations (Samantaray & Sahoo, 2020). Their return period can be 50, 100 and 500 yearly depending on the importance of engineering applications. When determining flood discharges, it is necessary to have the streamflow measurements for many years. The stream flow data are collected from Streamflow Monitoring Stations (SMS) installed in the rivers. The data are recorded instantaneously, daily, weekly, monthly and yearly. However, the data are either not available or insufficient in some streams, creeks and brooks (Gao et al., 2017). Various methods such as Rational, Mc-Math, Synthetic, Mockus and Snyder Methods can be applied to estimate the peak flood discharges (Gulbahar, 2016; Semerci et al., 2020). For these methods, firstly, it is essential to obtain and analyze rainfall data. Another important aspect is the determination of effective parameters for the rainfall-runoff (RR) relationship. In order to determine the flow heights, it is required to know the runoff coefficient and RR parameters which depend on the catchment structure, slope and vegetation density.

In this study, the runoff data performances of the methods mentioned above are evaluated trying to estimate directly and indirectly the flood discharges of a river. Calculations of flow estimation methods, which are frequently used in hydrology, are shown in detail and frequency analyzes are made. The most appropriate method is specified for medium-sized catchments and it is concluded that it could be also used safely in catchments of similar size. It is also intended that the study will be a guide for those who work on the subject in practice.

Material and Method

Study Area

Formed by tectonic origin, Lake Van is the world's largest soda lake, as well as being the world's fourth largest closed lake. It is also the largest lake in Türkiye. Lake Van basin, which is a closed basin, has an area of approximately 20,000 km^2 and 3713 km^2 of the basin (roughly 20%) is the lake surface area. It is about 1740 m above sea level, its deepest point is calculated as 450 m, and the volume of the lake is approximately 607 km^3 (Litt et al., 2009). The Yeniköprü Stream catchment, the study area, within the borders of the Ahlat District of Bitlis is located in the Ahlat-Ovakışla sub-basin of the closed drainage area of Lake Van (Figure 1). The starting point was accepted as the 25-010 SMS of State Hydraulic Works (DSI) at the 1769 m elevation of Kınalıkçı Village on Süfresur Creek, and the catchment area of 336 km^2 of the basin has been studied. 28 years of flow data and Maximum Annual Instantaneous Flow (MAIF) data between 1963-1990 have been gathered from DSI's 25-010 numbered SMS (General Directorate of State Hydraulic Works [DSİ], 1994). Lake Nazik at 1815 m elevation, is connected to Yeniköprü Stream via Suçikan Creek and drains into Lake Van at 1647 m elevation. The study area, which has a volcanic structure due to close to the Nemrut Caldera, is relatively flat and has been turned into agricultural lands over time. The northeastern valleys, where the main stream extends, are more mountainous and sloped than the other parts of the study area.

Figure 1

Yeniköprü Stream Catchment

Note. Google Earth

Catchment Characteristics

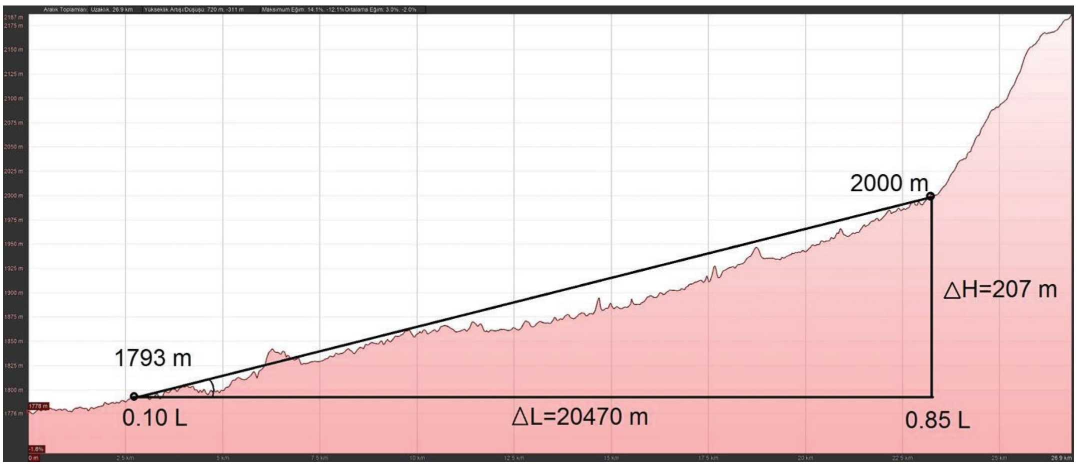
Benson's slope equation was used to determine the catchment slope. In this method, 10% to 85% of the length of the main stream is marked on the map and the slope of the line between two points is calculated (Figure 2):

$$Benson\ Slope = \frac{\Delta H}{\Delta L} = \frac{207}{20470} = 0.010$$

$$S = 0.010 \times 1000 = 10\ m/km$$

Figure 2

Benson's Slope of the Study Area



The characteristics of the Yeniköprü Catchment were determined approximately as in Table 1.

Table 1

The Catchment Characteristics

Catchment Area, A (km^2)	Main Stream Length, L (m)	Elevation Difference H (m)	Catchment Slope S (m/km)
336	27300	410	10

Methodology

The study consists of three main sections as the rainfall analysis, the rainfall-runoff (RR) relationships and the flow frequency analysis.

First, the rainfall of the area must be analyzed to predict the runoff in streams having no gauging stations. The rainfall can be converted into streams with the help of RR relations and used in the design of water structures. The relations known as Intensity–Duration Frequency (IDF) curves are widely used in the design of engineering structures and have various calculating equations and formulas developed in literature (Chen, 1983; Koutsoyiannis et al., 1988). As the importance of the structure to be built grows, and structures that will cause serious damage in case of collapse, data with large return period should be used. As the return period increases, the magnitude of the rainfall intensity to be used also increases. The Gumbel distribution is generally used for rainfall frequency analysis (Chow et al., 1988). The annual maximum rainfall for each selected duration is taken from the rainfall records, and frequency analysis is then applied to the annual data. Frequency analysis test and distribution graphs according to Gumbel distribution of maximum rainfall of different durations are given in Figures 3 and 4, respectively. Rainfall intensity also depends on its duration. Duration of the rainfall increases, the total rainfall height increases, but intensity decreases. The relation $i=\Delta P/\Delta t$ gives the rainfall intensity (mm/h), in which Δt: rainfall duration (h), and ΔP: rainfall height during this duration (mm).

The second step is the determination of the RR relationship. For this aim, five different methods were used: Rational Method, McMath Method, Synthetic Method, Mockus Method and Snyder Method.

As a third step, frequency analysis was carried out by taking into account the Maximum Annual Instantaneous Flow (MAIF) values for each year of WMS numbered 25-010 of SWW, which was accepted as the starting point of the study area (DSİ, 1994). In the study, two well-known distribution functions for hydrological processes (Long-normal and Gumbel) were used for flow frequency analysis. These distributions were applied to the flow data based on Bayazıt et al. (2009) and Bayazıt (2011).

The details related to these methods are given in the Results and Discussion section.

Results and Discussions

Rainfall Analysis

Just a rainfall measurement station 17810 in Bitlis-Ahlat of the General Directorate of Meteorology (MGM, 2022) close to the study area has hourly total rainfall data for many years. Assuming the rainfall was distributed uniformly in the catchment and the IDF curves were obtained depending on the rainfall data.

Figure 3

Gumbel Distribution Test Results of Rainfall of Different Durations

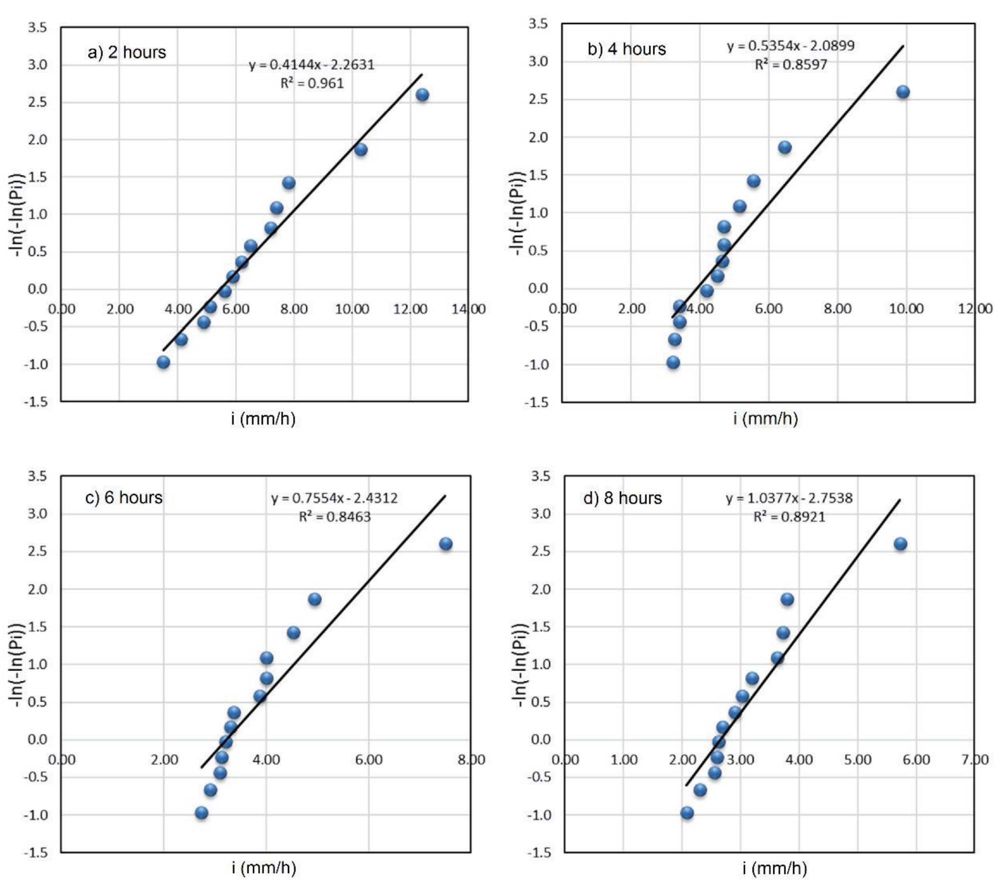


Figure 4

Gumbel Distribution Probability Density Function (PDF) and Cumulative Distribution Function (CDF) of Rainfall of Different Durations

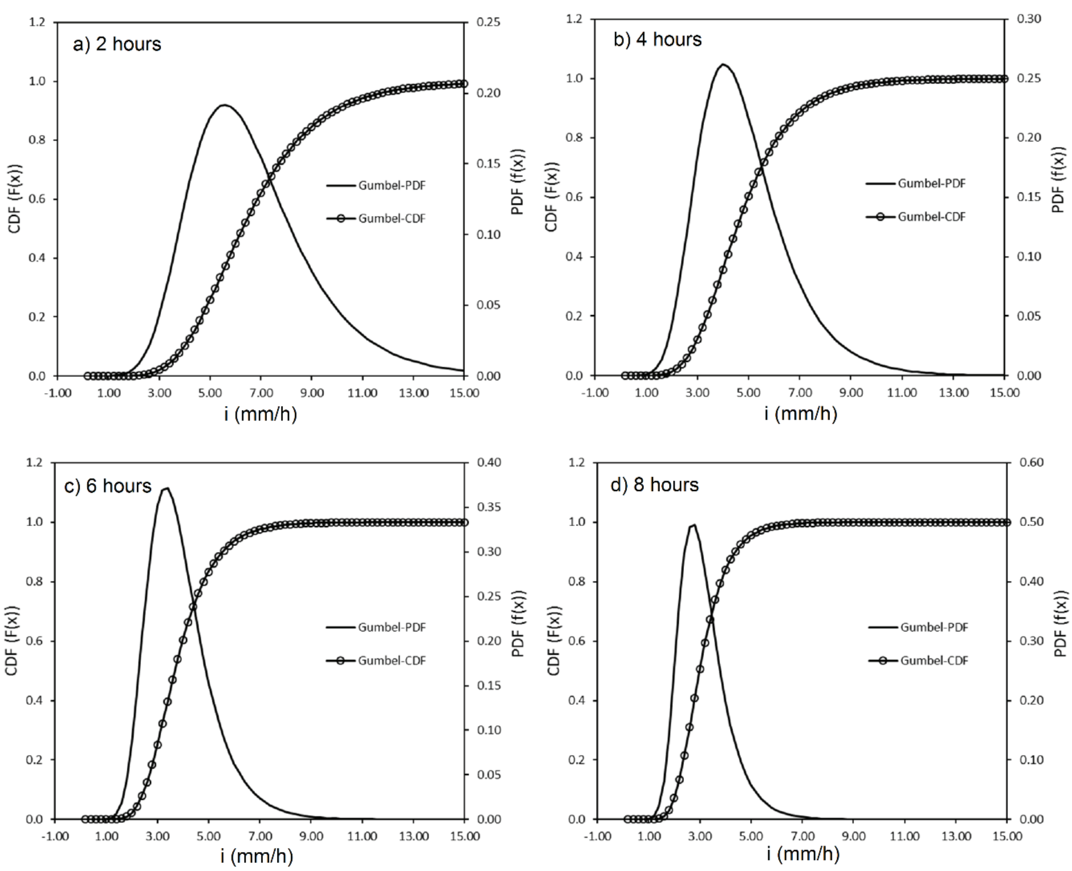
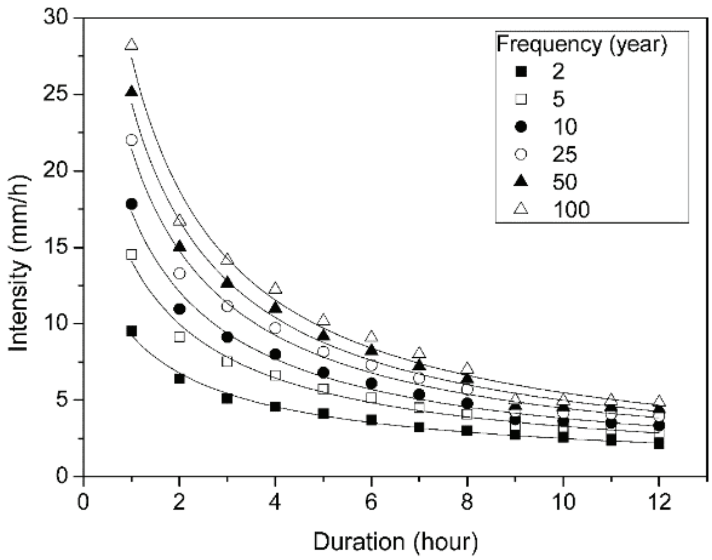


Figure 5

Intensity-Duration Frequency Relations of Station No: 17810



As shown in Figure 5, the intensity-duration frequency curves for Ahlat station were obtained with R^2=98-99% accuracy by the relation given with Eq. 1.

$$i = \frac{a}{(1+t)^b} \tag{1}$$

Where, *i*: rainfall intensity (mm/h), *t*: rainfall duration (h), *a* and *b* are coefficients depending on location and frequency, and the coefficients obtained by curve fitting for rainfall data are given in Table 2.

Table 2

Coefficients of Eq. 1 for Station No: 17810

T (year)	2	5	10	25	50	100
a	15.75	25.47	32.01	40.34	46.54	52.68
b	0.77	0.85	0.89	0.92	0.93	0.94

The data for Eq. (2) was obtained from Ahlat station and Eq. (2) was calculated by using the IDF relationship suggested by Chow et al. (1988) based on Wenzel's (1982) approach:

$$i = \frac{c \times T^m}{t + f} = \frac{23.23 \times T^{0.22}}{t + 1.33} \qquad (2)$$

Here; *i*: rainfall intensity (mm/h), *t*: rainfall duration (h) *T*: frequency (year) and *c* and *f* are location dependent coefficients. The coefficients were calculated as *c*=23.23, *m*=0.22 and *f*=1.33 for station 17810 by curve fitting using the least-squares method. The compatibility of the function obtained with these coefficients with the real data was successful at the rate of R^2=98% (Figure 6). IDF relationship can also be given in logarithmic scale as in Figure 7, so that it can be easily read from the graphs. McCuen (1998) also determined a detailed mathematical representation of IDF curves.

Figure 6

Comparison of Equation (2) Calculation Values with Observation

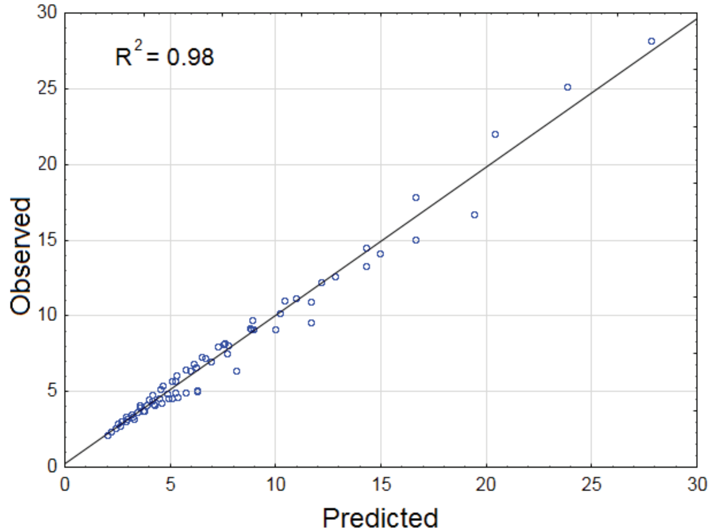
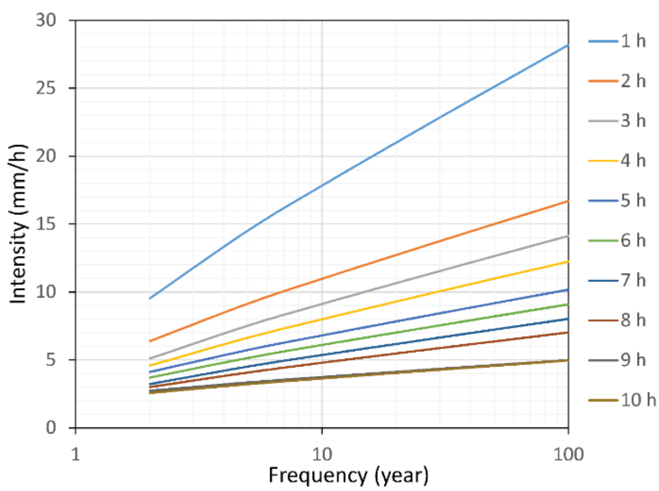


Figure 7

Intensity-Duration Frequency



RR Prediction Methods

Rational Method

The rational method, which dates back to the middle of the nineteenth century, is still a widely used method for the design of storm sewers today (Pilgrim, 1986; Linsley, 1986). The method is used with a maximum drainage area of 25 km^2 but it is generally used in drainage areas up to 15 km^2. According to some other references, this limit could be reduced to 1 km^2. Even though the investigated drainage area (336 km^2) is rather larger than its limit value, the method was used for testing its success in the study. The total discharge through the runoff during a rainfall is calculated by the following equation (Eq. 3) (Özbek, 1989).

$$Q = \frac{CiA}{3.6} \tag{3}$$

where, Q: discharge (m^3/s) i: rainfall intensity (mm/h), C: runoff coefficient, A: drainage area (km^2). Rainfall time will be taken as the time of concentration of the water. Time of concentration (T_c, min) can be calculated based on the maximum length of travel of water (L, m) and catchment slope (S) with the following set of equations (Eq. 4):

$$T_c = 0.0195K^{0.77}, K = \frac{L}{S^{1/2}} \quad (4)$$

$$K = \frac{27300}{0.010^{1/2}} = 273000, T_c = 0.0195 \times 273000^{0.77} = 300\ min = 5\ hours$$

The runoff coefficient (*C*) varies according to the catchment terrain and slope, and the flood frequency. Approximately 70% of the Yeniköprü catchment area is flat (<2%) and 30% is moderately sloped (2% - 7%) and consists mostly of cultivated land:

10 years flood C_{10} = 0.70 x 0.36 + 0.30 x 0.41 = 0.38

100 years flood C_{100} = 0.70 x 0.43 + 0.30 x 0.48 = 0.44

Runoff intensities corresponding to the time of concentration T_c=5 hours were calculated by the methods mentioned previously and showed in Table 3. From the Table 3, Equation (2) gave results closer to the values read from the curves in Figure 7 (prepared with the actual data). In other words, Equation (2) gave more successful results than Equation (1).

Table 3

The Rainfall Intensity Obtained by the Different Methods Corresponding the Concentration Time

Method	T_c (hour)	i_{10} (mm/h)	i_{100} (mm/h)
Equation (1)	5	6.50	9.78
Equation (2)	5	6.09	10.11
Figure 6	5	6.81	10.18

$$Q_{10} = \frac{0.38 \times 6.81 \times 336}{3.6} = 241\ m^3/s$$

$$Q_{100} = \frac{0.44 \times 10.18 \times 336}{3.6} = 418\ m^3/s$$

Depending on the Q_{10} and Q_{100} discharges, the discharge from Q_{500} was also calculated with the following equation (Eq. 5) (Kumanlıoğlu & Ersoy, 2018).

$$Q_T = Q_{10} + ZT \times (Q_{100} - Q_{10}) \quad (5)$$

$$ZT = 0.99 \times \log T - 0.98 = 0.99 \times \log 500 - 0.98 = 1.69$$

$$Q_{500} = 241 + 1.69 \times (780 - 241) = 540\ m^3/s$$

McMath Method

McMath (1887) method gives good results in determining the capacity of surface drainages on flat lands of any expanse. The flood discharge is calculated in m^3/s with the following equation (Eq. 6) (Özbek, 1989):

$$Q = 0.0023.C.i.S^{1/5}A^{4/5} \quad (6)$$

Here; *C*: a coefficient giving the catchment features depending on vegetation, soil and topography, *i*: rainfall intensity according to time of concentration and selected frequency (mm/h), *S*: catchment slope x 1000; *A*: catchment area or rainfall area (ha). The *C* coefficient was taken as *C*=0.30+0.12+0.06=0.48, with the vegetation cover of the land is bare (C_1=0.30), soil type is light (C_2=0.12) and topography is slightly inclined (C_3=0.06). The time of concentration T_c (min) was calculated as:

$$T_c = 0.0195 \times \left(\frac{L^3}{H}\right)^{0.385} \quad (7)$$

$$T_c = 0.0195 \times \left(\frac{27300^3}{410}\right)^{0.385} = 256\ min = 4.26\ hours$$

If the rainfall intensities corresponding to this time were calculated from Equation (2): i_{10}=6.90 mm/hour, i_{100}=11.45 mm/hour were obtained.

$$Q_{10} = 0.0023 \times 0.48 \times 6.90 \times 10^{1/5} \times 336000^{4/5} = 318\ m^3/s$$

$$Q_{100} = 0.0023 \times 0.48 \times 11.45 \times 10^{1/5} \times 336000^{4/5} = 528\ m^3/s$$

$$Q_{500} = 318 + 1.69 \times (528 - 318) = 673\ m^3/s$$

Synthetic Method

This method can be used to find flood discharges in rivers where long-term flow measurements are not available. The following steps are applied in the method (Özbek, 1989):

1. Rainfall periods leading to floods are predicted. The period was generally accepted as 2 hours. The rainfall intensity was multiplied by time to obtain rainfall height: P_{10}=2x10.98=21.96 mm, P_{100}=2x16.71=33.42 mm.

2. The curve number (CN) is determined from the relevant tables (SCS, 1972 and 1986) according to the land features and vegetation of the drainage area. It was considered CN=80 for this study.

3. Rainfall height (P) and runoff height (h_a) by curve number are obtained from RR curves. According to this; Rainfall and runoff heights were calculated for P_{10}= 21.96, h_a= 2 mm, and for P_{100}=33.42 mm, h_a= 8 mm.

4. Catchment features are determined such as drainage area and main stream length as in Table 1 for this study. The distance between the projection of the center of gravity of the rainfall area on the main collector and the point where the collector leaves the rainfall area was assumed to be (L_c) ≈ 8 km. Additionally, the harmonic slope, which is the slope of the catchment, was calculated and shown in Table 4 with the following equation.

5. $$S = \left(\frac{10}{\sum \frac{1}{\sqrt{s_i}}} \right)^2 \quad (8)$$

6. q_p=35 lt/s.km^2.mm was obtained from synthetic unit hydrograph graphs with the help of $\frac{L \times L_c}{\sqrt{s}} = \frac{27.3 \times 8}{\sqrt{0.0102}} = 2162$ and area.

7. The discharge value is obtained by the following equation depending on the q_p:

$$Q = A \times q_p \times h_a \times 10^{-3} \quad (9)$$
$$Q_{10} = 336 \times 35 \times 2 \times 10^{-3} = 24\, m^3/s$$
$$Q_{100} = 336 \times 35 \times 8 \times 10^{-3} = 94\, m^3/s$$

$$Q_{500} = 24 + 1.69 \times (94 - 24) = 142\, m^3/s$$

Table 4

Harmonic Slope Calculations

No	Elevation (m)	Heigth h (m)	Distance L_i (m)	$S_i = h/L_i$	$(s_i)^{1/2}$	$1/(si)^{1/2}$
0	1777	-	-	-	-	-
1	1794	17	2730	0.0062	0.0789	12.67
2	1811	17	2730	0.0062	0.0789	12.67
3	1840	29	2730	0.0106	0.1031	9.70
4	1861	21	2730	0.0077	0.0877	11.40
5	1872	11	2730	0.0040	0.0635	15.75
6	1900	28	2730	0.0103	0.1013	9.87
7	1935	35	2730	0.0128	0.1132	8.83
8	1977	42	2730	0.0154	0.1240	8.06
9	2071	94	2730	0.0344	0.1856	5.39
10	2185	114	2730	0.0418	0.2043	4.89
		Total	27300			99.25
					S=	0.0102

Mockus Method

Mockus (1949) proposed a method for catchments without SMS. According to this method, it is stated that runoff estimates can be based on information and data such as soil, land use, previous rainfall, duration of storm, and average annual temperature. The time of concentration is calculated in hours with the following equation according to this method (Özbek, 1989).

$$T_c = 0.00032\frac{L^{0.77}}{S^{0.385}} \tag{10}$$

Here, for L= 27300 m and S=0.0102, T_c=4.87 hour, unit downpour time D (hour):

$$D = 2\sqrt{T_c} = 2 \times \sqrt{4.87} \cong 5\ hours$$

In practice, the nearest integer greater than D is taken for the rainfall time (hours) corresponding to the time of concentration. However, if $T_c \leq 1, D = 1$ was taken. The time of rise of the hydrograph was: $T_p = 0.5D + 0.6T_c = 0.5 \times 5 + 0.6 \times 4.87 = 5.42\ hours$.

The recession time of the water: $T_r = 1.67T_p = 1.67 \times 6.7 = 9.05\ hours$ the flood period: $T_s = T_p + T_r = 5.42 + 9.05 = 14.5\ hours$, D= 5 hours of rainfall versus rainfall heights: for i_{10}= 6.81 mm/hour, P_{10}=5x5.74=34.05 mm, for i_{100}=10.18 mm/hour, P_{100}= 5x10.18=50.90 mm. If CN=80 was taken, from the RR curves: for P_{10}=34.05 mm, h_a=6 mm, and for P_{100}=50.90 mm, h_a=15 mm were found (Bayazıt et al., 2009). Accordingly, peak flood discharges were calculated with the following equation.

$$Q_p = \frac{0.208 \times A \times h_a}{T_p} \tag{11}$$

$$Q_{10} = \frac{0.208 \times 336 \times 6}{5.42} = 77\ m^3/s$$

$$Q_{100} = \frac{0.208 \times 336 \times 15}{5.42} = 193\ m^3/s$$

$$Q_{500} = 77 + 1.69 \times (193 - 77) = 273\ m^3/s$$

Snyder Method

Snyder (1938), who conducted a study of catchments ranging in size from about 10 to 10,000 mi^2 (30 to 30,000 km^2) in the Appalachian Highlands of the United States, found synthetic relationships for some properties of the standard unit hydrograph. It can be applied by dividing large catchments into small areas. This method was applied as follows (Özbek, 1989).

Peak time of the hydrograph in hours is calculated by the following equation (Eq.12):

$$T_p = C_t \times (L \times L_c)^{0.30} \tag{12}$$

C_t is a coefficient depending on the soil type and was taken from Table 5 given below (C_t=1.50).

$$T_p = 1.50 \times (27.3 \times 8)^{0.30} = 7.5\ hours$$

Table 5

C_t Coefficients Depending on Soil Type (Özbek, 1989)

Soil Type	C_t	C_p
Very Sandy	1.65	0.56
Moderately sandy clay	1.50	0.63
Very clayey or rocky	1.35	0.69

Downpour time per unit hydrograph, T_y, was calculated as follows and taken as the nearest hour.

$$T_r = T_y = \frac{T_p}{5.5} = \frac{7.5}{5.5} = 1.36 \cong 1\ hour$$

By taking C_p=0.63 from Table 5, drainage efficiency was calculated with the following equation (Eq. 13).

$$q_v = 276 \times \frac{C_p}{T_p} \tag{13}$$

$$q_v = 276 \times 0.63/7.5 = 23.2\ lt/s/km^2/mm$$

Unit hydrograph peak discharge:

$$q_p = A \times q_v \times 10^{-3} = 336 \times 23.2 \times 10^{-3} = 7.80\ m^3/s.m$$

Unit hydrograph volume:

$$V_b = A \times 1 \times 10^3 = 336 \times 10^3\ m^3$$

The hydrograph time is calculated by the equation below (Eq.14).

$$T_s = 3 + \frac{3T_p}{24} \tag{14}$$

T_{w75} and T_{w50} values were read from the Snyder chart, depending on their q_v values (for $0.75q_p$ and $0.50q_p$). Rainfall intensity versus T_y=1-hour duration was read from the IDF curves and flow heights were found. If the runoff heights corresponding to this flow height were obtained from the RR chart according to the curve number (CN=80): for i_{10}=17.84 mm/h and P_{10} = 2x17.84 = 35.68 mm, and for i_{100}=28.19

mm/h and P_{100} = 2x28.19 = 56.38 mm, h_a≈6 mm and h_a≈16 mm were obtained, respectively. Accordingly, flood peak discharges:

$$Q_{10} = A \times q_v \times h_a \times 10^{-3} = 336 \times 23.2 \times 6 \times 10^{-3} = 47\ m^3/s$$

$$Q_{100} = A \times q_v \times h_a \times 10^{-3} = 336 \times 23.2 \times 16 \times 10^{-3} = 125\ m^3/s$$

$$Q_{500} = 47 + 1.69 \times (125 - 47) = 179\ m^3/s$$

Flow Frequency Analysis

Lognormal Distribution Function

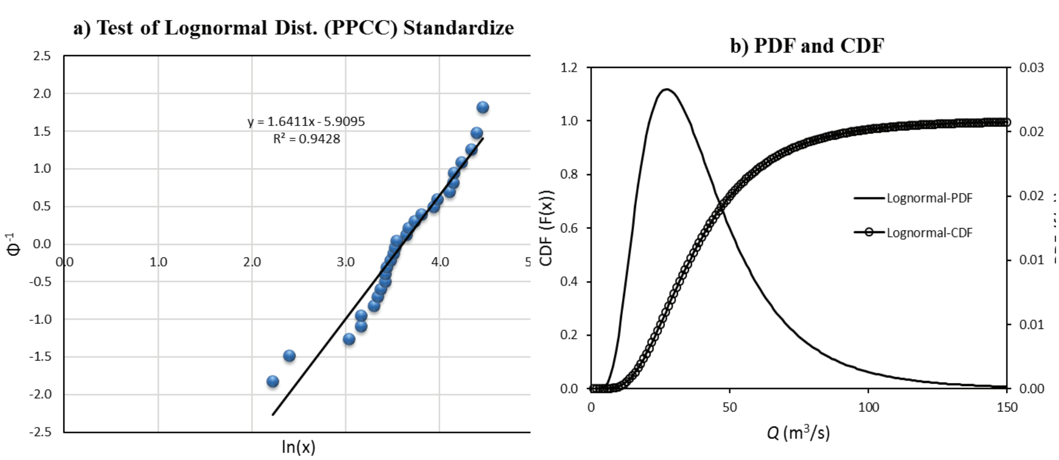
Hydrological variables generally are skewed distribution. Since it has only positive values and the distribution is skewed (C_s>0), this distribution is frequently used for hydrological variables. Lognormal distribution results are given in Figure 8 by using the MAIF values of numbered 25-010 SWW for WMS.

According to the Lognormal distribution, the peak flood discharges of this station were:

$$Q_{10} = 73\ m^3/s\ , Q_{100} = 129\ m^3/s, Q_{500} = 174\ m^3/s$$

Figure 8

Lognormal Distribution Function

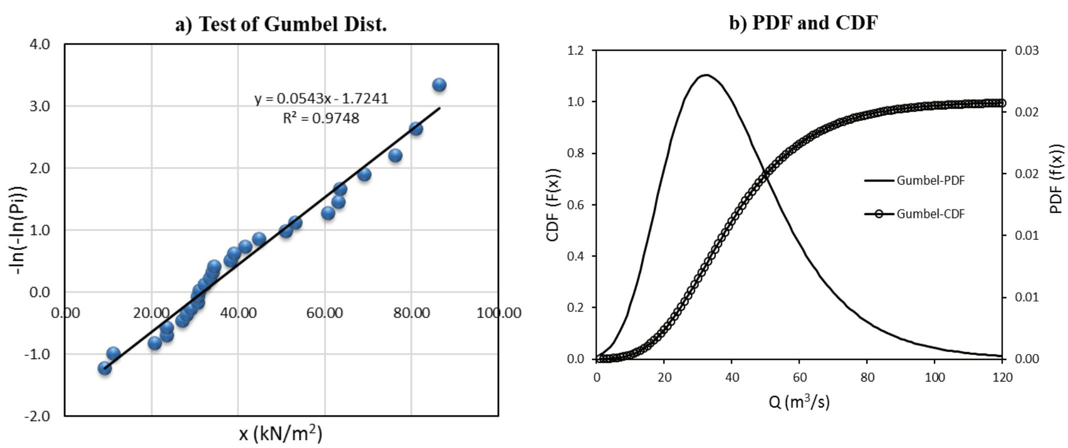


Gumbel Distribution

Another widely used skew distribution function in hydrology is the Gumbel Distribution. Gumbel Distribution results are given in Figure 9 by using the MAIF values of numbered 25-010 SWW for WMS.

Figure 9

Gumbel Distribution



According to the Gumbel distribution, the peak flood discharges of this station were:

$$Q_{10} = 73\ m^3/s, Q_{100} = 117\ m^3/s, Q_{500} = 147\ m^3/s$$

The results obtained by applying the methods are summarized comparatively in Table 6. The first five methods in Table 6 are direct methods based on precipitation data, while the last two are direct methods based on flow measurement data. The WMS values in the 6th and 7th lines of the table can be used as a reference since they are obtained from the actual flow measurement values.

Table 6

Comparison Table of Peak Flood Discharges

No	Methods	Flood Discharges (m^3/s)		
		Q_{10}	Q_{100}	Q_{500}
1	Rational Method	241	418	540
2	Mc-Math Method	318	528	668
3	Synthetic Method	24	94	142
4	Mockus Method	77	193	273
5	Snyder Method	47	125	179
6	WMS-Lognormal	73	129	174
7	WMS-Gumbel	73	117	147
	Average	122	229	303
	Max. Q	318	528	668

Conclusion

The performances of the methods frequently used in the practice to determine peak flood discharge in rivers were evaluated in this study. It focused on calculating the flood discharge in rivers with limited measured data. For this purpose, the study evaluated under three main section as the rainfall analysis, the rainfall-runoff (RR) relationships and the flow frequency analysis. The study was performed using indirect (RR analysis) and direct (flow-frequency analysis) approaches in a designated area to determine the performance of the methods. According to the results of the study;

The methods with highest values were the Mc-Math and Rational Methods. It was already stated that the Rational Method would not be appropriate for the given catchment scale (336 km^2). However, it can be said that the Mc-Math method, which gives higher values than the Rational Method, does not give appropriate values in these catchment scales. The method with lowest value was the Synthetic Method. Therefore, it can be said that the Synthetic Method can yield smaller values than expected for a basin of this scale. Although the Snyder Method gave results that are close to WMS values, especially in 500-year return-period, the accuracy of this method was very sensitive to the selected parameters, so care should be taken in its use. Among these methods, it was seen that the Mockus method was the most reliable. Although it gave higher results than WMS values at high return-periods, it can be said that this method gave better results than other methods, since it remained on the safe side. In line with these explanations, the methods in the 3rd, 4th and 5th rows in Table 6 can be used for medium-sized basins for which flow data are not available or limited. As another approach, these results may be averaged after eliminating the extreme values as frequently used in statistics. In future studies, the methods used in this study can be applied in larger and smaller basins in order to see model performances.

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References

Bayazıt, M. (2011). *Hidroloji*, Birsen Press.

Bayazıt, M., Avcı İ., & Şen Z. (2009). *Hidroloji uygulamaları.* Birsen Press.

Chen, C. L. (1983). Rainfall intensity-duration-frequency formulas. *Journal of Hydraulic Engineering*, *109*(12), 1603-1621. **https://doi.org/10.1061/(ASCE)0733-9429(1983)109:12(1603)**

Chow, W. T., Maidment, D. R., & Mays, L. W. (1988). *Applied hydrology*. McGraw-Hill, Inc. **http://ponce.sdsu.edu/Applied_Hydrology_Chow_1988.pdf**

DSİ. (1994). *Türkiye akarsu havzaları maksimum akımlar frekans analizi* (MAFA). Bayındırlık ve İskan Bakanlığı, Devlet Su İşleri Genel Müdürlüğü, Etüt ve Plan Dairesi Başkanlığı Press.

Ekinci, R., Büyüksaraç, A., Ekinci, L. Y., & Işik, E. (2020). Natural disaster diversity assessment of Bitlis Province. *Journal of Natural Hazards and Environment, 6*(1), 1 - 11. **https://doi.org/10.21324/dacd.535189**

Gao, Z., Long, D., Tang, G., Zeng, C., Huang, J., & Hong, Y. (2017). Assessing the potential of satellite-based precipitation estimates for flood frequency analysis in ungauged or poorly gauged tributaries of China's Yangtze River basin. *Journal of Hydrology*, *550*, 478-496. **https://doi.org/10.1016/j.jhydrol.2017.05.025**

Gulbahar, N. (2016). A comparison study of some flood estimation methods in terms of design of water structures. *International Journal of Engineering Technologies* IJET, 2(1), 8-13.

Işık, E., & Özlük, M. H. (2012). *Bitlis ilinin doğal afetler açısından incelenmesi ve öneriler: Proceedings of the International Conference on Science, Technology and Engineering*. Dubai.

Kadıoğlu, M. (2008) Sel, heyelan ve çığ için risk yönetimi. In M. Kadıoğlu & E. Özdamar (Eds.), *Afet zararlarını azaltmanın temel ilkeleri* (pp. 251-276). JICA Türkiye Ofisi Press. **https://www.researchgate.net/publication/258108315_Sel_Heyelan_ve_Cig_icin_Risk_Yonetimi**

Koutsoyiannis, D., Kozonis, D., & Manetas, A. (1998). A mathematical framework for studying rainfall intensity-duration-frequency relationships. *Journal of Hydrology*, *206*(1-2), 118-135. **https://doi.org/10.1016/S0022-1694(98)00097-3**

Kumanlıoğlu, A. A., & Ersoy, S. B. (2018). Akım gözlemi olmayan havzalarda taşkın akımlarının belirlenmesi: Kızıldere Havzası. *Dokuz Eylül Üniversitesi-Mühendislik Fakültesi, Fen ve Mühendislik Dergisi*, *20*(60), 890 – 904. **https://doi.org/10.21205/deufmd. 2018206070**

Linsley, R. K. (1986). Flood estimates: how good are they?, *Water Resour. Res*., vol. 22, no. 9, supplement, pp. 159S-164S, 1986.

Litt, T., Krastel, S., Sturm, M., Kipfer, R., Örcen, S., Heumann, G., Frans, O. S., Ülge, B. U., & Niessen, F. (2009). 'PALEOVAN', International Continental Scientific Drilling Program (ICDP):

site survey results and perspectives. *Quaternary Science Reviews, 28*(15-16), 1555-1567. **https://doi.org/10.1016/j.quascirev.2009.03.002**

McCuen, R. H. (1998). *Hydrologic Analysis and Design*, Pearson Education.

McMath, R. E. (1887). Determination of the size of sewers. *Transactions of the American Society of Civil Engineers*, 16(1), 179-190.

MGM, (2022). *Ahlat ilçesi saatlik toplam yağış verileri*. Çevre Şehircilik ve İklim Değişikliği Bakanlığı Meteoroloji genel Müdürlüğü, Bitlis İl Müdürlüğü.

Mockus. V. (1949). Estimation of total (and peak rates of) surface runoff for individual storms. *Interim Survey Rep. Grand (Neosho) River Watershed*, Exhibit A in Appendix B, U.S. Department of Agriculture, Washington, D.C.

Özbek, T. (1989). *Hidroloji*. Gazi Üniversitesi Press.

Pilgrim, D. H. (1986). Bridging the gap between flood research and design practice, *Water Resources Res*., vol. 22, no. 9, supplement, pp. 165S-176S, August 1986.

Samantaray, S., & Sahoo, A. (2020). Estimation of flood frequency using statistical method: Mahanadi River basin, India. *H2Open Journal*, *3*(1), 189-207. **http://dx.doi.org/10.2166/h2oj.2020.004**

Semerci, A., Tayfur, G., & Pulat, H. F. (2020). Obtaining of the unit hydrograph by selecting appropriate flood prediction method for designing Filyos river levees. IV. ICONTRENDS, St. Petersburg/Russia-2020.

Snyder, F. F. (1938). Synthetic unit- graphs. Eos, *Transactions American Geophysical Union*, 19(1), 447-454.

Soil Conservation Service (SCS), (1972). Hydrology. In: *National Engineering Handbook, Section 4.* USDA Soil Conservation Service Washington, D.C.

Soil Conservation Service (SCS), (1986). *Technical Release 55: Urban Hydrology for Small Watersheds.* USDA (U.S. Department of Agriculture). Available at <**https://data.nal.usda.gov/dataset/small-watershed-hydrology-wintr-55**>

Wenzel, H. G. (1982). *Rainfall for urban stormwater design, in Urban Storm Water Hydrology*, ed. By David F. Kibler, Water Resources Monograph 7, Washington, D. C: American Geophysical Union.

Extended Turkish Abstract
(Genişletilmiş Türkçe Özet)

Akarsulardaki Taşkın Debilerinin Farklı Yöntemlerle Tahmini Üzerine bir Durum Çalışması

Akarsu havzaları en büyük eğim doğrultusunda yüzeysel suları bir ağ şeklinde toplayarak ana kol (dere, çay, nehir gibi) halinde deniz ve göllere aktaran sistemlerdir. Diğer bir ifadeyle yağışları akışa çeviren operatörlerdir. Su toplama havzaları, drenaj alanı olarak da adlandırılan akarsu havzaları bu özellikleriyle su ayrım çizgisi denilen kesin sınırlarla birbirilerinden ayrılırlar. Akarsuların taşkın debileri drenaj havzalarının özellikleriyle yakından ilişkilidir. Havza alanı, havzanın ortalama eğimi, şekil faktörü, çatallaşma oranı gibi özellikler havzaları karakterize eden önemli özellikleridir. Bununla birlikte havzadaki bitki örtüsü, toprak yapısı, yağış tekerrür aralıkları, yağış şiddeti gibi parametreler de yağışların taşkına dönüşmesinde en önemli etkenler olarak nitelendirilir. Baraj hazne işletmesi, su kuvvetleri tesisleri, akarsu düzenlemesi ve taşkın koruma yapılarının hesap ve tasarımları için akarsuların getirebileceği maksimum debilerin tespiti gerekir. Bazı tasarımlar için yıllar içinde gözlenen en büyük debiler tasarım debisi olarak kabul edilebilirken, taşkınların önemli olduğu mühendislik tasarımlarının çoğunda ölçülmesi mümkün olmayacak zaman aralıklarındaki tekerrür debilerinin bilinmesi istenir. Bu debiler bazı istatistik yöntemler ve/veya tecrübe formülleriyle belirlenebilir. Bunlar, mühendislik uygulamasının önemine göre 50, 100 ve 500 yılık tekerrürlü debiler olabilmektedirler. Debi ölçümleri DSİ tarafından akarsu üzerine kurulan akım gözlem istasyonları (AGİ) aracılığıyla yapılmaktadır. Bu ölçümler anlık, günlük, haftalık, aylık ve yıllık olarak kayıt altına alınmaktadır. Ancak özellikle, dere ve çay sınıfında bazı akarsularda bu ölçümler ya hiç yapılmamakta ya da yeterli miktarda veri elde edilmemektedir. Bu gibi akarsuların taşkın debilerinin ölçülmesinde Rasyonel Yöntem, Mc-Math Yöntemi, Sentetik Yöntem, Mockus Yöntemi, Snyder Yöntemi gibi çeşitli yöntemler geliştirilmiştir. Bu yöntemlerin kullanımında öncelikle yağış verilerinin elde edilmesi ve analiz edilmesi oldukça önemlidir. Diğer önemli bir husus da yağışın akışa geçmesinde etkili parametrelerin belirlenmesidir. Akış yüksekliklerinin belirlenmesi için arazi yapısı, eğimi, bitki örtüsü gibi etkenlere göre akış katsayısı, yağış-akış gibi ilişkilerin bilinmesi gerekir.

Bu çalışmada, bir akarsuya ait taşkın debileri çeşitli dolaylı yöntemler ve akış verilerine dayalı doğrudan yöntemlerle belirlenmeye çalışılarak yöntemlerin performansları değerlendirilmiştir. Bu çalışmanın konuyla ilgili uygulamada çalışanlar ve ihtiyaç duyanlar için bir rehber olması amaçlanmıştır. Çalışma alanı olarak Van Gölü kapalı havzası içerisindeki Ahlat ilçe sınırlarındaki Yeniköprü Çayı havzası seçilmiştir. Çıkış noktası, Süfresur Deresi üzerinde Kınalıkçı Köyü mevkii 1769 m kotundaki DSİ'ait 25-010 Akım Gözlem İstasyonu (AGİ) kabul edilerek havzanın 336 km^2'lik drenaj alanı dikkate alınmıştır. Çalışmada, yapılan tahminler ile gerçek akım verilerinin, frekans analizleri kullanılarak karşılaştırılması amaçlanmıştır. Bu noktaya yakın DSİ'nin 25-010 numaralı AGİ'ye ait 1963-1990 yılları arası 28 yıllık Yılda Anlık Maksimum Akım (YAMA) verileri temin edilmiştir. Nemrut Kalderası nedeniyle volkanik bir yapıya sahip olan çalışma alanı nispeten düzlük bir alandır ve zaman içinde tarımsal kullanıma açılmıştır. Akarsuyun ana kolunun uzandığı kuzeydoğu vadileri havzanın diğer kesimlerine göre daha fazla dağlık ve eğimlidir.

Akım istasyonu olmayan akarsulardaki akışları tahmin etmek için öncelikle bölgenin yağış verilerinin analiz edilmesi gerekir. Elde edilecek yağış verileri yağış-akış ilişkileri yardımıyla akışa çevrilerek su yapılarının tasarımında kullanılabilir. Şiddet – Zaman – Tekerrür (Intensity – Duration Frequency, IDF) eğrileri olarak bilinen bağıntılar mühendislik sistemlerinin tasarımında oldukça

yaygın olarak kullanılmaktadır. Yapılacak yapının önemi büyüdükçe ve yıkılması durumunda ciddi zararlara neden olacaksa tekerrür aralığı büyük seçilmelidir. Tekerrür süresi büyüdükçe kullanılacak yağış şiddetinin büyüklüğü de artar. Yağış tekerrür analizlerinde genel olarak Gumbel dağılımı kullanılır (Chow vd., 1988). Seçilen her süre için yıllık maksimum yağış yüksekliği yağış kayıtlarından çıkarılır ve daha sonra frekans analizi yıllık verilere uygulanır. Farklı süreli maksimum yağışların Gumbel dağılımına göre frekans analizi test ve dağılım grafiklerine de çalışmada yer verilmiştir. Yağış şiddeti ayrıca yağış süresine bağlıdır. Süregelen yağış süresi arttıkça toplam yağış yüksekliği artar fakat yağış şiddeti azalır.

Çalışma alanına yakın Meteoroloji Genel Müdürlüğü'nün Bitlis-Ahlat ilçesindeki 17810'nolu yağış ölçüm istasyonunun uzun yıllara ait saatlik toplam yağış verileri mevcuttur. Çalışmada bu yağışların havzaya üniform dağıldığı kabul edilerek Şiddet – Süre – Tekerrür eğrileri yağış verilerine bağlı olarak elde edilmiştir. Çalışmada ayrıca farklı yöntemlerle elde edilen farklı tekerrürlü taşkın pik debileri tablolar ile karşılaştırmalı olarak verilmiştir. Bu tablolarda AGİ değerleri gerçek akım ölçüm değerlerinden elde edildiğinden referans olarak kullanılabilir. Sonuç olarak, elde edilen değerler arasında en yüksek değerleri veren metotlar Mc-Math ve Rasyonel Yöntemler olmuştur. Rasyonel Yöntemin verilen havza ölçeğinde (336 km^2) uygun olmayacağı bir gerçektir. Ancak çalışmada bu yönteme de yer verilerek çıkan sonuçlar karşılaştırılmıştır. Çalışmada, Rasyonel Yönteme göre daha büyük değerler veren Mc-Math yönteminin de bu havza ölçeğinde uygun değerler vermediği tespit edilmiştir. Kullanılan metotlar arasında en düşük değeri veren metot ise Sentetik Metot olmuştur. Dolayısıyla bu ölçekteki bir havza için Sentetik yöntemin beklenenden daha küçük değerler verebileceği söylenebilir. Snyder Yöntemi özellikle 500 yıllık tekerrürde AGİ değerlerine yakın sonuçlar verse de bu yöntemin doğruluğu seçilen parametrelere çok fazla duyarlı olduğundan kullanımı dikkat gerektirmektedir. Kullanılan tahmin yöntemleri arasında en güvenilir sonuç veren ise Mockus Yöntemi olmuştur. Bu metot her ne kadar yüksek tekerrür sürelerinde AGİ değerlerinden büyük sonuçlar verse de güvenli tarafta kaldığından bu yöntemin diğer yöntemlere göre daha iyi sonuç verdiği söylenebilir. Bu açıklamalar doğrultusunda akım ölçümleri yapılmayan orta ölçekli havzalar için kullanılacak yöntemler belirtilmiştir. Bir başka yaklaşım olarak uç değerleri çıkartıp ortalama değeri kullanmak da istatistikte sıkça kullanılan bir yoldur.