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Synthetic unit hydrograph for ungauged basin using Synder, Taylor-Schwarz model, SCS method by GIS techniques

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ABSTRACT

In hydrology, estimation of the design hydrograph (DH) is a crucial challenge because of lack of rainfall-runoff data. The lack of rainfall-runoff data makes developing credible DHs particularly difficult in small and ungauged basins. A synthetic unit hydrograph(SUH) is a way to represent the flow of water in a stream or river as a single point. It is used to calculate runoff and other hydraulic functions by using watershed characteristics for similar watershed. On the basis of watershed and watershed features or characteristics, equations for estimate of synthetic unit-hydrograph parameters based on rainfall and runoff data for small watersheds were developed. Estimating runoff is a crucial part of river basin planning, development, and management. This paper discusses the application of synthetic unit hydrographs in the Dhamani drainage basin in Maharashtra, India. Traditional method of SUH are used to calculate the peak discharge and time to peak. The calculated discharge by using Synder method, Taylor- Schwarz model, SCS method were compared with each other. In a drainage basin, the relative mean error (RME) and the root of mean square error (RMSE) were compared for selection of better option or to find minimum error method.
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1. Introduction

Sherman created the synthetic unit hydrograph approach in 1922, and it is still commonly used in hydrologic study and synthesis, particularly for un-ganged watersheds. Every watershed should, in theory, have its own unit hydrograph. It would be conceivable to construct a new SUH model that resembles those created by earlier scholars if the physical and hydrological conditions in general are fairly identical[1]. Because SUH Models were researched and created in locations with watersheds that are vastly different from the ones used, they frequently produce erroneous results, affecting the design of the hydro structure. As a result, some parameters for the ideal instances required to be calibrated. SUH can be developed in a variety of ways. Regression analysis is used in one of them[2]. The Synthetic Unit Hydrograph's limiting physical parameters have already been investigated. One of the most difficult problems in practical hydrology is predicting runoff in ungauged or poorly gauged watersheds. As a result, simple runoff estimation methods are especially useful in hydrologic applications like flood design and water balance calculation models[3].(See Fig. 1 Fig. 2 Table 1 Table 2 Table 3).

Rainfall is a natural occurrence that is difficult to manage or modify. The rainfall thickness, rainfall duration, and rainfall distribution in space and time are the three variables of rainfall that are commonly utilised in analysis, prediction, and design. It can be classified as other rainfall variables based on the primary variables, such as rainfall intensity, rainfall probability, or the return period of the rainy event[45]. In technological design, these variables are extremely essential. Rainfall intensity is determined by the duration and frequency with which it occurs, resulting in a range of amounts. There are numerous approaches to calculating rainfall intensity in relation to rainfall duration[6].

More attention has been paid to the water situation in recent years, although no data has been collected in this regard. It is obvious that scientific flood catastrophe plans cannot be implemented without first understanding the geomorphology and hydrology of the watershed. Studies of drainage basins with a focus on geomorphologic factors have an impact on the discharge characteristics of major rivers[7].

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Fig. 1. Digital elevation model DEM.

Table 1
Characteristics of catchment and stream length.

Catchment characteristics	Symbol (SI unit)	Dhamani Basin
Area	A(km2)	148.39
Watershed perimeter	P (km)	49.4
Slope of main channel	Sc (m/km)	0.21
Number of first order stream	N1	445
First order stream length	L1 (km)	285.4
Number of second order stream	N2	122
Second order stream length	L2 (km)	83.4
Number of Third order stream	N3	34
Third order stream length	L3 (km)	63.2
Number of fourth order stream	N4	7
Fourth order stream length	L4 (km)	13.3
Number of fifth order stream	N5	1
Fifth order stream length	L5 (km)	17.8

2. Snyder's synthetic unit hydrograph

Synder was developed the empirical equations for derive unit hydrograph by using watershed characteristics. He considered the length of main stream and length between the outlet to centre of watershed for develop empirical equation for time to peak (tp). Similarly, area of watershed and time to peak considered for the empirical equation of discharge (Qp) and base time. Ct and Cp are non-dimensional constants which are considered for calculation of time to peak and discharge[87].

$$t_p = C_t(LL_c)^{0.3} \quad \text{(i)}$$

$$Q_p = 2.78\left(\frac{A_W C_p}{t_p}\right) \quad \text{(ii)}$$

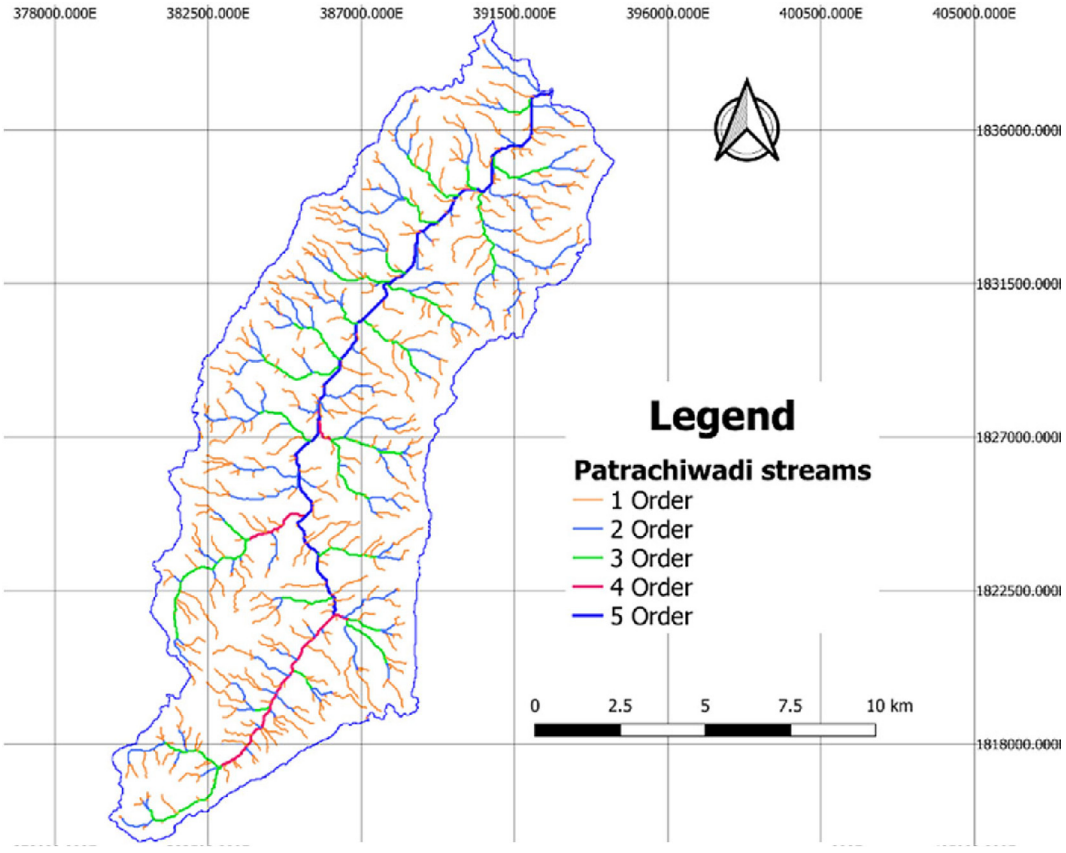


Fig. 2. Drainage network map.

Table 2
Selected event and the peak discharge estimation.

Sr.No.	Date of Event	Precipitation P, (mm)	Discharge (m3/*sec*)			
			Synder	Taylor- Schwarz	SCS	Observed
1	13 June 2004	2.1	32.33	55.45	56.58	25.69
2	10 Sept 2004	1.25	30.13	31.21	32.33	15.64
3	13Oct 2004	1.44	31.1	34.56	35.45	17.25
4	23 June 2005	0.88	22.35	24.58	25.1	10.26
5	14 Sept 2005	2.11	33.45	56.23	57.52	26.32
6	9 Oct 2005	1.25	30.13	53.54	54.23	24.89
7	12 Oct 2005	0.55	21.5	20.28	21.22	9.39
8	15 June 2006	1.2	29.54	51.26	53.85	23.89
9	2 Sept 2006	2.12	33.45	55.55	57.21	24.8
10	18 Sept 2006	1.33	30.35	31.28	33.44	13.25
11	11 Oct 2006	1.89	31.5	46.25	48.35	21.74

Table 3
Comparative study of Root of mean square error (RMSE) and Relative mean error (RME).

Models	RMSE	RME
Synder	10.92	66.02
Taylor- Schwarz	23.54	117.04
SCS	24.903	124.58

$$t_b = 3 + 3\left(\frac{t_p}{24}\right) \quad \text{(iii)}$$

Where, A = Area of the catchment.
L = length of central stream.
tb = Base time,
Lc = Centre of catchment with respect to central stream to outlet point distance.

3. Taylor and Schwarz model

Taylor was proposed the model in 1952. He considered the 20 watersheds for derive equation for SUH (Area of that watershed near about 52–4144 km2). He considered the slope for derive the SUH which is similar to synder model. The slope of ith order stream is used to calculate average slope of main channel by following equation[89]:

$$S_c = \left[\frac{N}{\sum_{i=1}^{N}(1/S_i)^{0.5}}\right]^2 \quad \text{(iv)}$$

$$t_p = \left(\frac{0.6}{S_c^{0.5}}\right)e^{(m_1 D)} \quad \text{(v)}$$

$$Q_p = \left(\frac{382}{(LL_c)^{0.36}}\right)e^{(m_2 D)} \quad \text{(vi)}$$

$$t_b = 5\left(t_p + \frac{t_r}{2}\right) \quad \text{(vii)}$$

Where, N = the total number of reaches.
Si = the slope of the ith reach of the central stream.
Sc = the average slope of the central stream

$$m_1 = 0.212(LL_c)^{-0.36} \quad \text{(viii)}$$

$$m_2 = 0.121S_c^{0.142} - 0.05 - m_1 \quad \text{(ix)}$$

L = length of main stream.
Lc = Centre of catchment with respect to central stream to outlet point distance.

4. Soil conservation service method

Victor Mockus developed the SCS method in 1957. In SCS method, UH considered as a dimensionless UH. Estimation of surface runoff is troublesome as it rely upon many elements. Soil Conservation Service (SCS) Curve Number model is the technique to decide surface runoff. This strategy portrayed by Soil Conservation Services (1986) was advanced for uniform precipitations involving the suppositions for a hydrograph. From this strategy, runoff will be assessed as an element of current soil dampness content, soil condition and the board practice. Not set in stone from the water accessible to enter the dirt before the infiltrations[10]. The SCS arranged a record, which is called as the runoff Curve Number to address the joined hydrologic impact of soil, land use and land cover, horticulture class, hydrologic conditions and precursor soil dampness conditions. These variables can be gotten to from soil review and the site examinations and land use maps, while utilizing the hydrologic model for the plan[11]. The determinations of precursor dampness conditions is in many cases a strategy choice that propose the typical watershed conditions as opposed to acknowledgments of a hydrologic conditions at a specific time and places. Curve number represent as a CN that is 50 to 95. Hydraulic length of watershed is considered for calculation of lag time[8].

$$V = \frac{(q_p t_b)}{2} = \frac{1}{2}q_p(t_p + t_{rc}); \quad \text{(x)}$$

$$Q_p = 0.749\left(\frac{V}{t_p}\right) \quad \text{(xi)}$$

$$t_p = t_L + \left(\frac{t_r}{2}\right) \quad \text{(xii)}$$

$$t_L = \frac{L^{0.8}(2540 - 22.86CN)^{0.7}}{14104CN^{0.7}Y^{0.5}} \quad \text{(xiii)}$$

$$Q_p = 2.08\left(\frac{A}{t_p}\right) \quad \text{(xiv)}$$

Where, V = runoff volume.
tb = time base,
tp = time to peak,
trc = time to recession,
tL = lag time from centroid of excess-rainfall to peak discharge in hour.
tr = excess-rainfall duration for unit duration (hour).

where $t_{rc} = 1.67t_p$ (xv)

5. Material and methods

We need catchment characteristics (such as area, channel slope, and steam length etc.) to compute peak discharge and time to peak using the methods described above. As a result, we evaluated the catchment characteristics using QGIS software and the SRTM DEM. Aim of this paper is to apply the different synthetic unit hydrograph method on Dhamani basin and derive Unit hydrograph. Dhamni basin is located in Kolhapur, Maharastra, India. Daily rainfall data from self-recording rain gauge station at Patrachiwadi were collected from the HDUG, Nashik, India. Dhamani basin located on latitude 16°37′ and longitude 73°59′. Area covered by Dhamani basin is 148.39 km2. Length of main stream is near about 30.29 km. The elevation difference is maximum 955 m and minimum 555 m. Characteristics of catchment are presented in table no.1. In table no 2, the results of each model with comparison of observed discharge are presented as well as graphical representation in Fig. 3.

6. Root of mean square error (RMSE) and relative mean error (RME)

The root of mean square error is the squared root of the mean square error. The relative mean error is equal to one divided by the root of mean square error, which means that it is an absolute value: it tells us how far off we are from an expected value. Root of Mean Square Error is the performance index of peak discharge is introduced in Formula[6]:

$$RMSE = [1/n(\sum_{i=1}^{n} SE_i)]^{\frac{1}{2}} \quad \text{(xvi)}$$

$$SE_i = (Q_{op} - Q_{cp})^2 \quad \text{(xvii)}$$

Where, SEi = the relative error for each event.
Qcp = the calculated peak discharge.
Qop = the observed peak discharge.

Relative Mean Error connection is the performance index which is used for determined peak discharge from noticed peak discharge is introduced in Formula[6].

$$RME = 1/n \sum RE_i \quad \text{(xviii)}$$

$$RE_i = [(Q_{op} - Q_{cp}) * 100]/Q_{op} \quad \text{(xix)}$$

Where, REi = the relative error percentage for each of events.
Qcp = the calculated peak discharge.
Qop = the observed peak discharge.

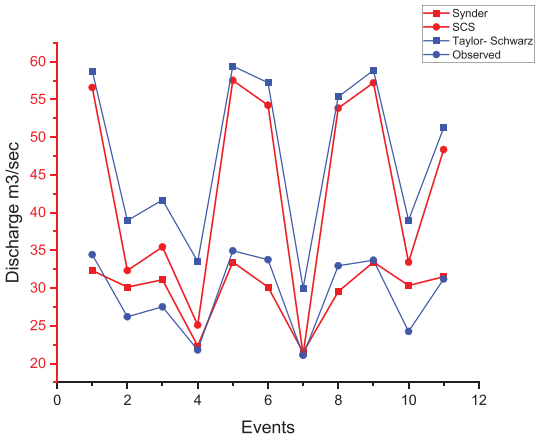


Fig. 3. Observed discharge and estimated discharge.

7. Results and discussion

Data needed for calculations, such as watershed characteristics, are gathered by DEM utilising QGIS software. The unit hydrograph for the Dhamani basin was calculated using rainfall data gathered from the HDUG in Nashik. A benchmark unit hydrograph for the Dhamani basin is used to compare the output of different methods. Traditional approaches are used in this paper to determine the Peak discharge and time for the Dhamani basin. These traditional models—Synder, Taylor- Schwarz, and SCS—are frequently employed in real - life conditions. These models' empirical equations are created while taking the watershed's characteristics into account. Peak discharge and time for the Dhamani basin were computed using that empirical equation.

This work showed how remote sensing and GIS might offer a suitable framework for the connectivity of enormous amounts of transdisciplinary data. In India and other developing nations, many watersheds have lack accurate watershed data and historical records necessary for physically based distributed models. In these situations, Snyder's Synthetic Unit Hydrograph can provide a better solution because the results demonstrate that Snyder's model has the RMSE 10.92 and RME 66.02 values. When comparing the Synder model, Taylor-Schwarz model, and SCS approach, the Synder model offers precision.

8. Conclusion

In this work, it was demonstrated that remote sensing and GIS can provide an appropriate platform for convergence of massive volumes of multidisciplinary data. Many watersheds in India and other developing countries lack the historical records and precise watershed data required for physically based distributed models. In these cases Snyder's Synthetic Unit Hydrograph can give an improved arrangement on the grounds that the outcome show that Snyder's model with the RMSE 10.92 and RME 66.02. Synder model give precision as think about between Synder model, Taylor-Schwarz model, SCS technique.

9. Future scope

Traditional methods were utilized in this study to figure out the peak discharge and peak time. Similar to the Clark-IUH, Nash-IUH, Gray model, and GIUH models (conceptual methods or geomorphological methods) are also employed to generate SUH. To determine the ideal SUH for an ungauged basin, we can compare the outputs of these models against one another.

CRediT authorship contribution statement

Onkar K. Chothe: Methodology, Software, Writing – review & editing. **Vijaykumar Devappa:** Supervision.

Data availability

Data will be made available on request.

Declaration of Competing Interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Onkar Krishnakant Chothe reports was provided by SG Balekundri Institute of Technology. Onkar Krishnakant Chothe

reports a relationship with SG Balekundri Institute of Technology that includes.

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