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Correlation of Radial Watershed Physical Parameters to the Unit Hydrograph Time Base

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Abstract: This study intends to investigate the radial watershed physical parameters that affect the unit hydrograph time base. The methodology consists of (1) determining the time base based on the unit hydrograph derived from data rainfall - the single peak of the flood, using the Collin method, (2) identifying the physical characteristics of the radial watershed, using Arc. GIS-based on topography map scale 1:50,000, and (3) investigating the relationship between the radial watershed physical parameters and the unit hydrograph time base, using the Pearson correlation method. The research locations are ten radial watersheds spread across South Sulawesi Province and several watersheds in Java Island. Ten radial watershed physical parameters have been tested. As a result, seven radial watershed physical parameters have a strong (R = 0.60 - < 0.80) to very strong (R ≥ 0.80) correlation, namely (1) topographic factors (T); (2) watershed area (A); (3) watershed perimeter (P); (4) the main river length (L); (5) factor of the main river length and the river length from outlet to nearest the center gravity of the watershed [L.Lc]; (6) river slope (S); (7) the main river length from outlet to nearest the center gravity of the watershed (Lc) and the remaining three parameters, namely upstream area of the watershed (RUA), the ratio between of the main river length and the river length from outlet to nearest the center gravity of the watershed [L/Lc] and drainage density (Dd) have a moderate to low correlation relationship (R < 0.60).

Keywords: radial watershed, time base, unit hydrograph, correlation.

徑向流域物理參數與單位水位圖時基的相關性

摘要: 本研究旨在調查影響單位流量過程線時基的徑向流域物理參數。該方法包括 (1) 根據從數據降雨量 - 洪水的單峰獲得的單位水文過程線確定時基，使用方法，(2) 確定徑向流域的物理特徵，使用。基於地形圖比例尺 1:50,000 的，以及 (3) 使用相關方法調查徑向流域物理參數與單位水文過程線時基之間的關係。研究地點是分佈在南蘇拉威西省的 10 個放射狀流域和爪哇島的幾個流域。已經測試了 10 個徑向流域物理參數。因此，7 個徑向流域物理參數具有很強的（電阻 = 0.60 - < 0.80）到非常強（電阻 ≥ 0.80）的相關性，即（1）地形因素；（2）流域面積；（3）流域周長；（4）主要河流長度；（5）主要河流長度和從出口到最近流域重心的河流長度的因子；（6）河坡；(7) 主要河流從出水口到最近流域重心的長度和其餘 3 個參數，即流域上游面積、主要河流長度與出水口河流長度之比到最接近流域的中心重心和排水密度具有中到低的相關關係 (電阻 < 0.60)。

关键词：径向流域、时基、单位水文图、相关性。

1. Introduction

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Experts divided watershed shapes into three groups, namely (1) elongated watershed, (2) radial watershed, and (3) parallel watershed, in which each watershed shape will respond to the rainfall input and the results hydrograph different [1, 2, 3]. The main characteristic of the elongated watershed is that it only has one main river, where all tributaries flow to the main river and have the characteristics of small but long-period flooding. The radial watershed is characterized by its fan-like shape (wide upstream), and its tributaries are concentrated at one point radially and have high flood characteristics, especially at the rivers' locations. Parallel watershed is characterized by the wide of the watershed, which is almost the same downstream and upstream and has two river lanes that merge downstream.

The watershed response to a unit of rainfall in the hydrological concept is called unit hydrograph, a typical hydrograph for a particular watershed [4, 5, 6]. The unit hydrograph concept has its limitations. It requires a rain-runoff data pair to generate it. For this reason, the lack of data pairs triggered the idea of a synthetic unit hydrograph (SUH) concept [7. 8. 9. 10].

Many experts have developed SUH since it was introduced by Sherman (1932), especially on peak discharge (Qp), time to peak (Tp), and rising & recession limb elements [6, 7, 8, 9, 10, 11]. However, research on a time base (Tb) is still very rare, and none of it has even been associated with aspects of watershed shape. This research exclusively focuses on investigating the radial watershed physical parameters that affect the unit hydrograph time base. Evidence of this proposed study is to understand better the role of the physical watershed to unit hydrograph time base.

2. Materials and Methods

2.1. Research Location

There are two main criteria used to determine the location of this research. The criteria are (1) the shape of the watershed is a radial watershed with watershed area < 1,500 km2; (2) automatic rainfall and discharge data have at least ten years.

Determining the shape of the watershed is used as two indicators, namely the width factor (WF) and the symmetry factor (SIM), which have been documented by [12]. The watershed is radial shape if the WF value > 1 and the SIM value 0.5. The formula and Figure 1 for calculating the width factor and the symmetry factor is as follows:

The width factor (WF)

$$W_F = W_U / W_l \quad (1)$$

The symmetry factor (SIM)

$$RUA = A_u / A \quad (2)$$

$$SIM = WF.RUA \quad (3)$$

where:

WF - width factor (-);
Wu - watershed width at 0.75 L (km);
Wl - watershed width at 0.25 L (km);
RUA - upstream area of the watershed (-);
Au - upstream watershed (km2);
A - watershed area (km2);
SIM - symmetry factor (-).

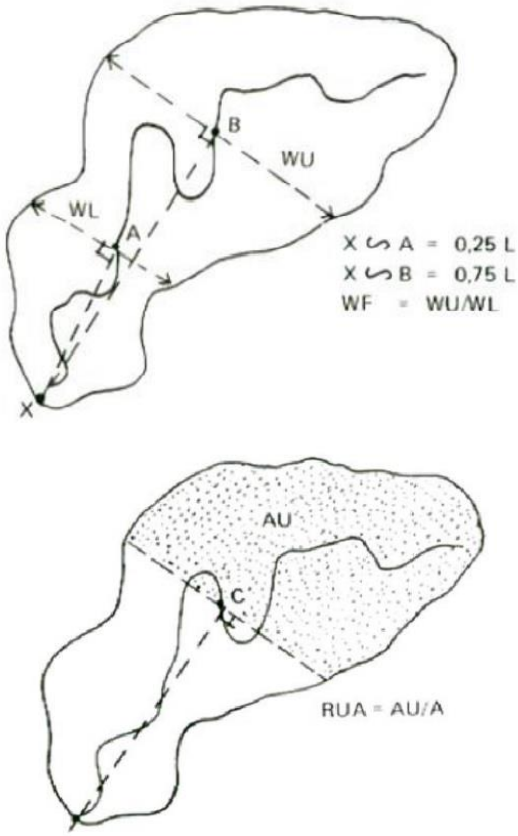

Fig. 1 Determination of WF & RUA parameters [12]

Several watersheds in South Sulawesi Province and several watersheds in Java Island are selected based on the criteria mentioned above. Table 4 shows the details of the watersheds selected as research sites.

Table 1 Research location

No.	Watershed	Area (km2)	Province	With Factor (WF)	Symmetry Factor (SIM)
1.	Bontojai	277.96	Sulawesi Selatan	2.50	1.37
2.	Daraha	26.01	Sulawesi Selatan	4.08	2.36
3.	Jonggoa	128.62	Sulawesi Selatan	1.43	0.74
4.	Kampili	630.43	Sulawesi Selatan	1.67	0.81
5.	Macini Sombala	666.69	Sulawesi Selatan	6.39	2.74
6.	Jenelata	222.95	Sulawesi Selatan	1.62	0.85
7.	Pataruman	1.387.49	Jawa Barat	1.24	0.62
8.	Guwo	170.54	Jawa Tengah	1.19	0.60
9.	Lesti	378.85	Jawa Timur	1.41	0.70
10.	Gadang	692.65	Jawa Timur	1.46	0.71

2.2. Research Methodology

The methods to be used are described in detail, as follows:

1) To obtain the time base data (Tb), a unit hydrograph of observation (UH) is needed, which is

derived from the direct runoff hydrograph. From the UH, a curve shape is obtained, and then the time base (Tb) is obtained. Collin's method is applied to derive UH for each flood case in every watershed. The calculation steps are as follows: (1) to prepare the direct runoff hydrograph; 2) to prepare the effective rainfall and separate the maximum one; 3) to analyze the volume of direct runoff; 4) to try the first ordinate of unit hydrograph regarding the direct runoff; 5) to analyze the multiplication of effective rainfall (except the maximum rainfall) and the trial ordinate of the hydrograph (ΣRe·U), Re = maximum effective rainfall, U = ordinate of hydrograph; 6) to analyze the calibration factor (F) for the next step, F = calibration factor; 7) to analyze the ordinate of estimation unit hydrograph; 8) to analyze the ordinate deviation at the beginning of trial due to the ordinate on the previous step and then it is carried out the return process until there is obtained the smallest deviation; 9) based on the each UH analysis, then there is measured the value of Tb. The value of the watershed time base is found to calculate the average individual time base (Tb).

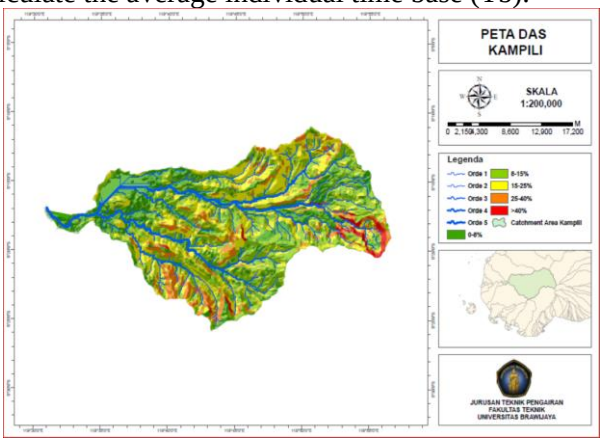

Fig. 2 An example of a research location (Kampili watershed)

2) The physical parameters of the watershed are derived from the Topographic Map scale of 1: 50,000 by using the Arc. GIS. The criteria and formulas used to estimate are as follows:

a. Watershed area (A)

The area surrounded by the ridgeline that demarcates the watershed is called the watershed area. It is estimated by measuring the area directly with the Arc. GIS.

b. Watershed perimeter (P)

The outer boundary of the watershed that surrounds its area is called the watershed perimeter. It is measured along the dividing line between watersheds with the Arc. GIS.

c. The main river length (L)

It is the length of the Main River. The main river is the longest.

d. The main river length from outlet to nearest the center of gravity of the watershed (Lc)

The method of determining the Lc is almost the same as determining the main river length. It is measured starting from outlet to nearest the center of gravity of the watershed. The center of gravity of the watershed is often determined by applying the grid method using Arc. GIS.

e. The factor of the main river length and the river length from outlet to nearest the center of gravity of the watershed [L.Lc]

It is the product of the main river length parameter with the main river length from outlet to nearest the center of gravity of the watershed parameter.

f. The ratio between the main river length and the river length from outlet to nearest the center of gravity of the watershed [L/Lc]

It is the ratio between the main river length parameter with the main river length from outlet to nearest the center of gravity of the watershed parameter.

g. River slope (S)

The slope of the main river (S) is the ratio between the height difference between upstream and downstream of the river and the length of the main river itself.

$$S = \frac{\Delta E_r}{L} \quad (4)$$

where:
S - river slope (-);
ΔEr - height difference between upstream & downstream of the river (m);
L - main river length (m).

h. Topography factor (T)

The topography factor (T) combines the slope factor and the length of the main river. Topography factors are using the Potten method [13].

$$T = \frac{L}{S^{0,5}} \quad (5)$$

where:
T - topography factor (km);
L - main river length (m);
S - river slope (-).

i. Drainage density (Dd)

River density is estimated by the formula below:

$$D_d = L_{tot}/A \quad (6)$$

where:
Dd - drainage density (km-1);
Ltot - total river length (km);
A - watershed area (km2).

j. Upstream area of the watershed (RUA)

It is defined as the ratio between the upstream watershed (Au) and the watershed area (A). Determination of Au parameter following Figure 1 (b), the equation (2) is used to estimate RUA.

3) The statistical correlation analysis identifies watershed physical parameters related to the time base (Tb). The linkage indicator is assessed from the magnitude of the Pearson correlation value (R). The range of R-values between -1 to +1 with the classification is as in Table 2. The value of R is close to 1, meaning that it has a stronger relationship. At the

same time, the positive and negative signs indicate the direction of the relationship, directly or inversely.

Table 2 Classification of correlation coefficients [14]

Classification	Relationship Level
0.000 – 0.199	Very low
0.200 – 0.399	Low
0.400 – 0.599	Medium
0.600 – 0.799	Strong
0.800 – 1.000	Very strong

3. Results and Discussion

3.1. Determining the Unit Hydrograph Time Base

Based on the data from pairs of discharge and rainfall collected, 10 (ten) cases of single peak flooding can be generated in each watershed so that 100 flood cases can be collected in the entire research watershed. Table 3 shows an example of 10 (ten) selected single peak data in the Kampili watershed.

Based on the flood cases above and the rainfall data that caused it, the calculation process is generated to obtain a unit hydrograph for each flood case. Table 4 is an example of a calculation to produce a unit hydrograph (UH) in the case of a flood on Sep 8, 2008.

Table 3 Selected Flood Cases at the Kampili Watershed

No.	Watershed	Flood event	Peak Discharge (m3/s)
1	Kampili	Sep 8, 2008	59.41
		Feb 1, 2009	68.78
		Feb 3, 2010	30.63
		Mar 9, 2011	47.36
		Oct 7, 2012	47.36
		Apr 20, 2013	49.20
		Jan 16, 2014	51.55
		Feb 12, 2015	49.20
		Apr 1, 2016	32.13
		Feb 3, 2017	48.87

Table 4 Unit hydrograph calculation for flood event on September 8, 2008

No	Date	Q Max	Q (Hour)			R (mm)	BF analysis		DRO (m3/dt)	Infil. Index (mm)	Reff (mm)
			Hour	WL	Q (m3/s)		ΔQ start-end	BF rate (m3/dt)			
1	8 Sep 2008	59.41	0	2.00	33.47	1	2.34	33.47	0.00	10.50	0
			1	2.10	35.15	1		33.73	1.41	10.50	0
			2	2.30	38.49	11		33.99	4.50	10.50	0.495
			3	3.55	59.41	1		34.25	25.16	10.50	0
			4	3.34	55.90	5		34.51	21.38	10.50	0
			5	3.10	51.88	10		34.77	17.11	10.50	0
			6	2.65	44.35	3		35.03	9.32	10.50	0
			7	2.40	40.17	1		35.29	4.87	10.50	0
			8	2.30	38.49	7		35.55	2.94	10.50	0
			9	2.14	35.81	1		35.81	0.00	10.50	0

Based on the calculations in Table 4, the resulting number of hydrograph ordinates (excluding zero values at the beginning and ending hours) or n = 8 and the number of effective rainfall hours or j = 1. So that the basic time is obtained Tb = n – 1 + 1 = 8 – 1 + 1 = 8 hours.

In the same way, the time base of the unit hydrograph for the other nine watersheds is estimated. The result is presented in Table 5.

Radial Watershed Physical Parameters

Using Geography Information System (GIS) software and applying Eq. (1) to Eq. (6), the physical parameter of the radial watershed has been estimated. The result is presented in Table 6.

Table 5 Unit hydrograph time base (Tb)

No	UH	Timebase (Tb) (Hour)									
		(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
1	UH-1	3	3	1	8	14	25	17	19	16	20
2	UH-2	1	7	3	10	25	22	15	22	17	19
3	UH-3	3	5	2	6	33	26	31	12	20	21
4	UH-4	4	3	3	10	22	10	26	13	15	14
5	UH-5	1	4	7	8	7	14	29	5	18	16
6	UH-6	4	8	4	10	12	7	23	7	20	11
7	UH-7	7	1	2	7	10	14	23	5	26	15
8	UH-8	3	4	2	10	17	18	16	6	20	17
9	UH-9	4	5	13	7	10	13	26	4	20	5
10	UH-10	7	8	14	4	5	5	25	5	21	18
	Average	3.7	4.80	5.1	8	15.5	15.4	23.1	9.8	19.3	15.6

Note: (1). (2). (3). etc. are the numbers of the research watershed according to Table 1

Table 6 Radial watershed physical parameters

No	Name of watershed	A (Km2)	P (Km)	L (Km)	Lc (Km)	S (-)	T (Km)	Dd (Km-1)	RUA (-)	L.Lc (-)	L/Lc (-)
1	Bontojai	276.26	117.99	36.14	21.88	0.04	177.62	0.90	0.55	790.62	1.65
2	Daraha	25.99	36.56	11.81	7.93	0.10	37.25	3.12	0.58	93.60	1.49
3	Jonggoa	128.53	73.89	21.26	12.81	0.06	86.06	1.76	0.52	272.34	1.66
4	Macini Sombala	661.49	252.95	79.21	54.76	0.02	553.21	0.80	0.51	4337.27	1.45
5	Jenelata	222.95	104.30	34.70	21.43	0.02	221.25	1.50	0.52	743.61	1.62
6	Pataruman	1398.14	297.39	101.97	52.03	0.01	1185.33	0.96	0.50	5304.78	1.96
7	Guwo	250.29	140.35	47.93	23.27	0.02	310.05	0.41	0.50	1115.38	2.06
8	Lesti	378.88	151.96	44.20	21.24	0.04	234.90	0.19	0.49	938.66	2.08
9	Gadang	719.31	216.33	40.40	15.74	0.03	250.04	0.20	0.48	635.70	2.57
10	Kampili	630.10	193.33	60.53	36.43	0.03	371.15	0.78	0.49	2205.00	1.66

3.2. Relationship between the Radial Watershed Physical Parameters and the Time Base

Statistical analysis of the correlation between time base parameter and radial watershed physical parameters was performed. It is used to identify the radial watershed physical parameters that affect the time base (Tb).

Correlation analysis was carried out by applying the Pearson correlation method. It was done based on logarithmic values for the average Tb (Table 5) and the radial watershed physical parameters (Table 6). The results of the correlation are summarized in Table 7.

Table 7 Correlation matrix between time base and radial watershed physical parameters

	A	P	L	Lc	S	T	Dd	RUA	L.Lc	L/Lc	Tb
A	1										.797**
P	.936**	1									.767**
L	.901**	.934**	1								.739*
Lc	.768**	.849**	.950**	1							.647*
S	-0.630	-.755*	-.748*	-.674*	1						-.677*
T	.927**	.853**	.944**	.846**	-0.632	1					.802**
Dd	-0.441	-0.630	-0.490	-0.364	.773**	-0.301	1				-0.262
RUA	-0.547	-.670*	-0.526	-0.382	.735*	-0.391	.843**	1			-0.447
L.Lc	.849**	.862**	.963**	.969**	-0.596	.933**	-0.269	-0.333	1		.721*
L/Lc	0.342	0.347	0.098	-0.173	-0.325	0.121	-.638*	-.649*	-0.105	1	0.274
Tb	.797**	.767**	.739*	.647*	-.677*	.802**	-0.262	-0.447	.721*	0.274	1

** Correlation is significant at the 0.01 level (2-tailed).

* Correlation is significant at the 0.05 level (2-tailed).

Based on Table 7, seven radial watershed physical parameters have a strong (R = 0.60 - < 0.80) to very strong (R ≥ 0.80) correlation, namely (1) topographic factors (T); (2) watershed area (A); (3) watershed perimeter (P); (4) the main river length (L); (5) factor of the main river length and the river length from outlet to nearest the center gravity of the watershed [L.Lc]; (6) river slope (S); (7) the main river length from outlet to nearest the center gravity of the watershed (Lc) and the remaining three parameters, namely upstream area of the watershed (RUA), the ratio between of the main river length and the river length from outlet to nearest the center gravity of the watershed [L/Lc] and drainage density (Dd) have a moderate to low correlation relationship (R < 0.60).

4. Conclusion

Ten radial watershed physical parameters have been tested. As a result, seven radial watershed physical parameters have a strong (R = 0.60 - < 0.80) to very strong (R ≥ 0.80) correlation, namely (1) topographic factors (T); (2) watershed area (A); (3) watershed perimeter (P); (4) the main river length (L); (5) factor of the main river length and the river length from outlet to nearest the center gravity of the watershed [L.Lc]; (6) river slope (S); (7) the main river length from outlet to nearest the center gravity of the watershed (Lc) and the remaining three parameters, namely upstream area of the watershed (RUA), the ratio between of the main river length and the river length from outlet to nearest the center gravity of the watershed [L/Lc] and drainage density (Dd) have a moderate to low correlation relationship (R < 0.60).

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