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Preliminary Assessment of the Morphometric and Hydrological Properties of Six Watersheds in the Eastern Part of East Java

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Abstract. The hydrological process on watersheds is driven by rainfall acting as the input. Physical properties also affect the extent of the response of the watershed to produce run-off. This paper presents the identification, assessment and visualisation of the morphometric and hydrological properties of six watersheds in the eastern part of East Java. Physical characteristics were obtained by cropping the GIS layer with a watershed, while the topographic and morphometric properties of the watersheds were derived from ASTER G-DEM2. In addition, hydrological properties were derived statistically by analysing available rainfall and discharge data; hydrological data (rainfall and discharge) are available for the period 1996 to 2014. Finally, simple statistical analysis by plotting the obtained values was employed to interpret the relationship between the morphometric and hydrological properties of the watersheds. The results show the quantitative number (unit) to describe these properties of the six watersheds that can be used for watershed classification.

Keywords: assessment, hydrological, morphometric, properties, watersheds.

Abstrak. Proses hidrologi di dalam suatu DAS dipengaruhi oleh besarnya hujan yang masuk ke dalam DAS. Karakteristik fisik DAS juga mempengaruhi besar kecil nya respon hidrologi DAS dalam menghasilkan aliran permukaan. Artikel ini memaparkan identifikasi, penilaian dan visualisasi sifat morfometrik dan hidrologis daerah aliran sungai (DAS). Enam (6) DAS di bavian timur dari Jawa Timur digunakan untuk analisis. Karakteristik fisik diperoleh dengan memotong lapisan GIS dengan batas DAS. Kemudian ASTER G-DEM2 digunakan untuk menurunkan sifat topografi dan morfometrik daerah aliran sungai. Selain itu, sifat hidrologis diturunkan secara statistik dengan menganalisis data curah hujan dan debit yang tersedia. Data hidrologi (curah hujan dan debit) tersedia dari tahun 1996 - 2014. Akhirnya, analisis statistik sederhana dengan memplot nilai yang diperoleh digunakan untuk menginterpretasikan hubungan antara sifat morfometrik dan hidrologis dari daerah aliran sungai. Hasilnya menunjukkan angka kuantitatif (unit) untuk menggambarkan sifat morfometrik dan hidrologi dari enam DAS yang dapat digunakan untuk klasifikasi DAS.

Kata kunci: penilaian, hidrologi, morfometrik, properti, daerah aliran sungai.

1. Introduction

Some hydrological models consider and count the physical properties of watersheds (i.e., soil layers, topography, land use and morphometrics) to calculate the run-off produced by rainfall events. One approach is elaborated by classifying watershed properties in a specific manner. This is done by by selecting similar properties of the watersheds and grouping them into categories (classes). However, nature is naturally heterogeneous or diversified and it is probably impossible to find two watersheds that are 100% similar. Nevertheless, some level of variability could be assumed to be similar using certain criteria. Some similarities amongst watersheds may exist in the form of physical, morphometric or hydrological properties. The similarity approach can be used to compare and evaluate watersheds properties, and the similarity concept can also be integrated into the modelling process. Furthermore, by considering the similarity concept, the hydrological process of watersheds can be identified. The physical properties of watersheds consist of form and size, river network, topography, land use, soil and geological layers. Each property is likely to have a substantial impact on run-off production or the rainfall process. Researchers have quantified some of these properties and included them in the modelling process.

Morphometric properties resume the quantitative relation between topography and river networks on the watershed. Interaction among morphometrics, land use and soil layers determines the watershed response when rainfall events occur. Morphometric properties can be used to conduct analysis of groundwater resource potential and to manage the watershed. Many hydrological phenomena have a significant correlation with form and area, slope, drainage density, and other watershed properties. Runoff produced on the watershed also depends on the structure and properties of the river morphometrics and catchment area. Generally, morphometric analysis uses the linear, area and relief aspects of the river network and watershed slope to derive parameters (Pande and Moharir, 2015)from the study, it is concluded that remote sensing data (SRTM–DEM data of 30 m resolution.

Thanks to the advances in GIS, the digital elevation model (DEM), hydro-informatics and remote sensing technology, more morphometrical and other related parameters (such as bifurcation ratio, drainage density, slope factor and soil wetness-index) can be derived automatically. Generally, the input for morphometrical analysis is DEM, which is widely available from many suppliers. For specific resolutions, DEM can be downloaded directly from the develop's website; for example, the ASTER Global Digital Elevation Model (GDEM) v2, which is is a product of NASA and METI. It is available at 30m pixel resolution can be downloaded from (https://asterweb.jpl.nasa.gov/gdem.asp).

The DEM Nasional or DEMNAS (http://tides.big.go.id/DEMNAS/) provides resolution finer than Aster GDEM2; it was developed from many data sources, for example IFSAR (pixel resolution = 5m), TERRASAR-X (pixel resolution = 5m) and ALOS PALSAR (pixel resolution = 11.25m). Masspoint data from stereo-plotting is integrated to produce DEMNAS. The spatial resolution of DEMNAS is 0.27-arcseconds, using vertical data of EGM2008. A DEM can also be produced by the interpolation method from topographical input data, such as the work initiated by Indarto, *et al*., (2009).

Furthermore, DEM is used as an input to determine the watershed boundaries, river network, morphometric parameters, and other indicators relevant to the topography and terrain, hydrology and soil, such as in the work of Tarboton *et al*., 1991. This function is facilitated by various GIS and remote sensing software, such as the Terrain Analysis System (TAS) (Lindsay, 2005) and its successor, Whitebox_GAT (Lindsay, 2016). Other geoscientific software such as SAGA (Conrad *et al*., 2015) (http://saga-gis.org/en/index.html) provides a more detailed function to derive morphometric, terrain and related soil-topographical parameters. Orfeo geoscientific software (https://www.orfeo-toolbox.org/) also provides similar functionality. Both Orfeo and SAGA have been integrated into open source GIS platforms such as Quantum GIS (QGIS) (https://qgis.org/en/site/) and GRASS (https://qgis.org/en/site/). Commercial GIS software (such as ArcGIS) provides a standard hydrological function that can be used to conduct similar tasks. Table 1 lists the 18 morphometric parameters derived from previous studies (Khare *et al*., 2014).

Table 1. Morphoetric parameters, adopted from Khare et al. (2014)

No	Morphometric Parameter	Description	References
	Linear Aspect		
1	Stream order (U)	*Hierarchical order*	Strahler, 1964
2	Stream length (Lu)	*Length of the stream*	Horton, 1933
3	Mean stream length (Lsm)	*Lsm = Lu/Nu, where Lu=Stream length of order; 'U' 1=Stream length of next lower order. 1=Stream length of next lower order.*	Horton, 1933
4	Stream length ratio (Rl)	*Rl=Lu/Lu-1, where Lu=Total stream length of order 'U' Lu-Lu=Total stream length of order 'U',1=Stream length of next lower order.*	Horton, 1933
5	Bifurcation ratio (Rb)	*Rb = Nu/ Nu+1; where Nu=Total number of stream segments of order'u'; Nu+1=Number of segmenst of next higher order*	Schumn,1956
	Relief Aspect		
6	Basin relief (Bh)	*The vertical distance between the lowest and highest points of the watershed.*	Schumn,1956
7	Relief ratio (Rh)	*Rh=Bh/Lb; where Bh=Basin relief; Lb=Basin length*	Schumn, 1956
8	Ruggedness number (Rn)	*Rn = Bh × Dd; where Bh =Basin relief; Dd=Drainage density*	Schumn, 1956
	Areal Aspect		
9	Drainage density (Dd)	*Dd = L/A; where L=Total length of streams; A=Area of watershed*	Horton, 1933
10	Stream frequency (Fs)	*Fs = N/A; where N=Total number of streams; A=Area of watershed*	Horton, 1933
11	Texture ratio (T)	*T = N1/P; where N1=Total number of first-order streams; P=Perimeter of watershed*	Horton, 1933
12	Form factor (Rf)	*Rf=A/(Lb) 2; where A=Area of watershed; Lb=Basin length*	Horton, 1933
13	Circulatory ratio (Rc)	*Rc=4πA/ P2; where A=Area of the watershed,* π=3.14, P=Perimeter of watershed	Miller, 1953
14	Elongation ratio (Re)	*Re=2√(A/π) /Lb; where A=Area of the watershed, π=3.14, Lb=Basin length*	Schumn,1956
15	Length of overland flow (Lof)	*Lof = 1/2Dd; where Dd=Drainage density*	Horton, 1933
16	Constant channel maintenance (C)	*Lof = 1/Dd; where Dd=Drainage density*	Horton, 1933
17	Index infiltration (IF)	*IF=FS X DD; where Stream frequency (Fs), Drainage density (Dd)*	Horton, 1933
18	Compactness constant (Cc)	*Cc = 0.2821 x P/ A0.5; Where, A= Area, P= Basin perimeter, km*	Horton, 1933

These parameters consist of the linear, areal and relief morphometric aspects. The linear aspect considers only one dimensional aspect of morphometric properties (i.e. length). Some examples of a linear aspect of morphometrics are stream order (U), stream length (Lu), mean stream length (Lsm), stream length ratio (RI) and bifurcation ratio (Rb). The areal aspect of morphometrics counts the properties that interact between the linear dimension of the river network and the area dimension of the watershed. Some examples or areal aspects of morphometric properties include drainage density (Dd), stream frequency (Fs), texture ratio (T), form factor (Rf) , circulation ratio (Rc), elongation ratio (Re), length of overland flow (lof), constant channel maintenance (C), index infiltration (IF), basin shape (Bs), and compactness constant (Cc). The relief aspect of morphometrics determines the properties that count the interaction between topography and river networks. Examples of relief aspects are basin relief (Bh), relief ratio (Rh) and ruggedness number (Rn).

Early studies by Horton (1933), Horton dan Robert (1945); Hermingler *et al*. (1993), Miller (1953), Schumn (1956) and Strahler (1964) discuss the importance of each morphometrical parameter for the hydrological processes on the watershed. Further studies conducted by many researchers in India and other parts of the world give examples of how morphometric parameters are derived from RS or GIS Data. Some researchers use morphometrical properties as criteria to determine the priority level for conservation based on morphometric properties (Guth, 2011; Toth, 2013; Rai *et al.*, 2014; Khare *et al.*, 2014; Singh and Singh, 2014;, Umrikar, 2016). The objectives of this study are: (1) to quantify the variability of the morphometric and hydrological properties of the watersheds, and (2) to establish the relationship between these properties.

2. Research Method

2.1 Study Area and Input Data

The research was conducted at the administrative water boundary of Unit Pelaksana Teknis – Pengelolaan Sumberdaya Air (UPT-PSDA) in Lumajang. Six watersheds were studied, namely Rawatamtu, Mayang, Sanenrejo, Wonorejo, Mujur and Sentul, as shown in Figure 1. Table 2 summarises their main physical properties (i.e. area, perimeter, form, range of altitude and outlet location). With a catchment area range of between ~167.74 km^2 to ~700 km^2, the watersheds can be classified in three different forms: wide, triangular and elongated. Their elevation ranges between 20 and 3040 m above sea level.

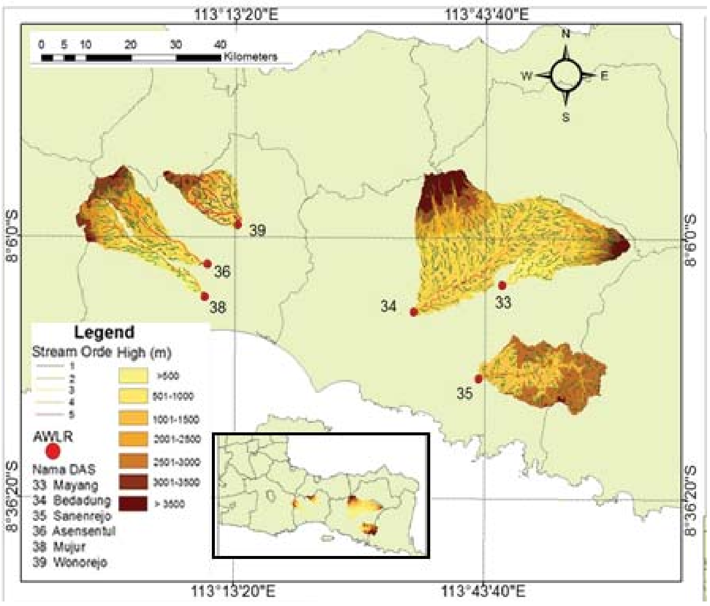

Figure 1. Site location: the six watersheds selected for the study

Table 2. Main physical properties of the watersheds

Form & Area	1_Mayang	2_Bedadung	3_Sanenrejo	4_Mujur	5_Sentul	6_Wonorejo
Area (km^2)	250	673	275.48	137.00	186.04	177.24
Perimeter (km)	80,1	149	83.18	88.8	100.12	81.92
Form	long	Triangle	long	long	wide	wide
Altitude (m)	107-3176	33-3040	20-1207	57-3049	95-2357	60-1569
Outlet location						
X-Coord (E)	113^0 76' 72"	113^0 54'00"	113^0 16' 42"	113^0 23' 57"	113^0 16' 42"	113^0 23' 78"
Y-Coord (S)	8^0 18' 84"	8^0 23' 23"	8^0 36' 66"	8^0 21' 39"	8^0 15' 25"	8^0 08' 09"

Table 3. Length of recording periods available

	1_Bedadung	2_Mayang	3_Sanenrejo	4_Mujur	5_Sentul	6_Wonorejo
Discharge	1996-2014	1996-2011	1996-2001	1996-2013	1996-2013	1996-2014
Rainfall	1997-2013	1997-2013	1997-2013	1997-2013	1997-2013	1997-2013

Seven types of land use dominate the watershed areas: residential use (urban areas), irrigated and non-irrigated paddy, plantation, forest, grass, and other cultivated land. It is noted that in this region the availability of time-series data for hydro-meteorological measurement is generally limited (Table 3).

The daily discharge data from the six outlets over the period 1996 to 2014 were used as input. The length of the data series varies among the watersheds; however, all the available daily discharge data were used for the analysis by assuming that variability due to the different lengths of recording period can be neglected. 136 rainfall measurement sites are located in this region. However, the variability of recording periods varies between 10 to more than 30 years of records. In this case, only selected sites were used for the study. Average daily rainfall data for each watershed were obtained by averaging the daily rainfall data from selected measurement sites located in or close to each watershed boundary. The average daily rainfall data from 1997 to 2013 were then used to describe the characteristics of the rainfall data for each watershed. Furthermore, a DEM for each watershed was extracted from Aster GDEM2 (https://asterweb.jpl.nasa.gov/gdem.asp). The clipped DEM was then used as input to derive the watershed boundary, river network and morphometric properties of the watersheds.

2.2 Procedures

2.2.1 Statistical analysis of hydrological data

First, the daily flow data from the six outlets were used to derive a statistical resume of the daily discharge data: Maximum, Minimum, Mean, Median and Mean daily baseflow (MDBF), and Percentiles 10, 25, 33, 66, 75, 90 and 95% (P10, P25, P33, P66, P75, P90, and P95). The mean and median are measures of central tendency. Mean is calculated as the average of the records (the sum of the values/number of days), while the median is the "middle" value of all the records: it is the value exceeded 50% of the time. For the flow data, the median is usually much lower than the mean daily flow because the distribution of discharge data is negatively skewed, with a lower limit of zero and no upper limit. The percentile value is the value that exceeded a certain percentage of the time. For instance, the 10th percentile is the value that is exceeded by 10% of the records. The statistical distribution values, i.e: Standard deviation (St_Dev), coefficient of variance (Cv), Kurtosis (Ku), Skewness (Skew), Variability (Var), Standard deviation of the log of daily flows (S_Log), Lane Variability Index

(Lane), Base Flow Index (BFI) and Flood Flow Index (FFI) were also calculated to represent the hydrological properties of the daily hydrograph. All the values were calculated using the Time Series Module of the River Analysis Package (Marsh, 2003).

Standard deviation (STDev) is a measure of how the values are dispersed from the mean value; it employs the same units as the input data. The coefficient of variation (Cv) is the division of a mean by the standard deviation value. The Cv of daily flow is the mean of all the daily flow values divided by their standard deviation. Skewness (Skew) is a measure of how different the mean and median are; Skew = mean/median. Skewness can be used to differentiate between catchments with fast and slow storm responses. For a small catchment, the base flow will usually be low, with a dramatic change in discharge during a storm event. Most of the discharge occurs during a storm. However, most days there is low flow. Hence the median flow is low, and the much larger event-based discharges will elevate the mean flow.

As a consequence, the skewness of a small catchment is more important than that of a large one. Similarly, the skewness of an unregulated stream will tend to be higher than that of a regulated stream (depending on the flow release strategy). The measure of variability (Var) used is based on the use of the median as a measure of central tendency. Variability is calculated as the range divided by the median. The user defines the range in terms of the percentile range of flows; the default setting for the range is the difference between the 10th and 90th percentile values.

The standard deviation of the log of daily flows (S_Log) is an estimate of the standard deviation of the logarithm (base 10) of the daily flow values (equation 1). Flow data is often logged to reduce the skew; S_Log is a measure of the distribution of these transformed data, and as such it describes the skew of the input data (Gordon *et al*., 1992).

$$S_{log} = \frac{\log(X_5) - \log(X_{95})}{3.29} \qquad (1)$$

where X5 and X95 are the 5th and 95th percentile values respectively

Lane's variability index (Lanes) is described as the standard deviation of the logarithms of the 5th, 15th, 25th, …., 85th and 95th percentile values. It is unsuitable for data sets with more than 5% zero values (i.e. 95th percentile = 0) or data sets dominated by zeros (Gordon *et al*., 1992).

Another indicator used in this study is an index of variability (Iv), or slope of flow duration curve (Sfdc). One approach to calculating Sfdc is by using a segment of fdc from percentile 33 **(P_{33})** to percentile 66**(P_{66}),** assuming that this segment is relatively linear (McMillan *et al*., 2016; Pallard, e*t al*., 2009; Taylor *et al*., 2009). *Sfdc* is then calculated using equation (2).

$$Iv = Sfdc = \frac{\ln(P_{33\%}) - \ln(P_{66\%})}{(0{,}66 - 0{,}33)} \qquad (2)$$

where :
S_{fdc} = slope of FDC,
$Q_{33\%}$ = flow at percentile 33%, and
$Q_{66\%}$ = flow at percentile 66%.

The steepest slope in the FDC curve shows that the river is subject to high variation in flow regimes. Conversely, a gentle slope in the curve indicates that the flow regime is relatively stable over time (during a year). The stability of the flow regime is formed by the combination of rainfall events that are distributed spatially around the part of the watershed area and the rainfall events that consistently occur during the year. A gentle FDC slope also shows that the contribution of groundwater to the river flow is significant. An example of the use of Sfdc to study river flow regimes was published and applied by Castellarin (2014). Practically, flow duration curve *(FDC)* analysis has been made using Hydro-office and plotted using Excel.

2.2.2 Statistical analysis of rainfall data

The same analysis was also conducted for daily rainfall data. Average data from each watershed were then entered into RAP to calculate several values of statistical resume and distribution, and monthly and annual rainfall were derived from the daily rainfall data using the Time Series Manager Module (TSM) in RAP. Analysis of the rainfall data was made on RAP to obtain related statistical values. Finally, the statistical values obtained from the analysis of daily discharge and rainfall data were compared between watersheds.

2.2.3 Morphometric Watershed Analysis

First, Aster GDEM v2 (http://asterweb.jpl.nasa.gov/GDEM.ASP) was clipped by the watershed boundaries to describe the watershed topography. A series of DEM treatment and watershed delineation was then processed for each watershed. Next, the watersheds areas were derived automatically from the DEM on the top of ArcGIS using the hydrological function. Finally, the main topographical areas of the watersheds were determined automatically from the DEM, and their properties were then compared among the watersheds. Second, the morphometric parameters of each watershed were processed from the DEM using ArcGIS and SAGA (Conrad et al., 2015). Subsequently, 18 morphometric parameters were obtained from these processes (see Table 1). Finally, the morphometric parameters were compared among the watersheds.

2.3 Interpretation

Further analysis using a simple statistical method was performed. This was used to find the possible relationships between the hydrological and morphometric parameters using the data from all the watersheds. Simple correlation based on a coefficient of determination was conducted to find the following relationships: (1) between the morphometric parameters; (2) between the discharge and morphometric parameters; (3) between the discharge and rainfall parameters; and (4) between the rainfall and morphometric parameters. In this case, simple statistical criteria based on the value of standard deviation (StDev) and coefficient of variance (Var) were used to identify the level of variability. If the values of StDev and Coef. Var were lower than << 1, the variability was categorised as "similar", meaning that a certain level of "similarity" existed. Conversely, if the level of variability measured by StDev and Coef. Var was greater than >> 1, then the variability was categorised as "different". Furthermore, these simple criteria were used to compare both the hydro-meteorological and morphometric parameters. This definition of similarity may be vague in other scientific fields; however, because in hydrology the phenomena always vary in space and time, simplification by classifying the level of variability into a single class called "similar" is useful for practical reasons in order to handle irregularities in hydrology.

3. Results and Discussion

3.1 Hydro-meteorological properties

3.1.1 Daily discharge data

The hydrological properties of the watersheds were represented by the values of the statistical variables, as shown in Table 4. Average discharge for all watersheds was recorded at between 4.25 to 32.84 m^3/day. The maximum daily discharge data ranged from 63 to 1049 m^3/day. Mean daily base flow (MDBF) ranged from 2.77 to 15.18 m^3/day. Each watershed showed variability in terms of daily discharge data, as indicated by the maximum, minimum, mean, median, percentile 10, percentile 90, and MDBF values (Table 4). The distribution of the daily discharge data is also different, as indicated by the values of standard deviation, variance and kurtosis.

Other relatively similar statistical values for the daily discharge data of the watersheds are coefficient of skewness (skew), coefficient of variability (Var), S-Log, Lane's variability index (Lanes), the baseflow index (BFI), the flood flow index (FFI), and the index of variability (Iv). The similarity between BFI and FFI shows that these watersheds are located at the same flow regime. Rainy and dry seasons determine the values of average BFI and FFI.

Figure 2 shows the specific FDC properties (Indarto *et al.*, 2016) for each watershed. The FDC for the 38_Mujur and 33_Mayang watersheds are relatively similar. This is also proved by similarity in the form of the two watersheds that are relatively elongated. Such watersheds tend to have a smoother slope of the FDC graphic (not the steepest). This is because runoff from any point of the watershed will arrive in the queue on the outlet.

Among the other watersheds, 35_Sanenrejo and 34_Bedadung show the steepest slopes in FDC form. This indicates that they are subject to flow regimes characterised by high flow discharges. The two watersheds have a form more widely (between a circle and triangle). Therefore, runoff from any point on the watersheds will probably join the outlet at the same time. The hydrograph will rise more quickly at the time of the high rainfall events.

Table 4. Statistical parameters of daily discharge data

Stat Value per watershed	Unit	Watershed Identification						Qualitative assessment		
		33_ Mayang	34_ edadung	35_ anenrejo	36_ Mujur	38_ Sentul	39 _Wonorejo	Mean	StDev	Qual. Ass
Maximum	m3/s	70.45	1049.00	283.00	62.40	104.00	196.06	294.15	346.28	different
Mean	m3/s	4.25	32.84	10.31	4.56	9.99	16.88	13.14	9.77	different
Median	m3/s	2.97	16.00	4.84	3.98	7.19	14.80	8.30	5.19	different
Percentile 10	m3/s	1.67	5.25	0.38	1.37	4.52	9.55	3.79	3.10	different
Percentile 90	m3/s	8.25	77.40	26.40	8.50	14.06	25.50	26.69	23.82	different
Mean Daily Baseflow	mdbf	2.77	15.18	4.25	3.28	7.35	13.03	7.64	4.83	different
Standard Deviation	StDEv	3.83	44.98	16.21	3.27	3.30	9.61	13.53	14.81	different
Variance	Var	14.60	2037.30	262.60	136.40	11.00	92.30	425.70	725.68	different
Kurtosis	Ku	25.7	59.2	44.5	28.2	31.3	41.3	38.37	11.50	different
Skewness	Skew	3.5	5.2	4.8	5.1	3.2	4.3	4.35	0.77	similar
Variability	Var	-1.25	-2.76	-2.87	-1.00	-0.76	-0.67	-1.55	0.91	similar
S_Log	S_Log	0.22	0.42	0.46	0.27	0.24	0.18	0.30	0.11	similar
Lane's Variability	Lanes	0.22	0.44	0.49	0.24	0.22	0.17	0.30	0.12	similar
Baseflow Index	BFI	0.65	0.46	0.41	0.72	0.74	0.77	0.63	0.14	similar
Flood Flow Index	FFI	0.35	0.54	0.59	0.28	0.26	0.23	0.37	0.14	similar
Index Variability	Iv	0.56	0.95	0.27	0.9	0.67	1.24	0.77	0.31	similar

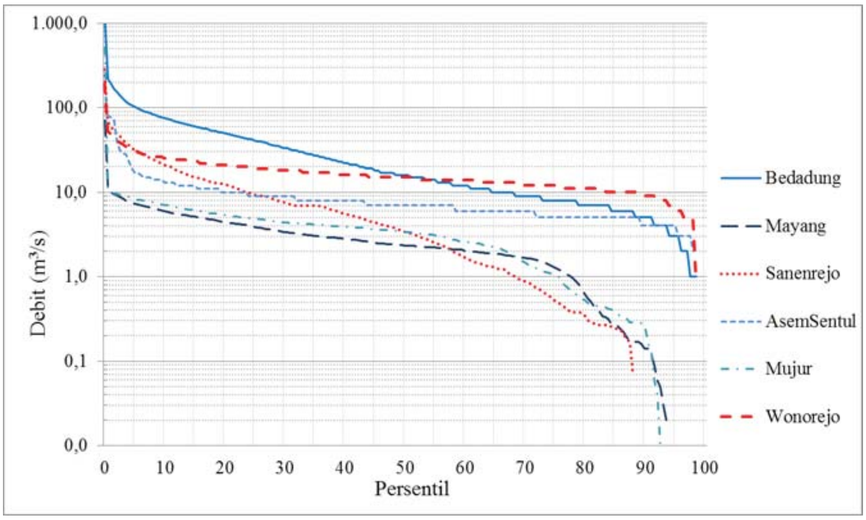

Figure 2. Flow duration curve of the six watersheds

Table 5. Statistical analysis of daily rainfall

Statistic value per watershed	Watershed Identification						Statistical value among watersheds					Qual. Assessment
							Min	Max	Mean	StDev	Var	
Mean	5.2	6	4.4	5.3	5.7	5	4.40	6.00	5.27	0.51	0.26	Similar
Median	1	1.3	0	0.7	1.3	1.3	0.00	1.30	0.93	0.47	0.22	Similar
Std. Dev	8.7	9.4	10.1	9.2	9.7	8	8.00	10.10	9.18	0.68	0.46	Similar
Coef. Var	1.7	1.6	2.3	1.7	1.7	1.6	1.60	2.30	1.77	0.24	0.06	Similar
Skewness	2.8	2.4	3.6	3.4	3.1	2.9	2.40	3.60	3.03	0.39	0.16	Similar
Max	84.5	80.1	104.5	149.7	101	99.3	80.1	149.7	103.1	22.6	511.2	Different

3.1.2 Daily rainfall data

Table 5 shows the results of the statistical analysis of the averaged daily rainfall data from the watersheds. In Table 4, it can be seen that the values of standard deviation (StDev) and variance (Var) of the daily rainfall parameters are lower than << 1. These values were obtained for statistical resume (i.e. average, mean, median, StDEv, coefficient of variation and skewness). However, the similarity is not evident in extreme rainfall events (i.e. maximum rainfall).

3.1.3 Monthly rainfall data

Having a tropical climate, two seasons are distinguishable in this region (rainy and dry seasons). The rainy season occurs from October to April and the dry season normally from May to September (Indarto *et al.*, 2016). The amount of rainfall received during the rainy season is important; more than 70% of total rainfall is received at this time. Therefore, the amount of rainfall over the year is very varied. This will influence the values of the statistical resume for monthly rainfall (i.e. mean, median, StDev, and Coef Var), as shown in Table 6. The same effect is observed in annual rainfall statistical values (Table 7).

It can be noted from Table 6 and Table 7 that the values of Coef. Var and Skewness are relatively similar among the watersheds. This means that the variability and distribution of rainfall from month to month and year to year are relatively similar.

Table 6. Statistical values of monthly rainfall data

Statistic value per watershed	Watershed Identification						Statistical values among watersheds					Qual. Assesment
	33	34	35	36	38	39	Min	Max	Mean	StDev	Var	
Mean	157.2	179.2	125.4	157.8	193.4	150.2	125.40	193.40	160.53	21.56	464.73	Different
Median	138.4	147.1	78.3	154.8	204.1	143.8	78.30	204.10	144.42	36.71	1347.52	Different
Std. Dev	141.3	163.6	126.7	114.3	127.3	112.3	112.30	163.60	130.92	17.46	304.93	Different
Coef. Var	0.9	0.9	1	0.7	0.7	0.7	0.70	1.00	0.82	0.12	0.01	Similar
Skewness	0.7	0.8	0.9	-0.4	0.5	0.4	-0.40	0.90	0.48	0.43	0.18	Similar
Max	594.8	678.9	560	468.3	573	458.5	458.50	678.90	555.58	75.40	5685.22	Different

Table 7. Statistical values of annual rainfall data

Statistic value per watershed	Watershed Identification						Statistical values among watersheds					Qual. Assesment
	33	34	35	36	38	39	Min	Max	Mean	StDev	Var	
Mean	1885.8	2150.4	1505	1721.6	2321.3	1802.9	1505.0	2321.3	1897.83	270.08	72941.2	Different
Median	1919.3	2187	1514.4	1661.3	2349.6	1717.4	1514.4	2349.6	1891.50	295.37	87242.6	Different
Std. Dev	289.5	461.6	374	289.5	541.7	436.5	289.5	541.7	398.80	91.55	8382.2	Different
Coef. Var	0.2	0.2	0.2	0.2	0.2	0.2	0.20	0.20	0.20	0.00	0.00	Similar
Skewness	0.4	0.6	-0.9	0.4	-0.7	1.6	-0.90	1.60	0.23	0.84	0.70	Different
Min	1432.3	1359.2	705	1228.7	1008	1111.2	705.00	1359.20	1140.73	241.12	58138.4	Different

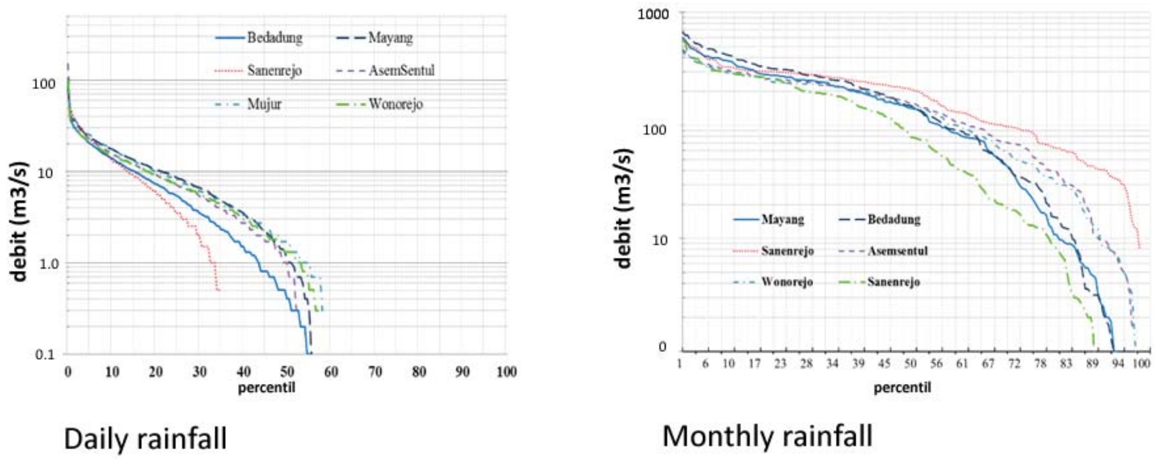

Figure 3. FDC applied to daily and monthly rainfall data

Figure 3 shows the FDC used to plot (a) the daily rainfall and (b) monthly rainfall of the watersheds. The individual curves for daily rainfall data are relatively close to each other, except for Bedadung and Sanenrejo, while for monthly rainfall, as shown in figure 3b, the individual curves are relatively separate from each other. This shows the differences between the watersheds in terms of monthly rainfall received.

3.2 Morphometric characteristics

3.2.1 Linear aspect

Table 8 presents the results of the statistical analysis of the linear aspect of the morphometric parameters among the six watersheds. By using the same criteria as for the comparison hydrological properties (SdDev and Coef.Var), some morphometric parameters are categorised in a similar way, while others are different.

Table 8. Morphometric parameters – linear aspect of watersheds

Morphometric parameter	Symbols	33 Mayang	34 edadung	35 anenrejo	36 Mujur	38 Sentul	39 Wonorejo	Mean	StDEv	CV	Quality Evaluation
Area	A	150	673	292	167	137	132	258.5	211.6	44768.3	Different
Perimeter	L	80	177	94	87	88.8	63	98.3	40.03	1602.2	Different
Total stream length	TLu	222.8	926	285	251	214	190	348.13	284.9	81211.3	Different
Stream order	U	4	5	4	4	4	4	4.17	0.41	0.167	Similar
Stream length	Lu	30	56	35	33	34	19	34.50	12.05	145.100	Different
Bifurication ratio	Rb	6.26	2.43	1.82	2.02	3.23	1.77	2.92	1.72	2.967	Different
Mean stream length	Lsm	1.46	1.39	0.89	1.02	0.81	1.42	1.17	0.29	0.085	Identical
Stream length ratio	Rl	1.06	1	1.16	1.4	0.95	1.02	1.10	0.16	0.027	Identical

Table 9. Morphometric parameters – relief aspect of watersheds

Morphometric parameter	Symbols	33 Mayang	34 edadung	35 anenrejo	36 Mujur	38 Sentul	39 Wonorejo	Mean	StDEv	CV	Quality Evaluation
Basin Relief	Bh	2.61	2.74	1.17	2.64	3.61	1.63	2.40	0.87	0.757	Identical
Relief Ratio	Rh	0.09	0.05	0.03	0.08	0.11	0.09	0.08	0.03	0.001	Identical
Ruggedness Number	Rn	0.13	0.07	0.03	0.12	0.17	0.12	0.11	0.05	0.002	Identical

Stream order (U) is similar (U= 4) among five watersheds, with the exception of Bedadung (U= 5). Main stream length (Lsm) and stream length ratio (RI) are also similar. Other linear parameters such as stream length (Lu) and bifurcation ratio (Rb) are relatively different among the watersheds.

3.2.2 Relief aspect

Table 9 shows the results of the statistical analysis of the relief aspect of the morphometric parameters. It can be seen that all of the three parameters (basin relief = Bh, relief ratio = Rh and ruggedness number = Rn) are similar among the watersheds.

3.2.3 Area aspect

Table 10 shows the results of the statistical analysis of the area aspect of the watershed morphometric parameters. It can be seen that most of the morphometric parameters (10/11) are categorised in a similar way, namely drainage density (Dd), infiltration index (If), stream frequency (Fs), texture ratio (T), form factor (Rf), circulation ratio (Rc), elongation ratio (Re), length of overland flow (Lof), constant channel maintenance (C), and compactness constant (Cc). Only basin shape (Bs) is different.

It can be concluded that most of the morphometric parameters, including linear, relief and area aspects, are relatively similar amongst the watersheds. A total of 17 out of the 20 morphometric parameters are categorised in a similar way, with only basin shape (Bs), bifurcation ratio (Rb) and stream length (Lu) different.

Table 10. Morphometric parameters – areal aspect of watersheds

Morphometric parameter	Symbols	33 Mayang	34 edadung	35 anenrejo	36 Mujur	38 Sentul	39 Wonorejo	Mean	StDEv	CV	Quality Evaluation
Area	A	150	673	292	167	137	132	258.5	211.6	44768.3	Different
Perimeter	L	80	177	94	87	88.8	63	98.3	40.03	1602.2	Different
Total stream length	TLu	222.8	926	285	251	214	190	348.13	284.9	81211.3	Different
Stream length ratio	Rl	1.06	1	1.16	1.4	0.95	1.02	1.10	0.16	0.027	Similar
Drainage Density	Dd	1.49	1.38	0.98	1.5	1.56	1.44	1.39	0.21	0.044	Similar
Infiltration Index	IF	1.58	1.38	1.15	2.94	2.89	1.41	1.89	0.80	0.647	Similar
Stream Frequency	Fs	1.06	1	1.17	1.96	1.85	0.98	1.34	0.45	0.199	Similar
Texture Ratio	T	1	1.9	1.84	1.95	1.32	1.03	1.51	0.44	0.196	Similar
Form Factor	Rf	1.39	0.21	0.24	0.15	0.12	0.37	0.41	0.49	0.237	Similar
Circulation Ratio	Rc	0.29	0.27	0.42	0.28	0.22	0.42	0.32	0.08	0.007	Similar
Elongation Ratio	Re	0.46	0.52	0.55	0.44	0.39	0.68	0.51	0.10	0.010	Similar
Length of Overland Flow	Lof	0.74	0.69	0.51	0.75	0.78	0.72	0.70	0.10	0.009	Similar
Constant Channel Maintenance	C	0.67	0.73	1.02	0.67	0.64	0.69	0.74	0.14	0.020	Similar
Basin Shape	Bs	6.00	4.66	4.20	6.52	8.44	2.73	5.42	2.00	3.989	Different
Compactness Constant	Cc	0.31	0.15	0.19	0.30	0.37	0.28	0.27	0.08	0.007	Similar

3.2.4 Relationship between the morphometric properties

Table 11 shows a simple analysis using coefficient correlation to establish the relationship between the morphometric properties. The analysis comprises all the morphometric parameters from the watersheds. It is shown that some have a strong correlation with other parameters. For example, area (A), perimeter (L), total stream length (Tlu) and stream length (Lu) are correlated with each other. A greater watershed area will generate perimeter stream, length and total stream length more important. Furthermore, a similar relationship exists between infiltration index (If), basin relief (Bh), relief ratio (Rh), ruggedness number (Rn), drainage density (Dd), stream frequency (Fs), basin shape (Bs), compactness constant (Cc), and length of overland flow (Lof).

Table 11. Coefficient correlation between morphometric parameters

	A	P	LU	NU	LSM	DD	FS	LOF	C	T	RF	IF	ER	CR	BH	RH	RN	RB	RL
A	1.00	.959**	.975**	.990**	-0.44	-0.28	0.09	-0.28	0.20	.946**	0.48	-0.24	0.51	0.07	-0.08	-0.55	-0.19	-0.22	0.13
P		1.00	.967**	.957**	-0.51	-0.11	0.12	-0.11	0.04	.885*	0.25	-0.01	0.28	-0.21	0.20	-0.30	0.09	-0.24	0.08
LU			1.00	.945**	-0.37	-0.07	-0.04	-0.07	-0.02	.973**	0.43	-0.08	0.45	-0.05	0.07	-0.39	-0.02	-0.17	0.10
NU				1.00	-0.54	-0.35	0.22	-0.35	0.28	.894*	0.42	-0.22	0.45	0.04	-0.08	-0.55	-0.19	-0.29	0.09
LSM					1.00	0.29	-.867*	0.29	-0.32	-0.23	0.02	-0.29	-0.03	0.20	-0.17	0.09	-0.10	.852*	0.58
DD						1.00	-0.47	1.000**	-.993**	-0.08	-0.38	0.79	-0.41	-0.61	0.75	.835*	.822*	0.19	-0.19
FS							1.00	-0.47	0.52	-0.17	-0.20	0.17	-0.14	-0.09	-0.02	-0.11	-0.08	-0.70	-0.46
LOF								1.00	-.993**	-0.08	-0.38	0.79	-0.41	-0.61	0.75	.835*	.822*	0.19	-0.19
C									1.00	-0.01	0.35	-0.75	0.38	0.61	-0.73	-0.79	-0.80	Be	0.11
T										1.00	0.60	-0.18	0.62	0.14	-0.09	-0.49	-0.16	-0.12	0.10
Rf											1.00	-0.56	.998**	.839*	-0.73	-0.78	-0.70	-0.24	-0.15
IF												1.00	-0.55	-0.75	.820*	.851*	.859*	-0.27	-0.52
ER													1.00	.832*	-0.73	-0.79	-0.71	-0.28	-0.17
CR														1.00	-.965**	-0.81	-0.92	-0.09	-0.03
BH															1.00	0.86	0.98	-0.01	-0.13
RH																1.00	0.92	0.09	-0.23
RN																	1.00	-0.01	-0.20
RB																		1.00	.87*
RL																			1.00

3.3 Interpretation

3.3.1 Morphometric vs hydrological properties

Two morphometric parameters (area and total stream length) show a strong coefficient correlation (greater than > 0.8) with some indicators of daily discharge data (i.e., mean, StDEv, Var, Kurtosis and maximal daily discharge). It is well known that a greater area and number of streams inside a watershed will generate more flow. Other morphometric parameters such as texture ratio (T) and elongation ratio (Re) have a moderate correlation with the hydrological property indicators. It can be see in Table 12.

Table 12. Coefficient correlation between morphometric and hydrological parameters

Morphometric parameter			Hydrological Properties							
	Mean		Mean	Median	StdDev	Var	Skew	Kurtosis	Max	Index variability
			Med	StDev	Var	Skw	Ku	Max	Ivar	
	Area	A	.871*	.567	.981**	.982**	.604	.873*	.984**	.060
	Total stream length	TLu	.885*	.608	.968**	.997**	.550	.819*	.981**	.183
	Bifurication ratio	Rb	-.445	-.522	-.358	-.214	-.652	-.513	-.273	-.313
	Mean stream length	Lsm	.446	.536	.282	.337	.084	.217	.347	.517
	Stream length ratio	Rl	-.207	-.225	-.102	-.234	.548	-.333	-.263	-.085
	Infiltration Index	IF	-.438	-.365	-.405	-.354	-.249	-.599	-.453	.110
	Basin Relief	Bh	-.123	-.191	-.065	.101	-.442	-.299	-.016	.121
	Relief Ratio	Rh	-.477	-.200	-.646	-.512	-.738	-.668	-.577	.381
	Ruggedness Number	Rn	-.471	-.236	-.604	-.463	-.719	-.668	-.541	.341
	Drainage Density	Dd	-.138	.049	-.277	-.131	-.445	-.465	-.227	.570
	Stream Frequency	Fs	-.476	-.458	-.385	-.381	-.123	-.552	-.464	-.080
	Texture Ratio	T	.407	.127	.616	.509	.798	.432	.491	-.186
	Form Factor	Rf	-.354	-.354	-.337	-.253	-.459	-.426	-.269	-.212
	Circulation Ratio	Rc	.083	.237	-.044	-.195	.307	.258	-.071	-.006
	Elongation Ratio	Re	.445	.661	.204	.107	.339	.488	.220	.434
	Length of Overland Flow	Lof	-.151	.038	-.290	-.145	-.450	-.474	-.241	.564
	Constant Channel Maintenance	C	.070	-.123	.225	.080	.406	.410	.172	-.624
	Basin Shape	Bs	-.525	-.642	-.356	-.244	-.500	-.565	-.352	-.317
	Compactness Constant	Cc	-.764	-.531	-.845*	-.749	-.769	-.862*	-.811	.063

Other morphometric parameters, such as Lsm, Rh, Rn, Dd, Re and Lof, have a fair correlation with flooding events, as represented by the index of variability.

4. Conclusion

Variability in the hydrological properties described using discharge and rainfall data exists amongst the watersheds. The variability is relatively different or similar, depending on the criteria. It is also shown by the watershed morphometric parameters. Quantitative measurement (or calculation) of this variability can help us to gain more understanding of nature (water resources), knowledge which will useful for us in managing our water resources better.

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