

## ORIGINAL RESEARCH ARTICLE

## Application of SCS and Snyder Unit Hydrograph Methods for Enhanced Flood Response and Peak Runoff Hydrograph Development in the Foma River Watershed, Ilorin, Kwara State

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### ABSTRACT

This study estimated unit hydrograph ordinates and developed runoff hydrographs for the Foma River watershed. The Snyder's and SCS synthetic approaches were used to produce the unit hydrograph ordinates, while the SCS type II curve was used to determine the cumulative excess rainfall values for storm depths with 20-yr and 50-yr return periods. To develop the peak runoff hydrograph, the synthetic unit hydrograph ordinates were convoluted with the cumulative excess rainfall for the 20-yr and 50-yr storm return periods, using the Gumbel Extreme Value Type I (EV-I) probability distribution. Peak runoff values obtained based on the SCS for the watershed ranged from 68.0 m<sup>3</sup>/s to 112.0 m<sup>3</sup>/s for the return periods of 20 and 50 years, while peak runoff values obtained based on the Snyders ordinates for the 20- and 50-year return periods varied between 70.0 m<sup>3</sup>/s and 90.0 m<sup>3</sup>/s. The findings demonstrate that the SCS approach was the most effective for calculating the flow ordinate required to develop the peak runoff hydrograph for various return periods in the research area.

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### INTRODUCTION

A unit hydrograph of a basin or watershed is rarely determined using rainfall and runoff data in most Nations worldwide (Yi *et al.*, 2022; Prakash *et al.*, 2025). The absence of gauging stations along most of Nigeria's rivers and streams makes this situation common. Planning and developing water management facilities and other hydraulic infrastructure in undeveloped watersheds often lack fundamental streamflow and rainfall data (Prakash *et al.*, 2025). Nevertheless, methods for creating synthetic unit hydrographs have been developed. These include the Soil Conservation Service (SCS) approach, Snyder's method, Gray's method, and Clark's instantaneous method. Design storm hydrographs are created from unit hydrographs produced using recognized techniques applied to determine the peak discharges of stream flow caused by rainfall.

The 1-hour unit hydrograph, as described by Arora (2004), is the hydrograph that provides a 1 cm depth of direct runoff during a 1-hour storm that occurs evenly throughout the watershed. A hydrograph is a continuous graph that displays the characteristics of stream flow over time. It is typically created using a continuous strip recorder that plots stages against time. A rating curve is

then used to convert the hydrograph into a discharge hydrograph. A drainage basin's unit hydrograph is the hydrograph of direct runoff produced uniformly over the basin area at a consistent rate after one unit of effective rainfall of a certain period (WMO, 2009a). The basin's area, slope, orientation, form, altitude, and stream pattern are all considered watershed qualities.

Ogunlela (1996) developed a unit hydrograph for a small agricultural watershed at the University of Ilorin, accounting for the watershed's storage characteristics by routing through an assumed linear reservoir using Clark's approach. At a time to peak of 0.33 hours, he achieved a unit hydrograph peak of 2.97 m<sup>3</sup>/s. In contrast, he obtained peak flows of 4.53 m<sup>3</sup>/s (at 0.58 hours) and 6.23 m<sup>3</sup>/s (at 0.58 hours) for the 25-year, 24-hour and 100-year, 24-hour storm hydrographs. Ayansola and Salami (2009) developed a unit hydrograph for the Awun River basin using the Snyder, SCS, and Grey methods; the peak unit hydrograph values were 299.27 m<sup>3</sup>/s, 307.28 m<sup>3</sup>/s, and 2083.40 m<sup>3</sup>/s, respectively. Salami (2009) assessed storm hydrograph techniques for the Lower Niger River basin watershed downstream of Jebba Dam. With the exception of the Snyder and SCS procedures, which have

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comparable values, the statistical analysis at the 5% level of significance revealed considerable disparities among the three methods under consideration: Snyder, SCS, and Grey.

Synthetic unit hydrograph methods are widely used for peak discharge estimation in ungauged basins where observed runoff records are unavailable. Recent studies have demonstrated the continued relevance of classical approaches, such as the Soil Conservation Service (SCS) and Snyder methods, particularly when combined with GIS-based extraction of watershed parameters (Patil *et al.*, 2023; Kesgin, 2025). Comparative evaluations in poorly gauged and ungauged basins have shown that these methods remain effective for preliminary flood assessment and hydraulic design applications (Al-Dughairi, 2023; Casado and López, 2025).

**MATERIALS AND METHODS**

**Description of the study area**

Foma River is located approximately 7 kilometres from the Emir’s Palace in Ilorin, Nigeria, at approximately 8.5°

N and 4.5° E, as shown in Figure 1 (Remote Sensing in Earth Systems Sciences, 2023). Ilorin has a tropical savanna climate characterized by distinct wet and dry seasons. Mean temperatures range between about 34 °C from November to January and increase to approximately 36 °C between February and April (Ajadi *et al.*, 2016; NiMet, 2020). The total annual rainfall in the area varies from approximately 990.3 mm to 1318 mm (Ajadi *et al.*, 2016; Olaniran, 2002). The river flows freely during rainfall and slows during the dry season (Ayansola and Salami, 2009). The feasibility study indicates that the river has its origin at Wahri, along Gerewu, Ilorin West Local Government Area of Kwara State. It joined the Asa River at a point called Ibu-Afonja, beneath the Sobi Rock, in Ilorin South, Kwara State. The river’s catchment area is calculated as 30.31 km<sup>2</sup> (Figure 1). The river, especially during the rainy season, overflows its banks, which, over the years, have resulted in several kilometres of floodplains. Table 1 shows the watershed characteristics of the Foma river.

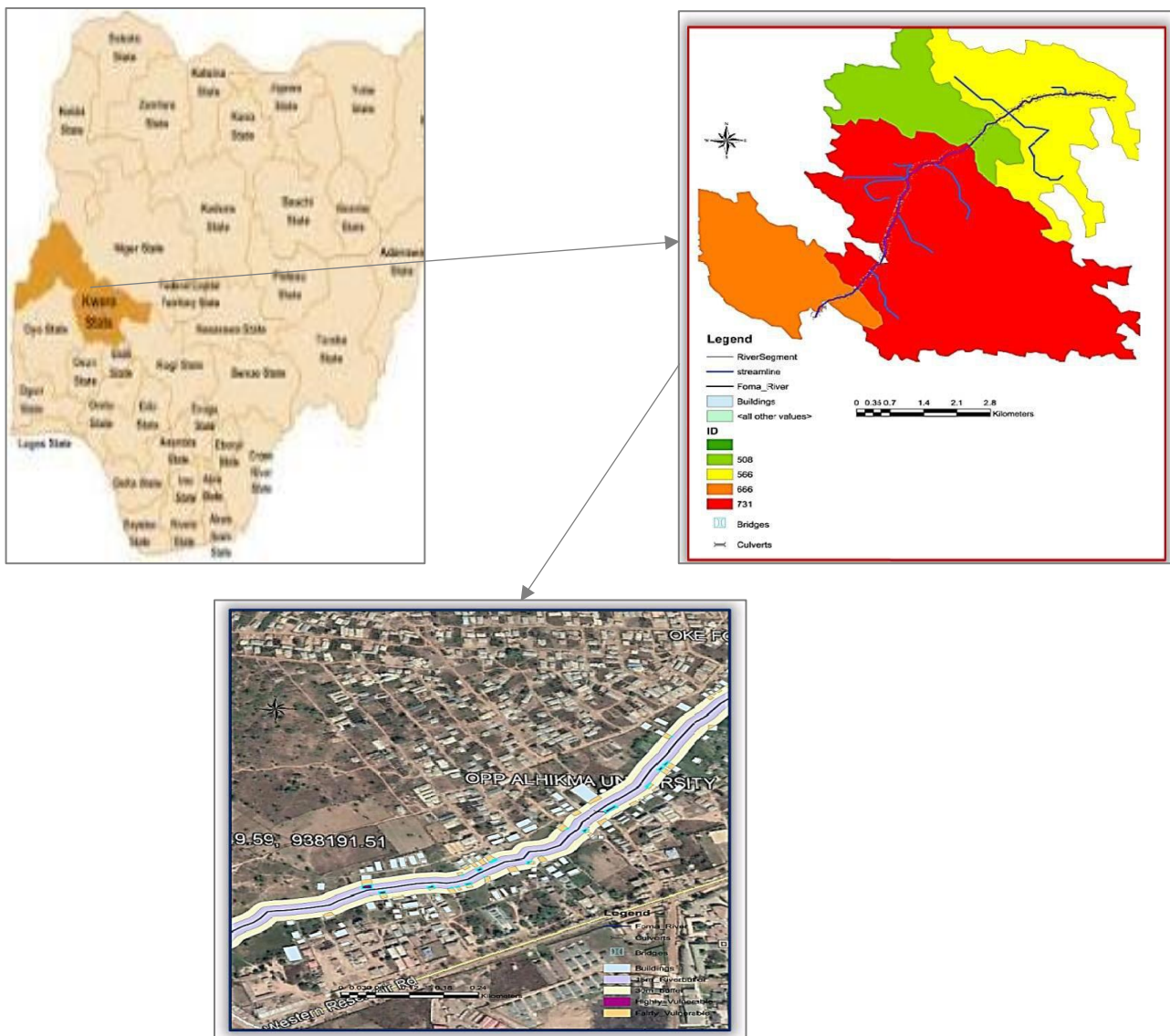


Figure 1: The Study Area

**Table 1: Catchment characteristics of Foma river**

Watershed	L (km)	L <sub>c</sub> (km)	A (km <sup>2</sup> )	S <sub>c</sub> (m/m)
Foma river	10.65	4.20	30.31	0.00722

Where;

L = The river channel length (Km)

L<sub>c</sub> = The river length from the outlet to a point near the centroid (Km)

A = Watershed area (Km<sup>2</sup>)

S<sub>c</sub> = Slope of river channel (m/m)

**Table 2: The parameters applied for the generation of the unit hydrograph (SCS Method)**

River Watershed	L (km)	A (km <sup>2</sup> )	S <sub>c</sub> (%)	T <sub>C</sub> (hr)	T <sub>I</sub> (hr)	T <sub>P</sub> (hr)	Q <sub>P</sub> (m <sup>3</sup> /s)
Foma River	10.65	30.31	0.00722	8.38	5.026	5.59	11.28

**Table 3: Unit hydrograph by SCS Method**

T (hr)	0.00	2.79	5.59	8.39	11.18	13.98	16.77	19.57	20.36	25.16	27.95
Q <sup>p</sup> (m <sup>3</sup> /s)	0.00	4.85	11.28	7.44	3.61	1.47	0.85	0.41	0.20	0.10	0.05

**Table 4: Estimated rainfall excess of Foma River for 20yr, 24-hr storm at P =174.17 mm**

Time (hr)	Precipitation Ratio (P*/24)	Precipitation P** (mm)	Cumulative Rainfall Excess Q <sub>d</sub> (mm)	Incremental Rainfall Excess (mm)	cm
(20-yr., 24-hr)			174.17	mm	
0	0.0000	0.0000*	0.0000	0.0000	0.0000
3	0.0350	6.0960*	0.0000	0.0000	0.0000
6	0.0800	13.9336*	0.0000	0.0000	0.0000
9	0.1470	25.6030	0.0000	0.0000	0.0000
12	0.6630	115.4747	52.9930	52.9930	5.2993
15	0.8540	148.7412	80.2451	27.2521	2.7252
18	0.9210	160.4106	90.2203	9.9752	0.9980
21	0.9650	168.0410	96.8623	6.6421	0.6642
24	1.0000	174.1700	102.1920	5.3287	0.5330

\* P\*\* < I<sub>a</sub>

**Table 5: Estimated rainfall excess of Foma River for 50yr, 24-hr storm at P =205.36 mm**

Time (hr)	Precipitation Ratio (P*/24)	Precipitation P** (mm)	Cumulative Rainfall Excess Q <sub>d</sub> (mm)	Incremental Rainfall Excess (mm)	cm
(50-yr, 24-hr)			205.36	Mm	
0	0.0000	0.0000	0.0000	0.0000	0.0000
3	0.0350	7.1876	0.0000	0.0000	0.0000
6	0.0800	16.4288	0.0000	0.0000	0.0000
9	0.1470	30.1879	0.0000	0.0000	0.0000
12	0.6630	136.1537	69.7025	69.7025	6.9703
15	0.8540	175.3774	103.2522	33.5493	3.3550
18	0.9210	189.1366	115.4315	12.1793	1.2179
21	0.9650	198.1724	123.5188	8.0873	0.8087
24	1.0000	205.3600	128.9967	6.4779	0.6478

**Estimation of synthetic unit hydrograph ordinate using SCS and Snyder methods**

The Soil Conservation Service (SCS) and Snyder's methodologies were the two approaches used to develop the synthetic peak runoff hydrograph. The SCS and Snyder synthetic unit hydrograph methods were adopted in this study due to their widespread application and proven suitability in ungauged watersheds. Recent applications have demonstrated their robustness in estimating peak runoff hydrographs using basin morphometric characteristics derived from GIS data (Patil

*et al.*, 2023; Kesgin, 2025). Similar methodological frameworks have been successfully employed in arid and semi-arid ungauged basins, yielding reliable peak discharge estimates for design storm events (Al-Dughairi, 2023).

**The Soil Conservation Service (SCS) approach**

In accordance with Viessman *et al.* (1989), the Soil Conservation Service (SCS) used a dimensionless hydrograph as the basis for their method of creating synthetic unit hydrographs. This method involved determining the catchment slope S, concentration time t<sub>c</sub>,

peak time  $t_p$ , and peak flow  $Q_p$ . As previously stated, the catchment properties encompass the basin's area, slope, orientation, shape, altitude, and stream pattern. The annual peak daily rainfall event over the watershed was applied to develop runoff hydrographs using the estimated synthetic unit hydrograph method under the SCS approach. The parameters listed in Table 2 for creating a unit hydrograph using the SCS approach are shown in Table 3.

**Rainfall excess estimation for the catchment area under varying return periods**

Equations 1 to 4 were applied to calculate rainfall excess, and additional parameters employed included rainfall depth at varying return periods and the curve number (CN), with reference to the research area's soils and land use (Plamonia et al. 2025).

$$Q = \frac{(R^{**} - I_a)^2}{(R^{**} + 0.8S)} \tag{1}$$

$$I_a = 0.2 * S \tag{2}$$

$$R^{**} = \frac{R^*}{24} * R_T \tag{3}$$

$$S = \frac{25400}{CN} - 254 \tag{4}$$

Where,

$R^{**}$  = The accumulated rainfall (mm)

$R_T$  = The catchment's area rainfall recurrence interval (mm)

$R^*$  = The precipitation ratio,  $\frac{P_x}{P_{24}}$

$S$  = Total storage volume (mm)

$CN$  = Runoff curve number (Based on the hydrologic soil group B and land use (Agriculture), the  $CN$  value of 75 was chosen (Plamonia et al. 2025).

Tables 4 and 5 present the estimations of rainfall excess at varying return periods when  $CN$ ,  $S$ , and  $I_a$  are 75, 84.67 and 16.93, respectively.

**The Snyder's Approach**

Snyder's approach uses the watershed's specific features to estimate the peak discharge, lag time, and time to peak. According to Viessman et al. (1989), the hydrograph's features include the lag time ( $T_L$ ), peak discharge ( $Q_p$ ), and effective rainfall duration ( $T_r$ ). These correlations allow the calculation of the five required unit hydrograph features for a specific effective rainfall duration. The basin lag  $T_L$ , the base time  $T_b$ , the peak discharge per unit of watershed area  $Q'_p$ , and the widths  $W$  of the unit hydrograph at 50 and 75 % of the peak discharge are the five characteristics. Ayansola and Salami (2009) used these relationships to generate five characteristics of a unit hydrograph required for a given effective rainfall duration using equations 5–12.

*Estimation of the Lag time ( $T_L$ )*

The lag time  $T_L$  calculated through the use of equation (5) as stated below;

$$T_L = C_t (L * L_c)^{0.3} \tag{5}$$

Where;

$T_L$  is the lag time (hr), and  $C_t$  is a coefficient that denotes variations in watershed slope and storage.

The values of  $C_t$  range from 1.0 to 2.2 (Arora, 2004) and the mean value of 1.60 was applied.

*Estimation of Unit-hydrograph duration,  $T_r$  (Storm duration)*

The storm's duration was estimated using equation (6).

$$T_r = \frac{t_l}{5.5} \tag{6}$$

The new unit hydrograph storm duration ( $t'_r$ ) and the accompanying basin lag time ( $t'_l$ ), however, can be calculated from equation (7) in the event that longer storm durations are planned to be achieved for the catchment.

$$t'_r = t_l + \left( \frac{t_l - t_r}{4} \right) \tag{7}$$

*Estimation of peak discharge,  $Q'_p$*

The peak discharge ( $Q'_p$ ) can be derived from equation 8 below;

$$Q'_p = \frac{2.78 * C_p * A}{t'_l} \tag{8}$$

Where;

$C_p$  is the coefficient representing the flood wave and storage condition ranges from 0.30 to 0.93 (Arora, 2004) with an average of 0.62.

*Estimation of Base time,  $T_b$*

Equation (9) was applied for calculating the base time ( $T_b$ ) in days;

$$T_b = 3 + 3 \left( \frac{t'_l}{24} \right) \tag{9}$$

*Estimation of Time width,  $W$*

The time width  $W_{50}$  and  $W_{75}$  of the hydrograph at 50% and 75% of the height of the peak flow ordinate in an hour, estimated from equations 10 and 11, respectively, by the US Army Corps of Engineers (Arora, 2004).

$$W_{50} = \frac{5.9}{(q'_p)^{1.08}} \tag{10}$$

$$W_{75} = \frac{3.4}{(q'_p)^{1.08}} \tag{11}$$

*Estimation of Peak discharge per area,  $q'_p$*

Equation 12 provides the peak discharge per area (cumec/km<sup>2</sup>);

$$q'_p = \frac{Q'_p}{A} \tag{12}$$

These parameters were substituted to derive the unit hydrograph and results obtained by Snyder’s method were presented in Tables 6 and 7.

**Peak runoff hydrograph estimation using convolution**

The convolution equations developed by using equation 16 to compute the direct runoff ( $Q_n$ ) by multiplying unit

hydrograph ordinates from the catchment (U) and incremental rainfall excess (R), adding and lagging them in sequence as stated in equations 13-16, are used to develop the design runoff hydrographs for selected rainfall events with recurrence intervals of 20 and 50 years.

The direct runoff hydrograph's first ordinate results solely from  $R_1$ 's effective rainfall pulse (Chow et al., 1988; Subramanya, 2013).

**Table 6: Parameters for the generation of unit hydrograph (Snyder’s method)**

River Watershed	L (km)	L <sub>C</sub> (km)	A (km <sup>2</sup> )	T <sub>1</sub> (hr)	T <sub>r</sub> (hr)	T <sub>1</sub> <sup>*</sup> (hr)	Q <sub>p</sub> <sup>*</sup> (m <sup>3</sup> /s)	T <sub>b</sub> (hr)	W <sub>50</sub>	W <sub>75</sub>
Foma River	10.65	4.20	30.31	5.00	0.91	5.03	10.40	87.12	34.7	106.68

**Table 7: Unit hydrograph by Snyder’s Method**

<b>T (hr)</b>	0.00	2.57	5.03	8.34	12.30	15.92	17.34	21.08	28.01	30.32	30.70
<b>Q<sub>p</sub>(m<sup>3</sup>/s)</b>	0.00	5.12	10.40	6.02	5.38	4.09	3.93	2.04	1.24	0.13	0.00

$$Q_1 = R_1 U_1 \tag{13}$$

The second ordinate is calculated from the effective rainfall of  $R_1$  and  $R_2$

$$Q_2 = R_2 U_1 + R_1 U_2 \tag{14}$$

The third ordinate is given by

$$Q_3 = R_3 U_1 + R_2 U_2 + R_1 U_3 \tag{15}$$

The excess rainfall ordinates are  $R_1, R_2, R_3, R_4$  and  $R_5$  while the unit hydrograph ordinates are  $U_1, U_2, U_3, U_4, U_5, U_6, U_7, U_8, U_9, U_{10}$  and  $U_{11}$  combined to generate equation (16).

Generally, the peak runoff ordinate is obtained using equation 8;

$$Q_n = R_1 U_n + R_2 U_{n-1} + R_3 U_{n-2} + R_4 U_{n-3} + R_5 U_{n-4} \tag{16}$$

Where;

R = incremental rainfall excess (cm),

U = unit hydrograph ordinate (m<sup>3</sup>/s/cm).

**Gumbel Extreme Value Type I (EV-I) distribution**

Rainfall depths corresponding to selected return periods were estimated using the Gumbel Extreme Value Type I (EV-I) probability distribution as depicted in equations 17 and 18. The distribution was applied to annual maximum rainfall series to determine design rainfall magnitudes for different recurrence intervals. The estimated rainfall depths were subsequently used as inputs for the computation of rainfall excess, which served as the basis for runoff and unit hydrograph analysis.

Rainfall depths corresponding to selected return periods were estimated using the Gumbel Extreme Value Type I distribution, which is commonly applied in rainfall and flood frequency analysis for design-oriented applications when data availability is limited (Badou et al., 2021).

**Gumbel frequency equation**

$$X_T = \bar{X} + K_T \sigma \tag{17}$$

where:

$X_T$  - rainfall magnitude corresponding to return period T,

$\bar{X}$  - mean of the annual maximum rainfall series,

$\sigma$  - standard deviation of the series,

$K_T$  - Gumbel frequency factor.

**Gumbel frequency factor**

$$K_T = \frac{\sqrt{6}}{\pi} \left[ \ln \left( \ln \left( \frac{T}{T-1} \right) \right) \right] \tag{18}$$

where:

T = return period (years).

**RESULTS AND DISCUSSIONS**

The peak runoff hydrograph generated for the Foma river watershed for 20-yr and 50- yr return periods using SCS and Snyder’s synthetic unit hydrograph approaches is depicted in Figures 3 and 4. These show the variations between the SCS and Snyder’s method. The Gumbel Extreme Value Type 1 distribution was applied to obtain storm depth values for 20-yr and 50-yr return periods, with values of 174.17 mm and 205.36 mm, respectively.

Figure 3 shows that the peak runoff hydrograph estimate occurred over a short duration, ranging from 68.0 m<sup>3</sup>/s to 112.0 m<sup>3</sup>/s, for the Foma River using the SCS method. Figure 4 indicates that the peak runoff hydrograph using Snyder’s method ranged from 70.0 m<sup>3</sup>/s to 90.0 m<sup>3</sup>/s for the Foma River. From the above, it is shown that the peak runoff hydrograph estimate for the SCS method is close to that of Snyder's method. The results also indicated that peak runoff occurred over a short duration and at a low discharge magnitude for the Foma River.

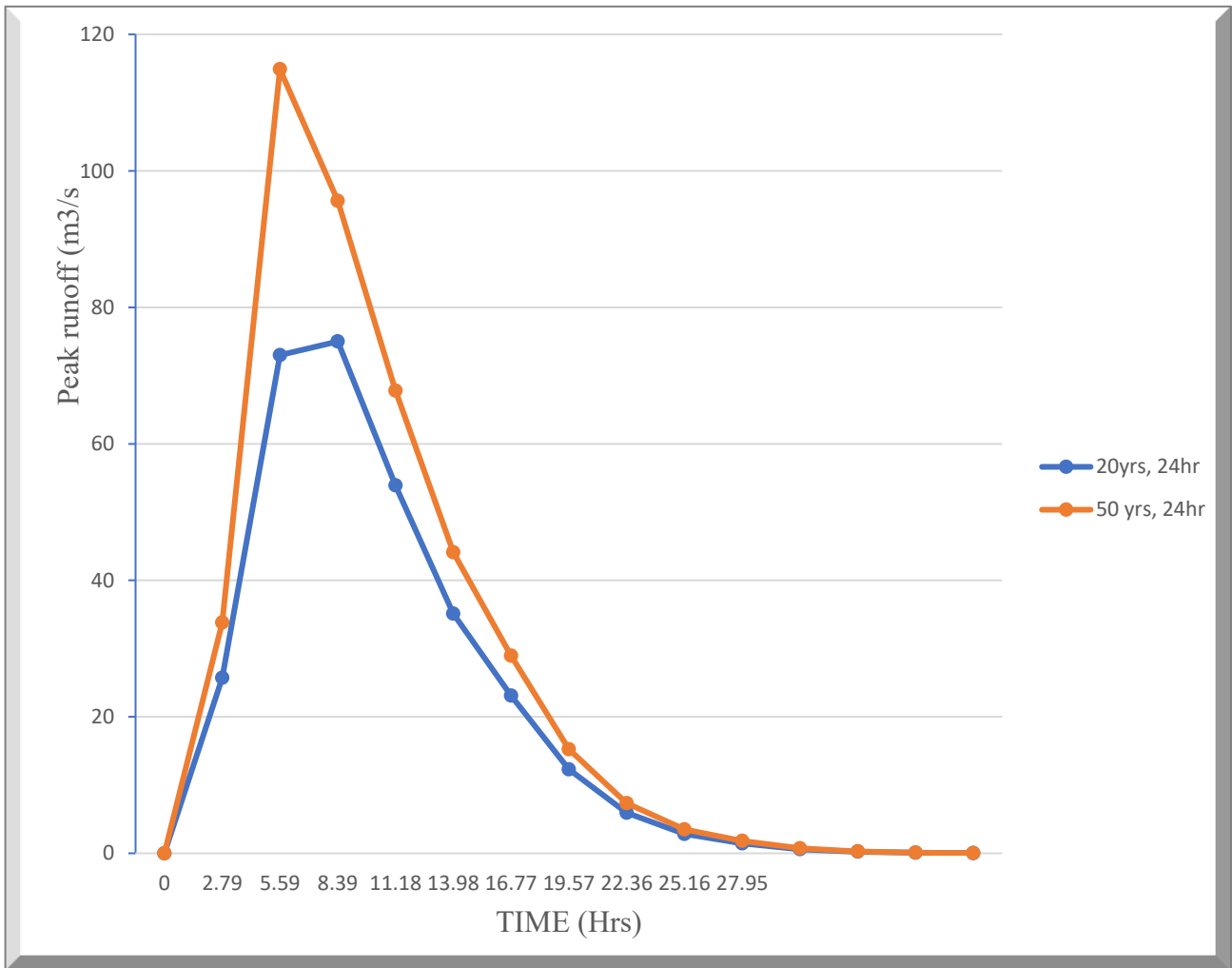


Figure 3: Runoff hydrographs of different return periods generated from unit hydrograph (SCS method)

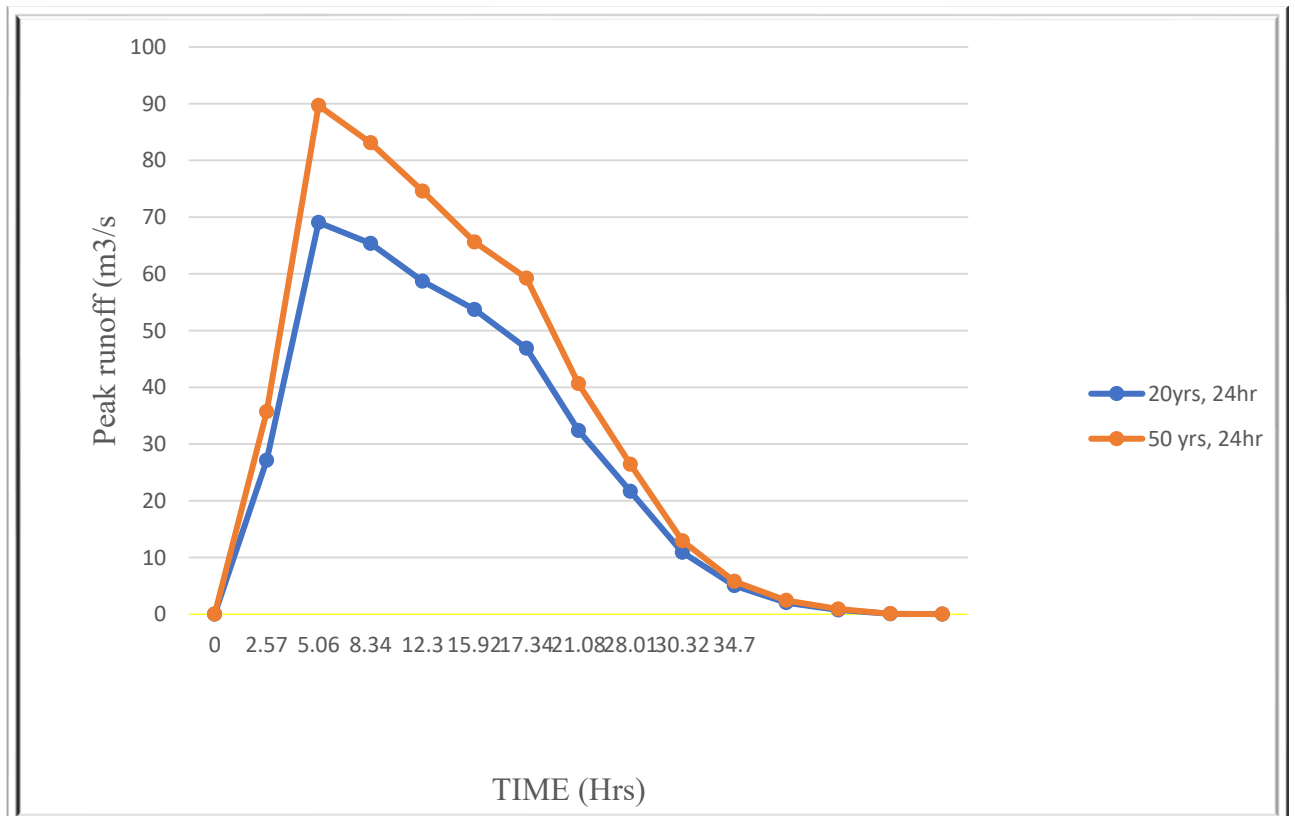


Figure 4: Runoff hydrographs of different return periods generated from unit hydrograph (Snyder method)

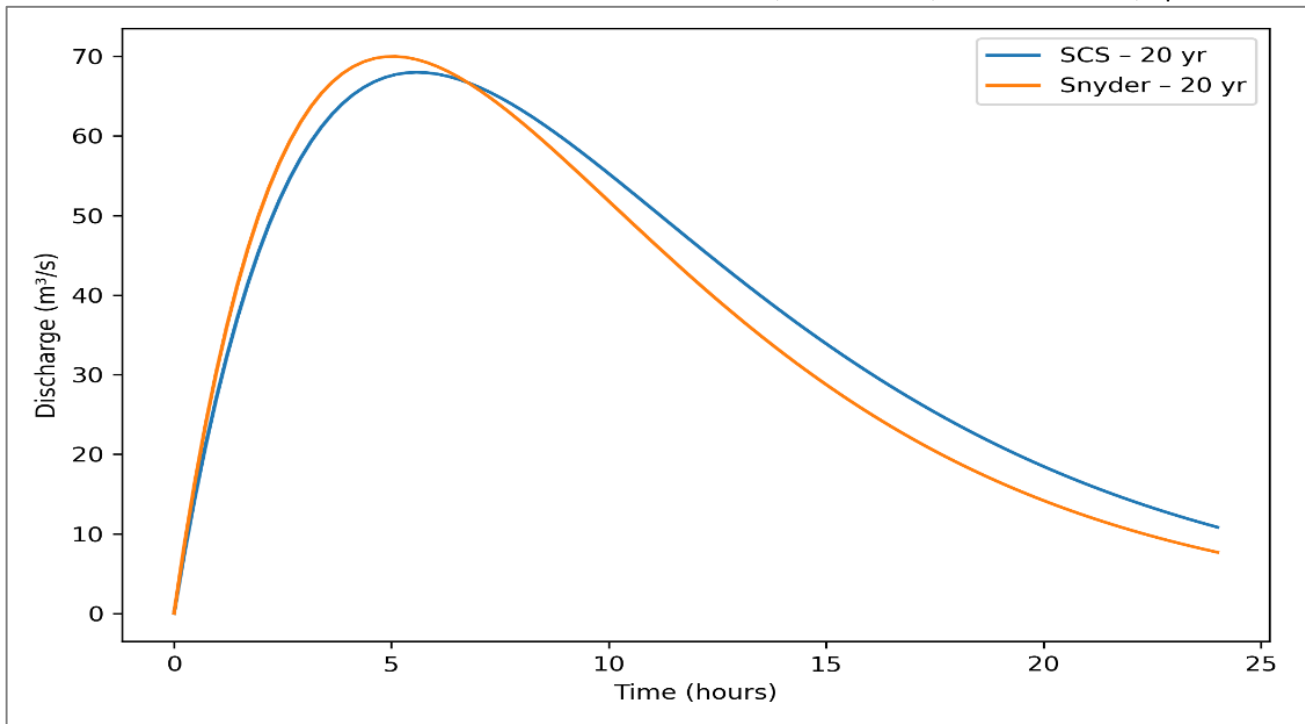


Figure 5: Peak runoff hydrographs for the 20-year return period of SCS and Snyder synthetic unit hydrograph methods

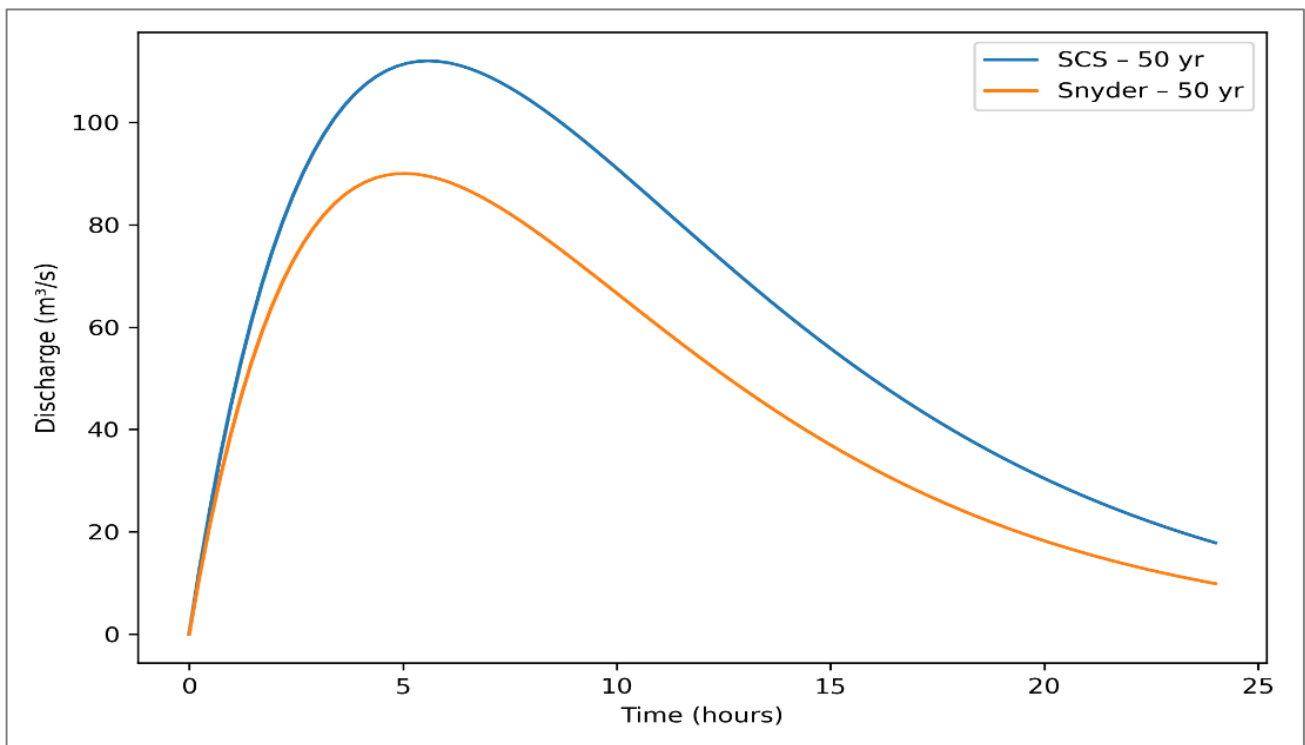


Figure 6: Peak runoff hydrographs for the 50-year return period of SCS and Snyder synthetic unit hydrograph methods

The 20-yr, 24-hr storm hydrograph discharges are 68.0 m<sup>3</sup>/s and 70.0 m<sup>3</sup>/s for the Foma River using both the SCS and Snyder methods. The percentage difference between the two estimates was approximately 2.86%, indicating close agreement between the methods for moderate storm events. This suggests that both approaches yield comparable peak runoff estimates under lower-return-period conditions (Figure 5). The 50-yr, 24-hr storm hydrograph discharges were 90.0 m<sup>3</sup>/s and 112.0 m<sup>3</sup>/s for the Foma river for both SCS and Snyder's

methods, also for the same return period; however, the SCS method produced a significantly higher peak discharge of 112.0 m<sup>3</sup>/s compared to 90.0 m<sup>3</sup>/s obtained using the Snyder method, representing a percentage difference of approximately 24.4%. This divergence indicates that the SCS method is more sensitive to increases in storm magnitude and return period, producing sharper and higher peak flows than the Snyder approach (Figure 6).

Figures 5 and 6 present schematic runoff hydrographs constructed for comparative purposes using the estimated peak discharges and time-to-peak values derived from the SCS and Snyder methods. These hydrographs are intended to illustrate relative differences in hydrograph shape, peak magnitude, and timing between the two approaches align with WMO (2009b) guidance for ungauged basins.

The stronger response of the SCS method can be attributed to its explicit consideration of watershed land use and soil characteristics through the Curve Number (CN) parameter, which directly influences rainfall excess generation. In contrast, the Snyder method relies on regional coefficients and basin geometry, resulting in a comparatively attenuated hydrograph response, particularly for extreme rainfall events similar to the findings reported by Salami (2009) and Ogunlela and Kasali (2002), who observed that SCS-based hydrographs generally produce higher peak flows than Snyder-based hydrographs for the same watershed conditions.

Overall, the results indicate that the SCS synthetic unit hydrograph method is more responsive to high-magnitude storm events and may therefore be more suitable for flood estimation and hydraulic structure design in the Foma River watershed, while the Snyder method remains useful for preliminary assessments and comparative analysis. The comparative hydrographs generated using the SCS and Snyder methods indicate close agreement for the 20-year return period, while greater divergence is observed for the 50-year storm event. Similar findings have been reported in recent comparative studies, where SCS-based methods tend to produce higher peak discharges under extreme rainfall conditions due to their explicit consideration of land use and soil characteristics (Casado and López, 2025; Kesgin, 2025). In contrast, the Snyder method exhibits a more attenuated runoff response, consistent with observations in other ungauged basin studies (Al-Dughairi, 2023).

The observed consistency of both methods across return periods supports previous findings that SCS and Snyder synthetic unit hydrographs remain suitable for runoff estimation in ungauged basins, with method selection largely dependent on storm magnitude and design objectives (Patil et al., 2023; Casado and López, 2025).

## CONCLUSION

The SCS methodology yielded greater peak discharge values than Snyder's method at 50-yr, 24-hr, indicating a substantial difference between the two approaches ( $112 \text{ m}^3/\text{s} > 90.0 \text{ m}^3/\text{s}$ ). In contrast, the SCS method's peak discharge at 20-yr, 24-hr was lower than the Snyder method's ( $68.0 \text{ m}^3/\text{s} < 70.0 \text{ m}^3/\text{s}$ ) result. In order to construct hydraulic structures, both the SCS and Snyder synthetic unit hydrograph methods demonstrated hydrologically consistent responses across short and long return periods, with peak discharge increasing monotonically with storm severity. The negligible

difference (2.86%) in peak discharge estimates for the 20-year storm indicates statistical equivalence of the two methods for moderate events, while the divergence observed at the 50-year return period reflects differences in method sensitivity rather than methodological inadequacy. Consequently, both approaches are suitable for estimating watershed parameters required for unit hydrograph development in the ungauged catchment, with method selection dependent on the design return period and application objective.

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