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DETERMINING PEAK DISCHARGE FACTOR USING SYNTHETIC UNIT HYDROGRAPH MODELLING (CASE STUDY: UPPER KOMERING SOUTH SUMATERA, INDONESIA)

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ABSTRACT: Synthetic unit hydrograph methods are popular and play an important role in many water resources design especially in the analysis of flood discharge of ungagged watersheds. These methods are simple, requiring only watershed characteristics such as area and river length and in some cases it may also include land use characteristics. Therefore, these methods serve as useful tools to simulate runoff from ungagged watersheds and watersheds undergoing land use change. To develop a synthetic unit hydrograph, several techniques are available. Several most popular unit hydrographs methods such as Nakayasu, Snyder-Alexeyev, SCS, and GAMA-1 are popular and commonly used in Indonesia for computing both peak discharge rate and the shape of flood hydrograph. This paper presents a simple approach for determining a consistent dimensionless unit hydrograph based on mass conservation principles. The results for peak discharge in several hydrographs methods are Nakayasu 607.32 m^3/sec, SCS 668.62 m^3/sec, ITB-1 675.42 m^3/sec, ITB-2 642.805 m^3/sec in periode time return 2 years.

Key Words: Synthetic Unit Hydrograph (SUH), Flood Hydrograph, Hydrology, Rainfall, Runoff.

1. INTRODUCTION

Unit Hydrograph (UH) is the most popular and widely used method for analyzing and deriving flood hydrograph resulting from a known storm in a basin area. The term ‘Synthetic’ in synthetic unit hydrograph (SUH) denotes the unit hydrograph (UH) derived from watershed characteristics rather than from rainfall-runoff data [1].

The determination of the pick discharge value and the runoff volume of a watershed are crucial in managing natural disasters and designing and constructing water structures. Therefore different methods have been developed. Dimensionless unit hydrograph developed by United States soil conservation service (SCS) provides a shape to the unit hydrograph and therefore leads to more reproducible results than the Snyder method [2]-[3].

The plotting positions of the SCS dimensionless unit hydrograph are expressed as the ratios t/t_p and Q/Q_p. tp is the time to peak Q_p is the peak discharge. S-curve hydrograph may be defined as the hydrograph of direct runoff resulting from a continuous effective rainfall of uniform intensity 1/D cm/h [4].

Human activities have always been accompanied by changes in land structure, the destruction of natural resources and urban developments. Cosmopolitan developments on the surface of the watershed will be included in the increase in peak discharge and runoff volume of the watershed [2]-[3]. Upper Komering basin is part of Musi River support operational at South Sumatera and it is located in equatorial region with the average annual rainfall is 2000 mm [5]. Estimating the maximum flood discharge is necessary for predicting watershed hydrological behavior. Major problems concerning hydrological predictions include a lack or low accuracy of rain data, high cost, lack of information about catchments and the length of time required to obtain study results [2].

The production and behavior of runoff are functions of land use types and changes. The hydrological response of a river basin is based on the relationship between basin geomorphology (catchments area, shape of basin, topography, channel slope, stream density and channel storage) and its hydrology. Many studies have been carried out on the efficiency of artificial unit hydrographs in Indonesia such as study at Citarum Basin and Upper Ciliwung [6]-[7].

2. STUDY AREA

The Upper Komering watershed an area of about 4260 km^2. The temperate humid climate $28.4^0 – 32.2^0$ C, humidity 80% and ratio sunshine 29%. An average annual rainfall 2602.08 mm, wet season during October-May and dry season during June-September [8]. The area's climate is equatorial region and it’s present at Figure 1.

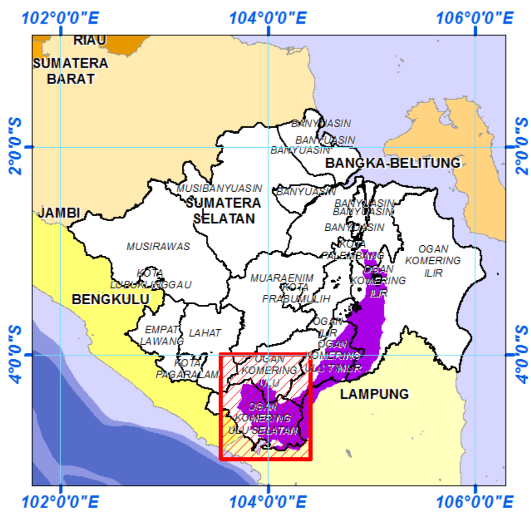

Fig. 1 The location of study area

3. MATERIALS AND METHOD

The study was intended to use methods and models to simulate rainfall-runoff processes in unit hydrograph. In addition, this study attempted to determine the shape and dimensions of outlet runoff hydrographs in a 4260 km^2 area in the Upper Komering Basin, which is located in the South Sumatera Province of Indonesia.

Model Description

SCS Model

The SCS (1957) method computes the runoff volume (V) and peak discharge (q_p) of a triangular hydrograph, respectively, as follows :

$$V- \frac{1}{2} q_p t_a - \frac{1}{2} q_p (t_p + t_e) \quad (1)$$

$$q_p = \frac{3}{4} V/t_p \quad (2)$$

where q_p is peak discharge in mm/h/mm, t_e is the time from peak to the tail end of the hydrograph (1.67t_p), and t_p is in hours (=1/2T + tL). To determine the SUH shape from the non-dimensional q/q_p versus the t/t_p hydrograph, the time to peak (tp) and peak discharge (q_p) are computed as follows :

$$t_p = D/2 + t_L \quad (3)$$

$$q_p = 484A/t_p \quad (4)$$

where D is the duration of rainfall (h), q_p is in cfs A is the area in square miles, t_p is in h (base time = 3/8t_p), and t_L is the lag time from centroid of rainfall to peak discharge (q_p) (h). The t_L can be estimated from watershed characteristics using curve number CN, watershed length, and slope. With known q_p, t_p, and the specified dimensionless UH, an SUH can be derived [1]-[2]-[9]-[10].

Snyder's Model

Snyder (1938) used three parameters, i.e., lag to peak t_L, peak discharge Q_p, and base time t_B, to describe the hydrograph, and these are expressed as :

$$t_L = C_T(L.L_{CA})^{0.03} \quad (5)$$

$$Qp = 640.Cp.A/t_L \quad (6)$$

$$t_B = 3 + 3.(t_L/24) \quad (7)$$

where L is the length of the main stream from the outlet to the catchment boundary in miles, LCA is the distance from the outlet to a point on the stream nearest to the centroid of the catchment in miles, CT is a non-dimensional coefficient, A is the area of the catchment in square miles, C_p is another non-dimensional coefficient, t_L, Q_p, and t_B are in h, ft^3/s (or cfs), and days. The formula hold for rainfall-excess duration $T_D = t_L/5.5$. For varying duration, the lag time is adjusted as: $t_{LR} = t_L + (T - T_D)/4$, where t_{LR} is revised lag time (h) and T is actual T_D. Snyder's method is applicable to fairly large catchments only, e.g., 100– 500 km^2 [1]-[2]-[9]-[10].

SUH ITB Model

SUH ITB model have two basic method SUH ITB-1 and SUH ITB-2 to describe curve hydrograph and these expressed as: SUH ITB -1 has curve equation is computed as :

$$q(t) = \{t^*\exp(1-t)\}^{\alpha Cp} \quad \alpha=3.7 \quad (8)$$

The formula given by (8) is express Incompletee Gamma Function, which is the curve also used by NRCS to defined NRCS SUH curve forms. SUH ITB-2 are computed as follows :

Rising curve ($0 \leq t < 1$):

$$q(t) = t^\alpha \quad \alpha=2.40 \quad (9)$$

Declining curve ($1 \leq t < \infty$) :

$$q(t) = \{t^*\exp(1-t)\}^{\beta Cp} \quad \beta= 0.86 \quad (10)$$

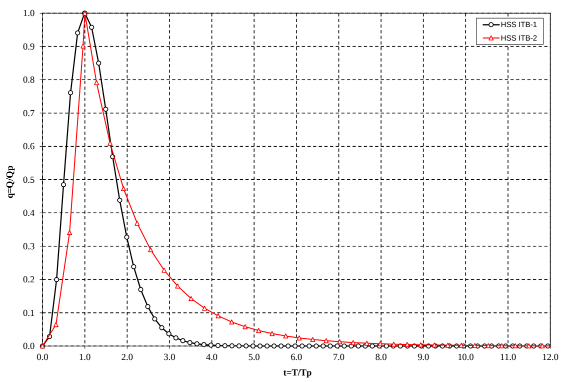

Fig. 2 SUH ITB-1 and ITB -2 dimensionless

Figure 2 describe the horizontal axis is $t = T/T_p$ and the vertical axis $q = Q/Q_p$. Base on SUH definition and mass conversion principle, it can be inferred the effective rainfall volume in watershed, SUH volume should equal with peak time (T_p) so the computation peak discharge derived ITB formula [11]-[12]-[13]. The formula respectively as :

$$Qp = \frac{Kp.R.Aw}{Tp} \text{ m}^3/\text{s} \qquad (11)$$

Qp = Peak discharge unit hydrograph m^3/s
Kp = $1/(3.6\ .\ A_{SUH})$ = peak rate factor $m^3/s/km^2/mm$
R = Rainfall unit in 1.00 mm
Tp = peak time in hour
Aw = Watershed area km^2
A_{SUH}= Dimensionless unit hydrograph area

Nakayasu Model

The Nakayasu method was developed by applying a dimensionless unit hydrograph based on the Horner and Flynt method for estimating design floods in several small urban watersheds of Japan [9]-[14]-[15]-[16]-[17]-[18]-[19].

4. RESULTS AND DISCUSSIONS

Komering river in upper has a catchment area 4260 km^2, effective lenght 180 km. In this study the rainfall datas undertaken from three rainfall station Banding Agung, Muara Dua and Martapura, then peak discharge data undertaken from Perjaya headwork. Table 1 describes of characteristics study area undertaken. Simulated hydrographs were used to observed hydrographs. The model results for peak discharge (q_p) and the time to peak (t_p). From listed in Table 1, were calculated by applying a SUH models and it present in Table 2. Table 3 shows the values of peak discharge. It were computed from rainfall distribution and the values of base flow from dimension unit hydrograph at the first hour 0.034. The peak discharge were computed and the values is 5,131.036 m^3/s. In addition, similarities were observed for the outlet runoff volume parameter in SCS, Snyder, ITB-1 and ITB-2. Triangular and comparisons have proven the difference among UH not significant and it presents in Table 4.

Table 1 Characteristics of Upper Komering area

Name	Remarks
Basin	Upper Komering
Catchment area	$A = 4260\ km^2$
Lenght	L = 180 km
Height unit Rainfall	R = 1.00 mm
Duration	Tr = 1.00 hour
Time coeff.	Ct = 1.00
Time lag	Tl = 18.32 hours
Peak time	Tp = 17.73 hours

Base time	Tb = 177.3 hours
Peak coeff.	1.00
Alpha	2.00
SUH area	1.3161
Qp	50.7 m^3/s
Rainfall volume	4,260,000 m^3

Table 4 Peak discharge values in all method

Time return (year)	QT (m^3/s) Nakayasu	SCS	ITB-1	ITB-2
2	607,315	668,617	675,420	642,805
5	844,157	977,715	978,548	913,429
10	1045,578	1218,335	1220,946	1128,841
20	1267,438	1481,886	1486,444	1481,886

Table 4 defines the hydrograph dimensions in the study basin using the Snyder, SCS and ITB methods. The results demonstrate that a comparable level of performance was achieved for all methods and it describes in Figure 3. Peak discharge hydrographs were similar and showed negligible errors, but the hydrographs differed more noticeably for peak discharge.

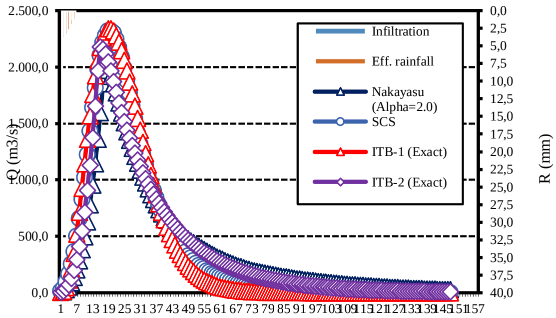

Fig. 3 The hydrograph in the study area

5. CONCLUSION

This study has determined that, compared to other models, to defined the model which is the most efficient model to use in determining peak discharge. The results demonstrate peak discharge hydrographs were similar. The proposed parameter estimations methods are simple to use, and gives accurate results of the actual as verified using simulation and field data.

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Table 2. Dimensionless and dimension unit hydrograph of Upper Komering River

i	T (hours)	Dimensionless unit hydrograph			Dimension unit hydrograph	
		t = T/Tp	q = Q/Qp	A	Q (m^3/s)	V (m^3)
	(1)	(2)	(3)	(4)	(5)	(6)
0	0.00	0.0000	0.0000	0.0000	0.0000	0.0000
1	1.00	0.0564	0.0007	0.0000	0.0335	60.3146
2	2.00	0.1128	0.0074	0.0002	0.3743	734.0876
3	3.00	0.1692	0.0277	0.0010	1.4054	3203.5774
4	4.00	0.2256	0.0666	0.0027	3.3769	8608.2457
5	5.00	0.2819	0.1253	0.0054	6.3533	17514.2962
6	6.00	0.3383	0.2020	0.0092	10.2395	29867.0299
7	7.00	0.3947	0.2925	0.0139	14.8319	45128.5658
8	8.00	0.4511	0.3919	0.0193	19.8689	62461.3640
9	9.00	0.5075	0.4946	0.0250	25.0743	80897.7093
10	10.00	0.5639	0.5954	0.0307	30.1882	99472.4853
11	11.00	0.6203	0.6901	0.0362	34.9867	117314.7935
15	15.00	0.8458	0.9510	0.0524	48.2126	169516.7717
89	89.00	5.0185	0.0001	0.0000	0.0056	21.9193
90	90.00	5.0749	0.0001	0.0000	0.0047	18.4722
			A_{SUH}	1.3161		

Table 3. The values of peak discharge

T	UH	Rainfall distribution						(BF)	Qb
Hours	m^3/s	59.84 mm	15.55 mm	10.91 mm	8.69 mm	7.34 mm	0.00 mm	mm	m^3/s
0.00	0.000	0.000						0.034	0.034
1.00	0.034	2.005	0.000					0.034	2.039
2.00	0.374	22.399	0.521	0.000				0.034	22.953
3.00	1.405	84.101	5.822	0.366	0.000			0.034	90.321
4.00	3.377	202.071	21.859	4.084	0.291	0.000		0.034	228.338
5.00	6.353	380.172	52.521	15.333	3.251	0.246	0.000	0.034	451.557
6.00	10.240	612.724	98.812	36.842	12.208	2.746	0.000	0.034	763.365
7.00	14.832	887.525	159.256	69.314	29.332	10.309	0.000	0.034	1155.769
8.00	19.869	1188.934	230.680	111.713	55.184	24.770	0.000	0.034	1611.315
9.00	25.074	1500.421	309.021	161.816	88.941	46.601	0.000	0.034	2106.833
10.00	30.188	1806.431	389.981	216.769	128.830	75.107	0.000	0.034	2617.152
11.00	34.987	2093.569	469.517	273.561	172.581	108.792	0.000	0.034	3118.053
12.00	39.292	2351.220	544.148	329.353	217.795	145.738	0.000	0.034	3588.288
13.00	42.978	2571.752	611.115	381.705	262.215	183.920	0.000	0.034	4010.741
15.00	48.213	2884.992	714.869	468.888	341.294	256.627	0.000	0.034	4666.705
89.00	0.006	0.333	0.103	0.085	0.081	0.081	0.000	0.034	0.716
90.00	0.005	0.281	0.087	0.072	0.068	0.068	0.000	0.034	0.609
						Peak discharge = 5,131.036 m^3/s			

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