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Flood Frequency Estimation in Data-Scarce Basins: Statistical vs. Synthetic Methods in Eastern Turkey

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Abstract: Floods are one of the most destructive natural disasters that cause loss of life and property. One of the most critical steps in mitigating the damages of this disaster is the correct sizing of flood protection structures. This requires reliable flood quantile estimates. In this study, flood repetition flows were calculated and compared with four different methods in a basin containing six water sources in Ağrı province, especially for D21A141 Yapılıköy Stream Gauging Station (SGS). The methods used are Flood Frequency Analysis (FFA), Regional Flood Frequency Analysis (RFFA), Mockus Method and DSİ Synthetic Method. RFFA demonstrates enhanced reliability and balance in results by utilizing data from the sub-basins. Despite its synthetic nature, Mockus and DSİ Synthetic methods yielded results consistent with RFFA. FFA, on the other hand, produced low values, especially at high return periods. The results acquired can enhance engineering practices in flood-prone regions and assist local governments in making more informed decisions.

Veri Kısıtlı Olan Havzalarda Taşkın Frekans Tahmini: Türkiye'nin Doğusunda İstatistiksel ve Sentetik Yöntemlerin Karşılaştırılması

Anahtar Kelimeler
Taşkın tekerrür debisi,
Akım rejimi,
Bölgesel taşkın frekans analizi,
Tekerrür süresi,
Akım gözlem istasyonu,
Sentetik yöntemler

Öz: Taşkınlar, can ve mal kayıplarına neden olan en yıkıcı doğal afetlerden biridir. Bu afetin zararlarını azaltmada en kritik adımlardan biri, taşkın koruma yapılarının doğru boyutlandırılmasıdır. Bu ise güvenilir taşkın tekerrür debisi tahminlerini gerekli kılmaktadır. Bu çalışmada, Ağrı ilinde yer alan ve altı su kaynağını içeren bir havzada, özellikle D21A141 Yapılıköy Akım Gözlem İstasyonu (AGİ) için dört farklı yöntemle taşkın tekerrür debileri hesaplanmış ve karşılaştırılmıştır. Kullanılan yöntemler; Noktasal Taşkın Frekans Analizi (FFA), Bölgesel Taşkın Frekans Analizi (RFFA), Mockus Yöntemi ve DSİ Sentetik Yöntemidir. RFFA'nın, yan havzalardan elde edilen verileri kullanarak daha dengeli ve güvenilir sonuçlar sağladığı gözlemlenmiştir. Sentetik yapıda olmalarına rağmen Mockus ve DSİ Sentetik yöntemleri, RFFA ile uyumlu sonuçlar vermiştir. Öte yandan FFA, özellikle uzun tekerrür sürelerinde düşük değerler üretmiştir. Elde edilen bulgular, taşkın riski altındaki bölgelerde mühendislik uygulamalarına katkı sunabileceği gibi, yerel yönetimlerin daha bilinçli kararlar almasına da destek olabilir.

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1. Introduction

The definition of flooding refers to a natural disaster that results from the overflow of river bed due to intense precipitation as well as the thaw of snow, frequently leading to significant environmental as well as socio-economic impacts. Globally, floods rank as about 44% of all weather disasters, but in Türkiye, that percentage rises to 30%, hence highlighting their significance at both the international as well as the domestic level [1]. Flooding causes a disturbance of the hydrologic balance of affected areas, often involving loss of lives, property destruction, as well as long-lasting disruptions of the affected communities' economies [2]. Over the past decades, the occurrence as well as magnitude of flooding has significantly increased due to the influence of global warming, expanding their coverage to some hitherto susceptible zones [3]. As such, accurate estimation of flood quantiles of a watershed has become a very essential component of formulating effective mitigation measures, hence significantly contributing to minimizing flood damages through timely as well as strategically targeted engineering measures [2], [4]. However, existing studies often focus on either statistical or synthetic approaches in isolation, leaving a gap in integrated evaluations that could better inform practical design choices.

The repetitive flow of a flood can be calculated by synthetic, statistical, and hydrological modeling methods. Statistical frequency analysis methods include methods such as Flood Frequency Analysis (FFA), Regional Flood Frequency Analysis (RFFA), while synthetic methods include different methods such as Mockus, Rational, Snyder, and DSİ Synthetic. While these methods have been individually validated in diverse hydrological contexts, few studies have systematically compared multiple statistical and synthetic techniques within a single, data-scarce basin to assess their relative strengths for real-world engineering applications. In his study, Saf [3] conducted Regional Flood Frequency Analysis for homogeneous sub-regions determined according to the L-moments homogeneity test and mentioned the advantages of the Regional Flood Frequency Analysis method over the Flood Frequency Analysis method. The study concluded that regional analyses based on homogeneous sub-regions can improve the accuracy of flood predictions even at stations with limited data. In contrast, Seçkin [4] applied the same RFFA approach to a different basin type, showing that while the method retains robustness, its performance may vary depending on regional hydrological characteristics. Şeker [5] conducted a flood frequency analysis study for 28 SGSs in the Antalya Basin with measurements over 10 years, and calculated flood repetition flows after determining which distribution is suitable for SGS. Compared to Şeker's focus on distribution fitting, Baykal and Terzi [2] extended the analysis by systematically testing multiple probability distributions using the K-S test, which provided a more formal statistical basis for selection. Baykal and Terzi [2] used probability distributions for the estimation of flood repetition flows in Küçük Aksu Stream, applied the Kolmogorov-Smirnov (K-S) test to these distributions, and determined Log-Pearson Type-III as the most appropriate probability distribution. Dikici and Kazezyılmaz-Alhan [6] obtained the peak flood flows of the SGS on Pirinçci stream in Alibeyköy basin for 50 and 100-year return periods by three different methods: statistical, synthetic, and basin hydrological modeling (deterministic method), and compared the results. The 50- and 100-year flood discharges obtained using the deterministic MIKE 11 NAM model applied in the study were found to be higher than the values obtained using statistical methods such as Log-Normal-III (LN3) and Log-Pearson Type-III (LPT III) distributions. Unlike these basin-scale hydrological model integrations, Dikici and Aksel [7] emphasized a comparative framework where all three method types-statistical, synthetic, and hydrological-should be applied jointly, with the highest estimated value guiding hydraulic design. Dikici and Aksel calculated flood peak flows with the help of synthetic, statistical and hydrological models to select the most appropriate flood flow calculation method in the Eastern Mediterranean Basin, and stated that all three of these methods should be used together, the value that gives the highest flood flow should be accepted and hydraulic modeling and flood risk maps should be determined according to this value. Al-Qazzaz and Paşa [8] calculated flood repetition flows by applying probability distribution functions to the peak flood data measured at 43 selected SGSs in the Ceyhan Basin, determined the most appropriate probability distribution functions at each SGS by various suitability tests, and revealed the differences between the functions. In line with the emphasis on data-scarce environments, Demir and Keskin [9] further demonstrated that synthetic rainfall-runoff approaches can complement RFFA when transferability from nearby gauged basins is feasible. Demir and Keskin obtained flood repetition flows with the annual instantaneous maximum flows of the SGS located in the Mert River, Samsun. They performed Regional Flood Frequency Analysis by transferring the flood repetition flows determined as a result of the Flood Frequency Analysis of the SGS close to the Mert River basin to the Mert River and obtained flood repetition flows. He also applied synthetic methods based on rainfall-runoff modeling in the Mert River and determined that synthetic methods should be used since the flow measurements of the Mert River are insufficient.

To minimize the damage of a major disaster such as flooding and to protect the areas where people live and agricultural areas, it is an indispensable need to build flood protection facilities in the river bed. To eliminate the damages caused by floods, it is necessary to estimate the flow rates for different repetition periods [10]. For this purpose, certain methods, such as statistical and synthetic methods, have been developed. By calculating flood flows with these methods, flood protection facilities can be sized, flood risk maps can be created, and flood disasters can be effectively combated. This study aims to reveal the differences between the flood repetition flows obtained by using Flood Frequency Analysis and Regional Flood Frequency Analysis, which are statistical methods, and Mockus and DSİ Synthetic Method based on rainfall-runoff modeling, which are synthetic methods, at a selected SGS and to select the most appropriate values. Beyond identifying methodological differences, the study explicitly links these findings to practical decision-making in hydraulic design, offering guidance for method selection in real-world flood protection planning. It is considered that this study will be useful in determining which of the methods developed for the flood repetition flow calculations required for the sizing of flood protection facilities will give more appropriate results. This research also presents an overall evaluation comparing statistical and synthetic methods of flood estimation in Eastern Turkey, thereby addressing a substantial gap in the literature, and contributes to the field by applying the Mockus algorithm beyond its conventional scale parameters. Implementation applies a large basin area of 227 km^2 as part of assessing its performance under conditions of scarce data availability. By integrating both statistical and synthetic approaches into a unified four-method comparative framework, the study delivers not only an academic contribution but also a decision-support tool for practitioners working in data-scarce basins.

2. Material and Method

2.1. Study area

The study area is located in the Eastern Anatolia Region of our country and within the borders of Ağrı province, and morphologically shows the characteristics of a river basin. The region where the study area is located is the region where there are six water resources within the borders of the Euphrates basin No. 21. Depending on the geographical factors in the region, the continental climate of the Eastern Anatolia Region is effective, and the summers are dry and hot, and the winters are long and cold. There is a large temperature difference between summer and winter and between day and night throughout the year [11].

All six water sources in the study area are downstream of the Murat River. On each of the selected water sources, there are SGSs opened and currently operated by DSİ. These SGSs are D21A141 Yapılıköy SGS, D21A202 Derecek SGS, D21A204 Kavak SGS, D21A216 Dönerdere SGS, D21A217 Çökelge SGS and D21A219 Altınyurt SGS. The SGSs are between 15 and 45 km away from Ağrı province in terms of basin area. Since the number of measurement years of D21A141 SGS is higher than the others and almost all of its basin is located within the Thiessen Polygon of Gültepe DSİ Meteorological Station, which has more rainfall data, it is more appropriate to and compare flood repetition flows by different methods at this SGS. The other stations were used only for Regional Flood Frequency Analysis (RFFA), and no studies were conducted at these stations with methods other than Regional Flood Frequency Analysis. The study area, selected SGS and basin areas, and Thiessen Polygon are shown in Figure 1.

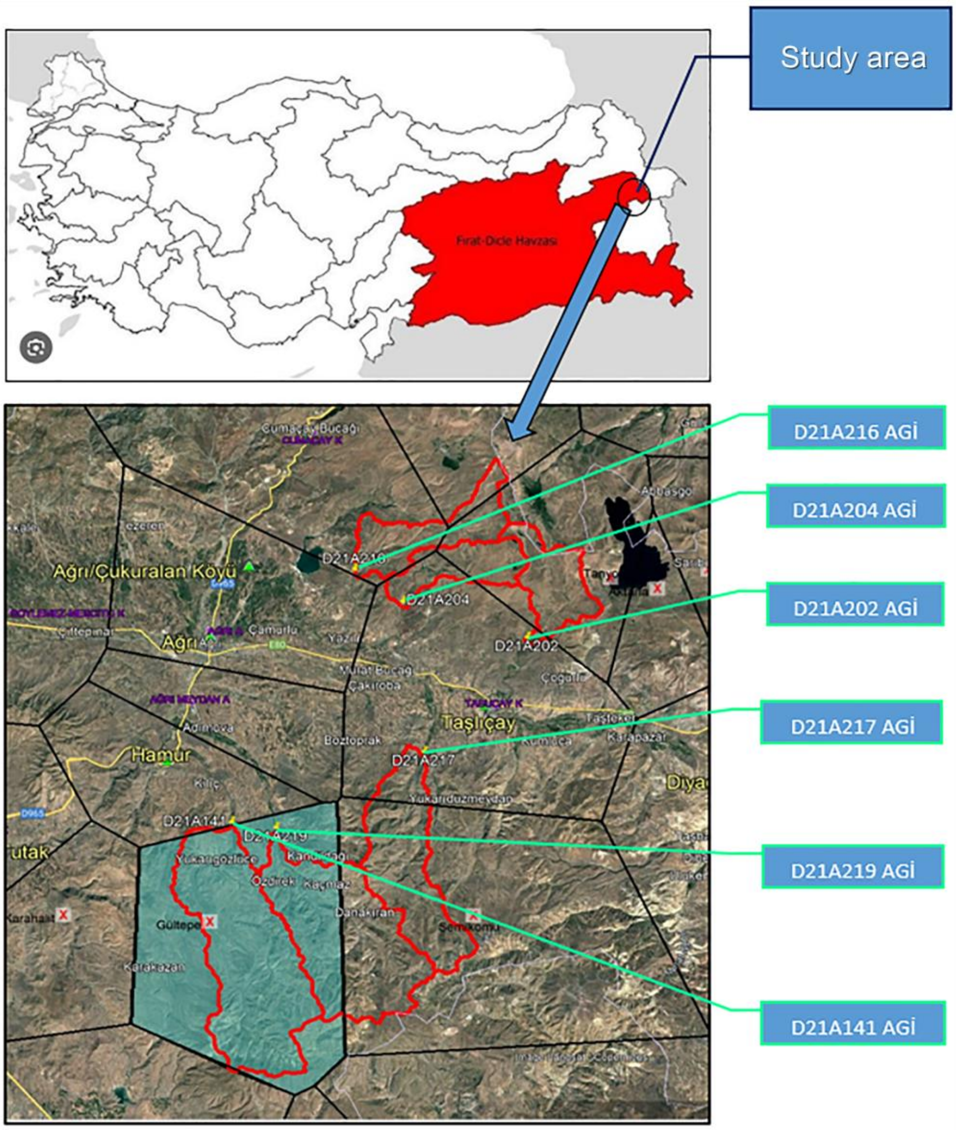


Figure 1. Study area, basin areas of SGSs, and Thiessen polygons

First of all, for this study, the location and measurement information of the SGSs and meteorological stations operated by the State Hydraulic Works (DSİ) were obtained. After this information was obtained, the SGSs and Thiessen Polygons were transferred to the KMZ environment, and the rainfall areas of the SGSs were created in the Global Watersheds environment. Then, 1/25000 scale maps of these basins were merged in the Global Mapper environment and transferred to the AutoCAD environment. In the Autocad environment, the final version was determined by drawing more precisely over the previous basin boundaries of SGSs. In the Autocad environment, the length of the watercourse (L) from the highest point of the basin area (rainfall area) of each SGS to the lowest point (SGS thalweg elevation or basin outlet point) was determined, this distance was divided into 10 equal parts and elevation information was read at a total of 11 points, including the lowest and highest points. In addition, the watercourse distance (Lc) from the center of gravity of the basin area to the point of projection on the water source and from the basin area to the basin outlet point was determined. The information about the SGSs used in this study is given in Table 1.

Table 1. Characteristics of SGSs

Station Code	D21A141	D21A202	D21A204	D21A216	D21A217	D21A219
Name	YAPILIKÖY	DERECEK	KAVAK	DÖNER DERE	ÇÖKELGE	ALTINYURT
Water Source	MANDALIK S.	DERECEK D.	TOPRAKKALE D.	HANOBA Ç.	MADRİK D.	SEYİTHANBEY S.
Observation Period (years)	38	17	29	36	25	23
Basin Area (km²)	227.456	61.476	57.119	74.954	129.287	193.126
L (m)	36608	20669	17278	24770	28335	30509
Lc (m)	18530	11552	9893	11868	14152	15478
Lower Point (Thalweg) (m)	1818	2069	1926	1807	1808	1795
Point 1 (m)	1845	2220	1994	1952	1853	1837

Point 2 (m)	1872	2326	2097	2048	1908	1891
Point 3 (m)	1913	2343	2170	2089	1952	1942
Point 4 (m)	1956	2349	2195	2232	2071	2023
Point 5 (m)	2003	2369	2273	2272	2117	2101
Point 6 (m)	2079	2393	2324	2334	2278	2179
Point 7 (m)	2156	2483	2344	2351	2405	2248
Point 8 (m)	2265	2485	2399	2381	2540	2360
Point 9 (m)	2420	2489	2487	2422	2841	2583
Upper point (m)	2894	2606	2545	2750	3311	3201

Then, flood repetition flows of Q_2, Q_5, Q_{10}, Q_{25}, Q_{50}, Q_{100}, Q_{500}, and Q_{1000} were calculated by FFA at D21A141 SGS. Afterwards, Regional Flood Frequency Analysis (RFFA) was performed at D21A141 SGS by utilizing the flood repetition flows found by FFA at other SGSs, and flood repetition flows of Q_2, Q_5, Q_{10}, Q_{25}, Q_{50}, Q_{100}, Q_{500}, and Q_{1000} were calculated. Subsequently, Mockus and DSİ Synthetic methods were used to calculate Q_2, Q_5, Q_{10}, Q_{25}, Q_{50}, Q_{100}, Q_{500}, and Q_{1000} flood repetition flows at this SGS. Lastly, the flood repetition flows calculated with the help of all these methods at D21A141 SGS were transferred to the table and graph for comparison, and the differences between them were revealed.

2.2 Methods

2.2.1 Probability distribution functions

In flood frequency analysis, which is one of the statistical methods, Probability Distribution Functions (PDFs) are used to calculate flood repetition flows, and Normal, Gumbel, Log-Normal-II, Log-Normal-III, Log-Pearson Type-III [9], [12], Pearson Type-III [2] and Kolmogorov-Smirnov (K-S) distributions are given below.

2.2.1.1 Normal (Gaussian) distribution

The normal (Gaussian) distribution is a symmetric, bell-shaped probability distribution in which the values of a random variable are mostly centered around the mean. In this distribution, data are more frequent when they are close to the mean, while the probability of extreme values gradually decreases. Variance determines the spread of the distribution; low variance creates a narrow curve, while high variance creates a broad curve. This structure is the basis for modeling uncertainty in methods such as Gaussian process regression [13]. It is defined by two different variables, and this function is calculated by numerical integration rather than analytically. It is usually characterized as follows.

$$f(x) = \frac{1}{\sqrt{2\pi\sigma_x^2}} \exp\left[-\frac{1}{2}\left(\frac{x-\mu_x}{\sigma_x}\right)^2\right] \tag{1}$$

The distribution is between $-\infty \leq x \leq \infty$, its mean is μx, and its variance is σx^2.

2.2.1.2 Gumbel distribution

The Gumbel distribution represents a two-parameter probability distribution, especially fitting to extreme events, which is a special case of the Generalized Extreme Value (GEV) distribution. Owing to simple parameter estimations and quantile function expressions, its widespread application to the analysis of flood frequencies, maximum assessments of precipitations, and forecasted values of design discharge can be explained to a large extent. However, due to its limited flexibility, it can introduce estimation errors, especially in data with high skewness. Therefore, its use should be carefully considered [14]. This distribution is defined as the distribution of the largest and smallest values of randomly selected variables and is a very frequently used distribution type.

$$f(x) = \frac{1}{a} \exp\left[-\frac{x-\xi}{a} - \exp\left(-\frac{x-\xi}{a}\right)\right] \tag{2}$$

The probability density function (PDF) of the Gumbel distribution is similar to that of the Log-Normal distribution with Csx=1.13.

2.2.1.3 Log-Normal-II distribution

This distribution has two parameters and is applied to the normal distribution by taking the logarithms of the variables as base e or base 10, and the parameters are defined in this way.

$$Y = \ln(x) \tag{3}$$

$$X = \exp(Y) \tag{4}$$

$$F(x) = P[Y \leq \ln(x)] = P\left[\frac{Y-\mu_y}{\sigma_y} - \frac{\ln(x)-\mu_y}{\sigma_y}\right] = \varphi[\frac{\ln(x)-\mu_y}{\sigma_y}] \tag{5}$$

In the above formula, φ is the additive distribution function of the standard normal distribution.

2.2.1.4 Log-Normal-III distribution

This distribution has three parameters. This distribution is logarithmically transformed so that the variables fit the normal distribution.

$$Y = \ln(x) \tag{6}$$

$$X = X_0 + \exp(Y) \tag{7}$$

Xo is the lower bound. The distribution of Y is a normal distribution.

2.2.1.5 Pearson Type-III distribution

In this distribution, the parameters can be identified by the method of moments or the maximum likelihood method.

$$Logx = \mu_{logx} + K_{S_{logx}} \tag{8}$$

K in the formula is the frequency factor and can be defined as a function of the skewness coefficient and the iteration period.

2.2.1.6 Log- Pearson Type-III distribution

This three-parameter distribution is often used in flood analysis. The logarithms of the variables are taken as base e or base 10. In this way, the parameters of the distribution are found.

$$\mathrm{Y} = \ln(\mathrm{x}) \tag{9}$$

$$X = X_0 + \exp(Y) \tag{10}$$

$$f(x) = |\beta| \left[\beta\left(x - \xi\right)\right]^{a-1} \frac{\exp\{\left(-\beta\left[\ln(x) - \xi\right]\right)\}}{a\,\Gamma\,(\mathrm{a})} \tag{11}$$

α is the shape, β the scale, and ξ the location parameter.

2.2.1.7 Kolmogorov-Smirnov (K-S) test

The purpose of this test is to determine which of the probability distributions is more appropriate for the observed data. This test is a test that asks whether a data group is uniformly distributed and to which distribution it is more suitable. For a single sample, this test is based on the examination of two cumulative distribution functions [9], [15]. For the current work, the Kolmogorov-Smirnov test was applied through a formulation-based approach using Microsoft Excel. Empirical, theoretical, as well as cumulative distribution functions were computed manually, and maximum absolute differences among these functions were utilized to carry out goodness-of-fit tests.

2.2.2 Statistical methods (Flood frequency analysis)

Flood frequency analyses are made by utilizing the monthly maximum flow data of the SGS.

2.2.2.1 Flood frequency analysis (FFA)

FFA is an easily applied method. However, since the data used for this analysis belong to a single station, its reliability depends on the data length [3], [16], [17]. This analysis method is based on the method of calculating flood repetition flows with the data obtained from a similar SGS with complete current data in the same basin, in case of incomplete or no measured flow values in the river or stream at the project location. With this method, flood repetition flows are calculated by statistical analysis of the SGS (sought) located on the river or stream where the project will be implemented, and the SGS (carried) to be utilized in the analysis. After the FFA is performed for the SGS (relocated), the calculated flood repetition flows are transferred to the project location SGS (called) in proportion to the rainfall areas and with the help of the coefficient n (a coefficient that differs for each basin), and the flood repetition flows are calculated for this SGS. If the SGS is located at the project site and the flow values are of the desired length and sufficient extent, FFA can be performed for this SGS without the need for another SGS. In this method, the most appropriate probability distribution function (PDF) is selected by applying tests to the annual maximum values of the SGS. One of the most appropriate test methods used for this method is the Kolmogorov-Smirnov (K-S) test.

2.2.2.2 Regional flood frequency analysis (RFFA)

With this method, the flood repetition flow of the project location is calculated with the data obtained from the nearby flow observation stations that are statistically similar to the flows and geographical conditions of the project location where the flood repetition flow is desired to be found. In this method, firstly, the maximum flows of each of the similar SGSs are subjected to the most appropriate probability distribution function Kolmogorov-Smirnov test, and flood repetition flows are calculated. Then, the calculated repetition flows of each SGS are made dimensionless by dividing by the Q_2 repetition flow, and the averages of these dimensionless values according to the repetition years (Q_T/Q_2) are found. These averages are the dimensionless values of the project location according to the repetition years. Then, the "Regional Flood Frequency Analysis Graph" is started to be drawn. In this graph, the points corresponding to the basin area and Q_2 flow rate of each SGS are marked on the log-log paper, and the envelope curve is drawn considering the characteristics of SGSs. The Q_2 of the project location is determined by drawing a horizontal line from where the basin area of the project location cuts the envelope curve. Other repetition flows are calculated by multiplying the average of Q_2 and (Q_T/Q_2) dimensionless values [18].

2.2.2.3 Synthetic methods (Rainfall-runoff model)

The model used in synthetic methods is the rainfall-runoff model. These methods are used in cases where sufficient observations have not been made in the water source for which flood repetition flow is to be calculated, or even if they have been made, these observations do not contain sufficient data. Thiessen polygons are created with rainfall data from meteorological stations, and in this way, flood repetition flows are calculated with the surrounding station data. Synthetic methods such as Mockus, SCS, Snyder, and DSİ Synthetic are widely used in determining flood repetition flows in basins where flow observations have not been made. Synthetic methods used in this study are given below.

2.2.2.4 Mockus method

It is a preferred method due to its practical calculation and ease of drawing the triangular hydrographs used [6]. It is suitable for basins with a drainage area between 1 and 10 km^2 [7]. In this method, firstly, the length and slope of the main water source of the basin where the flood repetition calculation will be made are determined, and the flood accumulation time is calculated using these data. Tc is calculated with the equation given below [19], [20].

$$Tc = 0.00032(\frac{L^{0.77}}{S^{0.85}}) \tag{12}$$

where Tc is the collection time (hours), L is the length of the water source (m), and S is the harmonic slope. The unit flood peak flow is calculated by the following equation.

$$qp = \frac{0.208A}{Tp} \tag{13}$$

where qp is the unit flood peak flow (m^{3}s^{-1}), A is the drainage area (km^2), and Tp is the time (hours) for the flood to reach the peak [20].

2.2.2.5 DSİ synthetic method

This method has been found suitable for basins with a basin area between 10 and 1000 km² (Dikici and Aksel, 2019). In larger basin areas, unit hydrographs are obtained by dividing the basin area into parts, and hydrographs of the entire basin area are obtained by summing the delayed hydrographs in the separated sections [20].

$$Q_p = qpA \tag{14}$$

where A is the basin area (km²), qp is the flow rate that a 1 mm flow height will create in the unit area and is found by the formula below;

$$qp = \frac{414}{A^{0.225}E^{0.16}} \tag{15}$$

where qp is the unit flow rate (m^3s^{-1} mm^{-1}), A is the basin area (km²), and the parameter E is calculated by the formula given below.

$$E = \frac{LL_c}{\sqrt{s}} \tag{16}$$

where L is the length of the water source (km), Lc is the length of the watercourse (km) between the projection of the drainage area basin center of gravity on the main water source and the lowest point of the basin (outlet point), and S is the harmonic slope of the basin (%). The volume of water (m³) that a 1 mm runoff height will generate from the total area.

$$Vb = Ah \tag{17}$$

where h is the flow height (mm), A is the drainage area (km²), and the base duration of the hydrograph;

$$Tb = 3.65\frac{Vb}{Q_P} \tag{18}$$

where Vb is the volume of water (m³) generated from the total area by a flow height of 1 mm and the time for the hydrograph to reach the peak;

$$Tp = \frac{Tb}{5} \tag{19}$$

where Tb is the hydrograph base time (hours) [20], [21].

3. Results

In this study, FFA and RFFA among statistical methods, and Mockus and DSİ Synthetic Method among synthetic methods were applied. The studies related to these methods applied to obtain flood repetition flows of Q_2, Q_5, Q_{10}, Q_{25}, Q_{50}, Q_{100}, Q_{500}, Q_{1000} at D21A141 SGS are summarized below.

3.1. Statistical methods

3.1.1. Flood frequency analysis (FFA)

First of all, FFA was performed with the maximum flows measured at D21A141 SGS. For this purpose, the instantaneous maximum flows measured at D21A141 SGS were ranked from small to large, and the percentages corresponding to each value were found in order. Then, the extreme distributions of the instantaneous maximum flow rates measured at D21A141 SGS were obtained according to six different probability distribution functions (Normal, Log-Normal-Type 2, Log-Normal-Type 3, Pearson-Type 3, Log-Pearson-Type 3, Gumbel). The extreme distributions obtained according to different types were subjected to the Kolmogorov-Smirnov (K-S) test, and according to this test, it was concluded that the values obtained according to the Log-Normal-Type 3 probability distribution function were the most appropriate distribution. The results are shown in Table 2.

Table 2. Extreme distributions of instantaneous maximum flows realized at D21A141 SGS according to different distribution types (m³/s) (FFA)

Distribution Type	Q_2	Q_5	Q_{10}	Q_{25}	Q_{50}	Q_{100}	Q_{500}	Q_{1000}
Normal Distribution	23.26	30.32	34.01	37.94	40.48	42.77	47.37	51.44
Log-Normal (2 Parameters)	21.88	29.37	34.25	40.36	44.86	49.35	59.78	64.45

Log-Normal (3 Parameters)	22.25	29.75	34.33	39.81	43.69	47.44	55.81	59.42
Pearson Type-3 (Gamma Type-3)	22.15	29.80	34.46	39.98	43.83	47.51	54.58	58.11
Log-Pearson Type-3	22.23	29.90	34.55	40.00	43.80	47.37	54.46	58.40
Gumbel	21.96	30.33	35.86	42.86	48.05	53.20	65.10	70.22

3.1.2. Regional flood frequency analysis (RFFA)

To calculate the flood repetition flows at D21A141 SGS with RFFA, the FFA results of the other 5 SGSs were utilized. While deciding which SGSs to be used for Regional Flood Frequency Analysis, it was taken into consideration that they are located in the same upper basin, they are on the tributaries of the main water source, they are climatologically close to each other [22], and they have similar basin characteristics such as geography, soil structure, etc. The extreme distributions of maximum flow values were found with the FFA performed at these SGSs, and the most appropriate distributions were selected according to the K-S test. According to the test, Gumbel distribution for D21A202 SGS, Log-Normal-Type 3 for D21A204 SGS and D21A216 SGS, Log-Normal-Type 2 for D21A217 SGS, and Log-Pearson-Type 3 for D21A219 SGS were found suitable. Flood repetition flow values of these SGSs are shown in Table 3.

Table 3. Flood repetition flows of SGSs included in the RFFA (m^3/s)

Station Number	N (yıl)	UDF	A (km^2)	Q_2	Q_5	Q_{10}	Q_{25}	Q_{50}	Q_{100}	Q_{500}	Q_{1000}
D21A202	17	G	61.48	9.81	14.31	17.29	21.06	23.85	26.63	33.04	35.79
D21A204	29	LN-3P	57.12	15.49	21.72	25.45	29.82	32.88	35.81	42.23	44.96
D21A216	36	LN-3P	74.95	14.50	20.34	23.92	28.17	31.19	34.11	40.60	43,60
D21A217	25	LN-2P	129.29	9.81	13.10	15.24	17.91	19.87	21.82	26.35	28.37
D21A219	23	LP-T3	193.13	14.34	21.77	27.38	35.23	41.64	48.54	64.60	74.53

For each of the 5 SGSs included in the RFFA, the flood repetition flows Q_2, Q_5, Q_{10}, Q_{25}, Q_{50}, Q_{100}, Q_{500}, Q_{1000} were dimensionless by dividing them by their own Q_2 value, and the averages of these dimensionless values (Q_T/Q_2) were taken for each repetition period.

Table 4. Dimensionless (Q_T/Q_2) values and averages of SGSs included in the RFFA

Station number	Q_2/Q_2	Q_5/Q_2	Q_{10}/Q_2	Q_{25}/Q_2	Q_{50}/Q_2	Q_{100}/Q_2	Q_{500}/Q_2	Q_{1000}/Q_2
D21A202	1.00	1.46	1.76	2.15	2.43	2.72	3.37	3.65
D21A204	1.00	1.40	1.64	1.93	2.12	2.31	2.73	2.90
D21A216	1.00	1.40	1.65	1.94	2.15	2.35	2.80	2.99
D21A217	1.00	1.34	1.55	1.82	2.02	2.22	2.68	2.89
D21A219	1.00	1.52	1.91	2.46	2.90	3.39	4.51	5.20
Mean	1.00	1.42	1.70	2.06	2.33	2.60	3.22	3.53

Then, the envelope curve was drawn by transferring the 5 SGSs pointwise to the Basin Area-Q_2 coordinate axis on the log-log paper, and the Q_2 value of D21A141 SGS was read with the horizontal line drawn on the dimensionless Q_2 ordinate axis from the point where the basin area of D21A141 SGS and this envelope curve intersect. In this study, the equation of the Area-Q_2 envelope curve was calculated as y = x0.6759, and the Q_2 value of D21A141 SGS was calculated as 39.18 m^3/s (Figure 2).

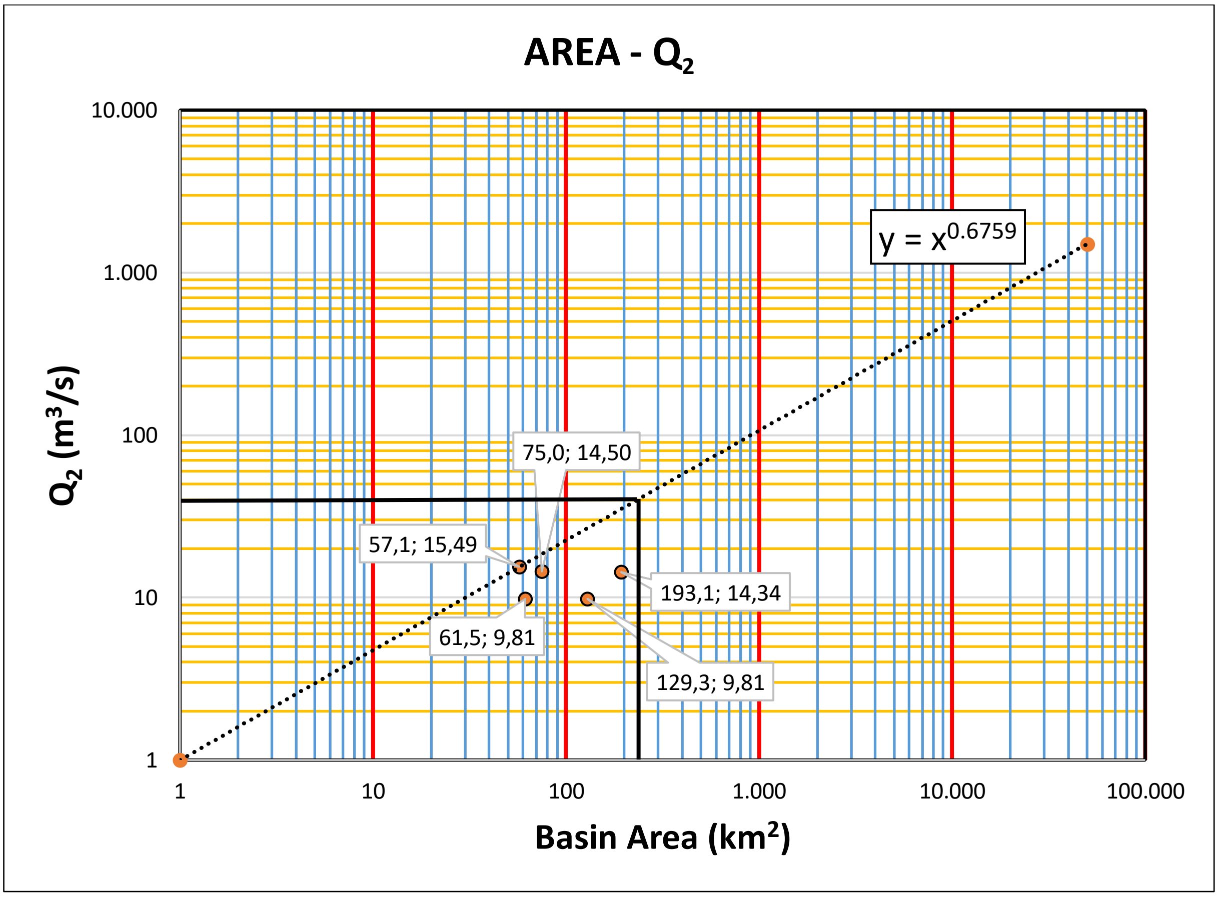


Figure 2. Area-Q_2 envelope curve and Q_2 value of D21A141 SGS

Finally, Q_5, Q_{10}, Q_{25}, Q_{50}, Q_{100}, Q_{500}, and Q_{1000} flood repetition flows were calculated by multiplying the basin area of D21A141 SGS by the Q_2 value.

$$Q_T = Q_2 x(Q_T/Q_2) \tag{20}$$

where Q_2 is the 2-year recurring flow, and Q_T is the flow corresponding to the year of repetition

Table 5. D21A141 SGS flood repetition flows (RFFA) (m^3/s)

D21A141 SGS Basin Area (A=227.456 km²)	Q_2	Q_5	Q_{10}	Q_{25}	Q_{50}	Q_{100}	Q_{500}	Q_{1000}
	39.18	55.78	66.74	80.69	91.17	101.77	126.04	138.18

3.2. Synthetic methods

3.2.1. Mockus method

First of all, the monthly maximum rainfall table obtained from the Gültepe Meteorological Station was utilized for this method. The maximum rainfall values of each year in this table were selected in the last column, and FFA was performed with these values, and the extreme distributions of maximum rainfall for this station were found. According to the K-S test, the most appropriate Log-Normal-Type 2 distribution was found, and the results are given in Table 6.

Table 6. Extreme distributions of instantaneous maximum flows realized at Gültepe meteorological station according to different distribution types (m^3/s)

Distribution Type	Q_2	Q_5	Q_{10}	Q_{25}	Q_{50}	Q_{100}	Q_{500}	Q_{1000}
Log-Normal (2 Parameters)	30.86	38.20	42.71	48.11	51.94	55.66	63.97	67.56

This method employed a CNII coefficient of 0.84, determined based on the land cover being classified as meadow or square, hydrological soil group C (characterized by low sand content and shallow vegetative soil), and hydrological conditions for infiltration ranging from weak to favorable, but closer to weak. The resulting values were obtained using the basin length (L), centroidal length (Lc), and point elevations specific to the D21A141 SGS basin.

Table 7. D21A141 SGS flood repetition flows according to the Mockus method (m³/s)

	Q_2	Q_5	Q_{10}	Q_{25}	Q_{50}	Q_{100}	Q_{500}	Q_{1000}
D21A141 SGS	21.51	40.43	54.08	72.11	85.90	99.95	131.46	145.36

3.2.2. DSİ synthetic method

The Q_{base} used in this method is a flow value that varies within certain limits throughout the year, typically increasing during winter and spring months in regions with heavy snowmelt and precipitation, and decreasing in other months. Especially in basins where snowmelt persists for an extended period, the base flow represents a significant value within the flood. Therefore, the base flow must be added to the flood value [9], [23]. For this purpose, the average flow rates for April and May months with the highest snowmelt-were calculated separately for each year from the monthly total flow table of D21A141 SGS. The highest average value of 35.5 hm³ was converted to flow rate, resulting in Q_{base} = 13.471 m³/s. The Q_{500} and Q_{1000} values, which are commonly used in flood risk mapping calculations and flood protection facility sizing, are derived from the Q_{10} and Q_{100} values [24], [25]. $Q_{500} = (Q_{100}-Q_{10}) \times 1.687 + Q_{10}$ and $Q_{1000} = (Q_{100}-Q_{10}) \times 1.99 + Q_{10}$ formulas are used for calculation. Therefore, the trend of the Q_{100} value, which is greater than Q_{10} during rainfall periods, was observed, and since this value reaches its peak at 12 hours and then begins to decline, it was deemed appropriate to use the 12-hour flood hydrograph. The flood recurrence discharges formed according to rainfall periods in D21A141 SGS are shown in Table 8.

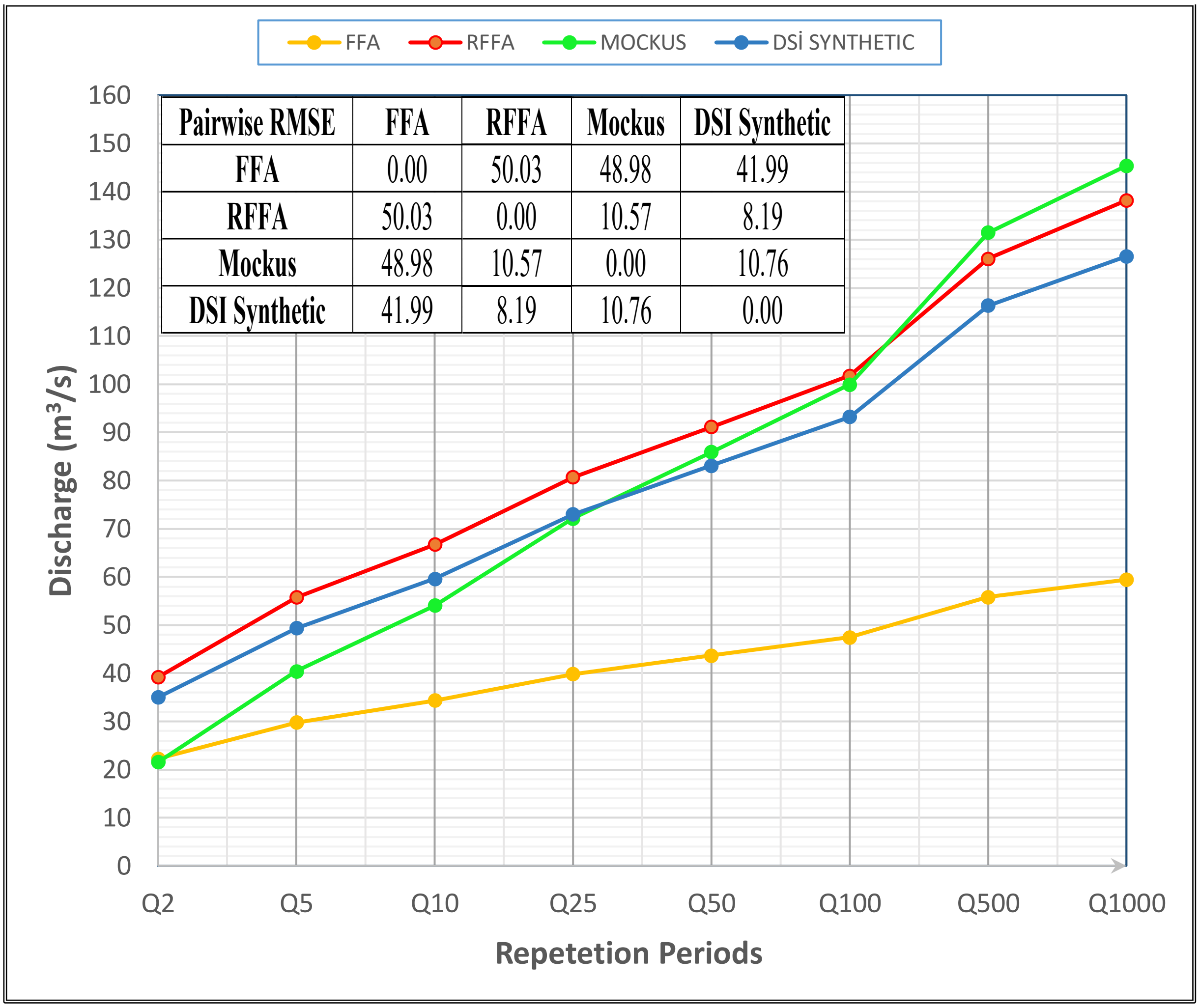
Table 8. D21A141 SGS flood repetition flows according to project rainfall periods (DSİ synthetic method) (m³/s)

Repetition period	2	4	6	8	12	18	24
Q_2	18.69	25.04	29.81	32.52	34.98	35.39	36.98
Q_5	25.95	36.39	43.63	47.05	49.32	49.53	51.02
Q_{10}	31.62	44.82	53.58	57.42	59.60	59.34	60.61
Q_{25}	39.47	56.11	66.67	70.92	72.97	71.92	73.01
Q_{50}	45.67	64.82	76.65	81.20	83.08	81.42	82.39
Q_{100}	52.11	73.75	86.79	91.71	93.25	91.03	91.86
Q_{500}	66.18	93.62	109.61	115.27	116.37	112.79	113.33
Q_{1000}	72.39	102.39	119.68	125.67	126.56	122.39	122.80

Flood repetition flows calculated according to the methods described above at D21A141 SGS are given in Table 9 and Figure 3. In addition, Figure 3 includes the pairwise Root Mean Square Error (RMSE) values, where RMSE-expressed in the same unit as the evaluated variable-estimates the average magnitude of the difference between two datasets, with values closer to zero indicating higher agreement between methods [26]-[27]. Pairwise RMSE in this context quantifies the mutual agreement between all method combinations without assuming any one method as the reference, thereby providing an unbiased measure of similarity.

Table 9. Flood repetition flows calculated by different methods at D21A141 SGS (m³/s)

Method	Q_2	Q_5	Q_{10}	Q_{25}	Q_{50}	Q_{100}	Q_{500}	Q_{1000}
FFA	22.25	29.75	34.33	39.81	43.69	47.44	55.81	59.42
RFFA	39.18	55.78	66.74	80.69	91.17	101.77	126.04	138.18
MOCKUS	21.51	40.43	54.08	72.11	85.90	99.95	131.46	145.36
DSİ SYNTHETIC	34.98	49.32	59.60	72.97	83.08	93.25	116.37	126.56



Pairwise RMSE	FFA	RFFA	Mockus	DSI Synthetic
FFA	0.00	50.03	48.98	41.99
RFFA	50.03	0.00	10.57	8.19
Mockus	48.98	10.57	0.00	10.76
DSI Synthetic	41.99	8.19	10.76	0.00

Figure 3. Flood repetition flow graph calculated by different methods at D21A141 SGS pairwise RMSE values showing the agreement between the methods.

4. Discussion and Conclusion

In this study, flood quantile (Q) values estimated by four different methods-Flood Frequency Analysis (FFA), Regional Flood Frequency Analysis (RFFA), Mockus Method, and DSİ Synthetic Method-were compared for the D21A141 Stream Gauging Station (SGS) located in a data-scarce basin in Eastern Turkey. Among the six SGSs located downstream of the Murat River, D21A141 was selected for detailed analysis due to its long observation record and the fact that most of its basin lies within the high-rainfall Thiessen Polygon of the Gültepe Meteorological Station. The remaining five SGSs were used exclusively in RFFA applications.

When the methods were evaluated, it was observed that FFA generally yielded lower flood quantile values, especially at longer return periods, while RFFA, Mockus, and DSİ Synthetic methods produced similar and statistically higher values. This divergence likely stems from the fact that FFA relies solely on single-station historical flow records, which, in data-scarce contexts, may underrepresent extreme events, whereas regional and synthetic approaches incorporate spatially distributed hydrological information or physically based parameters. In particular, RFFA results were the highest among all recurrence intervals except Q_{500} and Q_{1000}, which were slightly exceeded by Mockus. Although the Mockus method started with lower values at Q_2, it showed a steep increase in higher return periods, indicating its conservative estimates in short-term and aggressive tendencies in long-term projections. DSİ Synthetic Method, on the other hand, exhibited a more balanced behavior, closely matching the average results of the other methods. The closer alignment between RFFA and DSİ Synthetic also reflects the role of basin-scale morphometric inputs in reducing bias, as noted in similar applications by Kumanlıoğlu & Ersoy [29] and Sönmez et al. [30].

Mockus' methodology, which uses a greater set of parameters relevant to the particular basin of concern, may offer some benefit to flood flow estimation [29], [30]. It, however, falls into the rainfall-based synthetic category of methods, best suited for small catchments without flow recording stations, which usually cover catchment sizes of about 1 to 10 km^2.To observe the results of this method in a basin with different characteristics, it was applied in a basin with a flow observation station and an area of 227,456 km^2. Considering that this method is primarily recommended in the literature for small basins without flow observation stations and with an area of 1-10 km^2, it is suggested that its applicability in basins of different scales be carefully evaluated. The marked growth of Mockus-derived discharges at high return periods in this study suggests that, when applied beyond its typical scale, the method may amplify design values, which could be interpreted as a conservative safety margin in structural design, yet requires contextual calibration to avoid over-dimensioning.

One of the methods that can be used to calculate flood recurrence discharges by utilizing rainfall values in basins where sufficient flow values are not available is the DSİ Synthetic Method [31], [32]. The DSİ Synthetic Method is effective in regions with basin sizes ranging from 10 to 1000 km^2. Considering the basin area of D21A141 SGS, it can be stated that this method falls within its application range, and the practical validity of this suitability is confirmed by the balTamaanced nature of the obtained values. However, in basins where flow measurements are sufficient, it is recommended that evaluations regarding the use of this method, which is a synthetic method based on rainfall data, be conducted carefully and contextually. The close alignment of RFFA, Mockus, and DSİ methods, and the divergence of FFA results, support the finding that regional and synthetic methods are more robust in basins where observational data is limited. Pairwise RMSE analysis further quantified these relationships, showing the lowest RMSE values between RFFA and DSİ Synthetic (8.19) and between RFFA and Mockus (10.57), whereas FFA displayed substantially higher RMSE values with all other methods (≥ 41.99), confirming its systematic underestimation at higher return periods.This convergence is consistent with findings by Kesgin [33], who observed that synthetic unit hydrograph methods incorporating morphometric and land cover parameters tend to approximate regional frequency results when basin physiography is adequately represented. The practical applicability of methods such as Mockus and DSİ Synthetic in data-scarce basins has been increasingly emphasized in the literature, particularly due to their reliance on physically interpretable parameters and their tendency to yield conservative estimates in ungauged or partially gauged catchments [33].

RFFA, in particular, demonstrated superior consistency by incorporating data from sub-basins with similar hydrological and morphometric characteristics. Previous applications of RFFA on nearby SGSs yielded higher and more reliable estimates than point-based FFA, especially in regions where data scarcity is a concern [3], [34]–[37]. Based on the homogeneous region assumption, RFFA enables the transfer of hydrological information across basins, thereby reducing statistical uncertainty and enhancing estimation accuracy. In the context of climate change, where non-stationary hydrological conditions may render single-site statistical inferences less reliable, this integrative approach provides a resilient basis for future flood hazard assessment. Given the growing evidence of non-stationarity in hydrological systems due to climate change, the robustness of regional and synthetic methods-particularly those less dependent on long historical records-gains further importance for future flood risk projections.

The methods differ because they are based on different ideas and basic rules. Therefore, it is difficult to determine the best method universally. However, RFFA's spatially integrative structure and consistent results position it as a preferred method for flood prediction in similar contexts. Nevertheless, it is essential to acknowledge that the performance of each method may vary under different geographic and hydrologic conditions, and the findings of this study are site-specific. While RFFA provides enhanced accuracy by utilizing data from multiple sites, it does require a certain level of regional uniformity and consistency between basins. In contrast, synthetic methods like Mockus and DSİ are more useful in situations where data is scarce, but they may result in conservative discharge estimates. Therefore, the choice of method should balance practical feasibility, data requirements, and acceptable safety margins.

The results of this study have significant consequences for hydraulic design and flood risk policy. They indicate that in regions with scarce data, we should prioritize regional and synthetic techniques such as RFFA and DSİ Synthetic to ensure safety margins are met without excessive overdesign. For practitioners, this means that adding morphometric and land cover data to flood estimates at the design stage can make them more reliable. The results we have are particular to this site, so we need to verify how they hold up in basins that have different climatic, hydrological, or land-use characteristics before we can generalize. Looking ahead, research should focus on how well these methods work under expected climate change scenarios, using non-stationary frequency analysis to more accurately represent shifts in hydrological extremes.

In conclusion, the comparative evaluation conducted here offers valuable insights for both hydraulic design engineers and local authorities dealing with flood risk. The results highlight the importance of choosing methods that fit the specific characteristics of the basin, the data that's available, and safety considerations. With climate change reshaping flow patterns and heightening flood risks, it's crucial to share these studies and test these methods in different geographic areas. Furthermore, efficient flood management must extend beyond mere modeling; it should integrate technology, local governance, and community engagement to establish resilient systems.

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References

[1] Pancar, Z. B., and Gökce, D. 2022. Hidro-Meteorolojik Karakterli Afet Riski Bulunan Alanlardaki Mevcut Mekânsal Planlama Kararları: Serik (Antalya) Örneği. Mehmet Akif Ersoy Üniversitesi Fen Bilimleri Enstitüsü Dergisi, 13(2), 229-245. https://doi.org/10.29048/makufebed.1139695

[2] Baykal, T., and Terzi, Ö. 2017. Küçük Aksu Çayı Taşkın Frekans Analizi. Cumhuriyet Sci. J, 38(4), 639-646. http://dx.doi.org/10.17776/csj.348907

[3] Saf, B. 2009. Batı Akdeniz Havzalarının L-Momentlere Dayalı Bölgesel Taşkın Frekans Analizi. Pamukkale Üniversitesi Mühendislik Bilimleri Dergisi, 15(2), 153-165.

[4] Seçkin N. 2009. L-Momentlere Dayalı Gösterge-Sel Metodu İle Bölgesel Taşkın Frekans Analizi. Çukurova Üniversitei, Fen Bilimleri Enstitüsü, Doktora Tezi, 266s, Adana.

[5] Şeker, M. 2015. Antalya Havzası'nın taşkın frekans analizi. Pamukkale Üniversitesi Fen Bilimleri Enstitüsü, Yüksek Lisans Tezi, 121s, Denizli.

[6] Dikici, M., and Kazezyılmaz-Alhan, C. M. 2018. Alibeyköy Havzası İçin Farklı Hidrolojik Modelleme Yöntemleri ile Taşkın Debilerinin Belirlenmesi. Dicle Üniversitesi Mühendislik Fakültesi Mühendislik Dergisi, 9(2), 919-928.

[7] Dikici, M., and Aksel, M. 2019. Havza Büyüklüğüne Göre En Uygun Taşkın Debisi Hesap Yönteminin Bulunması-Doğu Akdeniz Havzası Örneği. ALKÜ Fen Bilimleri Dergisi, 1(3), 120-131. https://doi.org/10.46740/alku.582794

[8] Al-Qazzaz, Z. A. A., and Paşa, Y. 2021. Ceyhan Havzası'nın Taşkın Frekans Analizi. Van Yüzüncü Yıl Üniversitesi Mühendislik Fakültesi Dergisi, 2(2), 1-21.

[9] Demir, V., and Keskin, A. Ü. 2022. Yeterince Akım Ölçümü Olmayan Nehirlerde Taşkın Debisinin Hesaplanması ve Taşkın Modellemesi (Samsun, Mert Irmağı Örneği). Geomatik, 7(2), 149-162. https://doi.org/10.29128/geomatik.918502

[10] Turhan, E., Değerli, S., and Çulha, B. D. 2021. Çeşitli Tekerrür Periyotları için Taşkın Debilerinin Tahmininde Farklı Olasılık Dağılımlarının Karşılaştırılması: Ceyhan Nehri Örneği. Karadeniz Fen Bilimleri Dergisi, 11(2), 731-742. https://doi.org/10.31466/kfbd.997355

[11] MGM. 2025. https://mgm.gov.tr/genel/meteorolojisozlugu.aspx (Erişim Tarihi: 26.05.2025)

[12] Bayazıt M and Yeğen Oğuz B. 2013. Mühendisler için İstatistik. Birsen Yayın Dağıtım Ltd. Şti. 197s.

[13] Wang, J. 2023. An Intuitive Tutorial to Gaussian Process Regression. Computing in Science and Engineering, 25(4), 4-11. https://doi.org/10.1109/MCSE.2023.3342149

[14] Anghel, C. G. 2024. Revisiting The Use of The Gumbel Distribution: A Comprehensive Statistical Analysis Regarding Modeling Extremes and Rare Events. Mathematics, 12(2466).

[15] Gamgam, H. 1989. Parametrik Olmayan İstatistiksel Teknikler. Gazi Üniversitesi Yayınları, 289s.

[16] Cunnane, C. 1988. Methods And Merits of Regional Flood Frequency Analysis. Journal of Hydrology, 100(1-3), 269-290. https://doi.org/10.1016/0022-1694(88)90188-6

[17] Hosking, J. R. M., and Wallis, J. R. 1993. Some Statistics Useful in Regional Frequency Analysis. Water Resources Research, 29(2), 271-281. https://doi.org/10.1029/92WR01980

[18] Tekeli, S. 2000. DSİ 2000 Hidroloji semineri. DSİ Genel Müdürlüğü, 128.

[19] Mockus V. 1949. Estimation of Total (and Peak Rates Of) Surface Run-Off For Individual Storms. Exhibits A, Appendix B, Interim Survey Report, Grand (Neosho) River Watershed. U.S. Department of Agriculture, Washington DC. pp 61.

[20] Gevrek, İ., and İrvem, A. 2021. Antakya'da Taşkına Neden Olan Yan Derelerde Hidrograf Analizi ile Taşkın Tahmini. Mustafa Kemal Üniversitesi Tarım Bilimleri Dergisi, 26(3), 533-542. https://doi.org/10.37908/mkutbd.932723

[21] Tülücü, K. 2002. Hidroloji. Çukurova Üniversitesi, Ziraat Fakültesi, Yayın, (139).

[22] Erdin, İ. Taşkın Hidrolojisinde Bölgesel Taşkın Frekans Analizi (RFFA) Yöntemiyle Taşkın Debi Hesabı. Meteoroloji Mühendisleri Odası. https://meteorolojimuh.org.tr/wp-content/uploads/2024/09/taskin-hidrolojisinde-RFFA-yontemi-ile-taskin-debi-hesabi.pdf (Erişim Tarihi: 22.05.2025).

[23] Özdemir, H. 1978. Uygulamalı taşkın hidrolojisi. DSİ Genel Müdürlüğü Basım ve Foto-Film İşletme Müdürlüğü Matbaası, Ankara.

[24] Keskin, T. E., Çetiner, H. İ., Başdağ, S., Genç, S., and Kiliç, H. Y. 2018. Akım Gözlem İstasyonları Bulunmayan Nehirlerin DSİ Sentetik Yöntemi Kullanılarak Taşkın Debilerinin Tahmini Eskipazar Çayı Örneği (Karabük, Türkiye). In 2nd International Symposium on Natural Hazards and Disaster Management, Sakarya University Culture and Congress Center, Sakarya-Turkey 04-06 May 2018.

[25] Korkmaz, M. 2022. Nehirlerde Taşkın Tekerrür Debisi Hesabı ve Taşkın Risk Değerlendirmesi. El-Cezeri, 9(2), 532-541. https://doi.org/10.31202/ecjse.974134

[26] Zanchetta, A. D., & Coulibaly, P. 2022. Hybrid Surrogate Model for Timely Prediction of Flash Flood Inundation Maps Caused by Rapid River Overflow. Forecasting, 4(1), 126-148. https://doi.org/10.3390/forecast4010007

[27] Wee, G., Chang, L. C., Chang, F. J., and Amin, M. Z. M. 2023. A flood Impact-Based forecasting system by fuzzy inference techniques. Journal of Hydrology, 625, 130117. https://doi.org/10.1016/j.jhydrol.2023.130117

[28] Çırağ, B., Karagöz, R., Özer, A. E., Aydın, A. Ö., and Fırat, M. 2025. Modelling the dynamic performance of stormwater drainage systems integrated with infiltration trenches. Urban Water Journal, 22(2), 244-257. https://doi.org/10.1080/1573062X.2024.2446512

[29] Kumanlıoğlu, A. A., and 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.

[30] Sönmez, O., Hırça, T., Demir, F. 2017. Akım Ölçümü Olmayan Nehirlerde Farklı Yağış Akış Modelleri İle Tekerrürlü Taşkın Debisi Hesabı: Mudurnu Çayı Örneği. 5th International Symposium on Innovative Technologies in Engineering and Science. 29-30 September, Baku, Azerbaijan. 1091 – 1100.

[31] Çelik, H. E. 2012. Sel kontrolünde hidroloji, ÇEM sel kontrolu semineri, 15-17 Şubat 2012, Afyonkarahisar.

[32] Alkan, Ç. 2016. Küçük su havzaları hidrolojik modeli WinTR-55'in Bursa ili bazı sulama gölet havzalarına uygulanabilirliğinin araştırılması. Uludağ Üniversitesi, Fen Bilimleri Enstitüsü, Yüksek Lisans Tezi, 118s, Bursa.

[33] Kesgin, E. 2025. Flood Discharge Estimation in Ungauged Basins Using Synthetic Unit Hydrographs and GIS. Firat University Journal of Experimental and Computational Engineering, 4(2), 375-392. https://doi.org/10.62520/fujece.1645774

[34] Lettenmaier, D. P. and Potter, K. W. 1985. Testing Flood Frequency Estimation Methods Using a Regional Flood Generation Model. Water Resources Research, 21 (12), 1903-1914. https://doi.org/10.1029/WR021i012p01903

[35] Lettenmaier, D. P., Wallis, J. R. and Wood, E. F. 1987. Effect of Regional Heterogeneity on Flood Frequency Estimation. Water Resources Research, 23 (2), 313–323. https://doi.org/10.1029/WR023i002p00313

[36] Hosking, J. R. M., Wallis, J. R. and Wood, E. F. 1988. The Effect of Intersite Dependence on Regional Flood Frequency Analysis. Water Resources Research. (24), 588-600. https://doi.org/10.1029/WR024i004p00588

[37] Pilon, P. J. and Adamowski, K. 1992. The Value of Regional İnformation to Flood Frequency Analysis Using The Method of L-Moments. Canadian Journal of Civil Engineering, (19), 137–147. https://doi.org/10.1139/l92-014