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Regional Distribution of Frequency Fitted for East Java using Regional Flood Frequency Analysis

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ABSTRACT

Regional flood frequency analysis has been applied to the area of East Java. Regional division has been done through hierarchical clustering techniques. Regional identification is homogenous with discordancy measure and heterogeneity test base of L-Moment statistic and produces five homogeneous regions and one heterogeneous region. Each homogeneous region has unique growth curve. Dominant distribution in the region is Generalized Logistics and Generalized Pareto.

INTRODUCTION

Indonesia is a developing country. Currently,water infrastructure development gets so much attention. In the process of planning and design of water infrastructure development such as dams, bridges, and irrigation canals, an accurate estimate of the peak of flood in river and occurrence of intervals is required. Overestimation or underestimation of flood peak will affect the loss of the structure itself, the environment, and human life. Ideally, flood estimates are derived by selecting suitable frequency distribution with measurement data on river streams. However, as construction of the infrastructure is urgent, often the development is in the river without measurement. Therefore, hydrologists in Indonesia often apply indirect methods such as the methods of rational and Synthetic UnitHydrograph for analyzing flood frequency.

Overcoming the lack of data, Regional Flood Frequency is a popular method and has been applied in many countries (Haddad and Rahman, 2012). This method generally estimates statistics on gauged site and move it to ungauged site. Index floodmethod is the method most widely applied in the Regional Flood Frequency (Brath*et al*., 2001). This method analyzes data on gauged site to produce a standardized curve named as growth curve (Noto and La Loggia, 2009). The curve can be used to estimate the flood design in gauged site and ungauged site in the same region. In the process of data transfer, it is assumed that gauged site and ungauged site are in an area withhomogeneous hydrological statistics. This assumption is necessary as characteristics of catchmentdiverse. This leads as to seethat homogeneous areas have similarity in distribution of flood frequency.

The process of determining a homogeneous area is called regionalization. Regionalization consists of two stages. First, it is pooling gauged sites into the region and identification of homogeneity of the region formed. Region can be based on administrative boundaries, exiting geographical, or by objective techniques (Castellarin*et al.*, 2001). However, there is no universally accepted objective method (RamachandraRao and Srinivas, 2003) as factors that affect the occurrence of floods are not yet fully understood. Nevertheless, one of common approaches in delineating regions for regional flood frequency is based on clustering techniques (Noto and La Loggia, 2009). In cluster techniques, hierarchical clustering is one of the widely used methods in

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hydrology. Ward's method is most frequently used (Lin and Chen, 2006) and recommended by (Hosking and Wallis, 1997). Usually the process of delineating is based on physiographic characteristics such as catchment area, rainfall, length of the main river, the slope of the main river, and river discharge. Once the region is formed, they can be tested for homogeneity. Test homogeneity statistic based L-moment is widely used in regional flood frequency (Hussain, 2011) and has several advantages compared to other methods (Viglione*et al.*, 2007).

The importance of choosing the frequency distribution that matches the nature of the river flow has attracted a lot of attention. Haddad and Rahman (2011) investigate and select distribution for Tasmania, Richard M. Vogel *et al*. (1993a, b) for Australia and the United States, Ellouze and Abida, (2008) for Tunisia, and Karim and Chowdhury (1995) compared four distributions in Bangladesh. Many statistical distributions for flood frequency have been introduced in hydrological literature including Extreme Value Type 1 (Gumbel), General Extreme Value, Normal, Lognormal, Gamma, Exponential, and Log Pearson Type 3. Practitioners in East Java apply only Gumbel Distribution and Log Pearson Type 3, fitted to sample data, and one that gives the best fit is selected.

The objective of this paper is to identify the frequency distribution best fit to the data for regional flow in East Java of Indonesia. To our best knowledge, there have been no previous studies to select the best fit for regional flood frequency distribution in East Java.

MATERIAL AND METHOD

To achived the objective, we considered using cluster techniques of Ward's method and test homogeneity based L-moment in regionalization,thenfive different distributions having three parametersfitted on regions formed. Criteria for selection of the frequency distribution are comparable procedures of L-skewness and L-kurtosis and goodnes of fit test.

Watershed Grouping:

Cluster analysis is part of multivariate statistical analysis to divide objects into groups. In this regional analysis, factors of latitude, longitude, contributing area, circumference, length of the main rivers, elevation gauged site, discharge, rainfall, river slope, runoff coefficient, and Topographic Wetness Index are considered to be analyzed. As those factors have different units, standardizationis necessary, with a range from zero to one. With this technique, a site can be combined with others based on similar data. In hierarchical cluster, the similarity of data on the sites, which will be combined into groups (clusters),is measured from the smallest value between the sites based on Euclidean equation. Cluster relationships formed subsequently are analyzed using Ward equation that measures the degree of similarity of each cluster, until all sites combined into one cluster only. The results of cluster analysis in the form of dendogram present a picture of how the site merged into one cluster only. The decision on how many groups or regions formed is made using the pattern of similarity change or distance value that changes at every stage of cluster formation. In stage where a big change in similarity happens, then it is the for the cutting dendogram.

L-Moment:

L-moment is a statistical method that lately is used much in hydrological methods when dealing with regional flood frequency (Noto and La Loggia, 2009). L-moment is modified from its probability weighted moment (Greenwood *et al.*, 1979, by Hosking, 1990). L-moment is an alternative to summarize the statistical properties of hydrological data (Karim and Chowdhury, 1995). Just like product moment ratio, that is coeficient of variation, skewness and kurtosis, Hosking (1990) defines L-moment ratio as follows:

L-CV (L-Coefficien of varians)$t = \frac{2b_1 - b_0}{b_0}$ (1)

L-skewness$t_3 = \frac{6b_2 - 6b_1 + b_0}{2b_1 - b_0}$ (2)

L-kurtosis$t_4 = \frac{20b_3 - 30b_2 + 12b_1 - b_0}{2b_1 - b_0}$ (3)

In which

$$b_r = \frac{1}{n}\sum_{i=r+1}^{n} \frac{(i-1)(i-2)\dots(i-r)}{(n-1)(n-2)\dots(n-r)} x_i\,, \qquad r = 0, 1, \dots, n-1 \quad (4)$$

is unbias estimator and$x_i$is data that is sorted such that$x_1 \le x_2 \le x_i \le \dots \le x_n$

Discordancy test:

Hosking and Wallis (1997) laid the basis for the measurement of discordant of a region with n sites. At every site i Discordancy Measure is defined as follows:

$$D_i = \frac{1}{3}N(\boldsymbol{u}_i - \overline{\boldsymbol{u}})^T A^{-1}(\boldsymbol{u}_i - \overline{\boldsymbol{u}}) \qquad (5)$$

in which $u_i = \left[t_2^{(i)} t_3^{(i)} t_4^{(i)}\right]^T$, $\overline{\boldsymbol{u}} = N^{-1}\sum_{i=1}^{N}\boldsymbol{u}_i$, and $A = \sum_{i=1}^{N}(u_i - \bar{u})(u_i - \bar{u})^T$

This discordancy measure tes is useful to identify sites from formed region that gross discordant with that region as a whole and would be removed from that region. Irregularities are due to incorrect data values, outliers, trends, and shift in the mean of a sample that reflacted in L-moments of sample. Critical value of discordant usually depends on number of station in a region as given in tabular form (Hosking and Wallis, 1997).

Homogenity test:

Region formed based on similar physiographic needs acknowledgment of its homogeneity by heterogeneity size. The size of the sample is obtained by comparing the variability of L-moments ratio of sites in a region with expected variability in homogeneous region as defined by Hosking and Wallis (1993). The heterogeneity measured is defined as follows:

$$H = \frac{(V - \mu_V)}{\sigma_V} \qquad (6)$$

in which$V$is weighted variance for L-CV

$$V = \sum_{i=1}^{N} n_i\left(t^{(i)} - t^R\right)^2 / \sum_{i=1}^{N} n_1 \qquad (7)$$

The expected mean value (μ_v) and standard deviation (σ_v) are obtained from repeated simulation of homogeneous region having same record of length n of site i, t^R is regional average L-CV. Following Hosking and Wallis (1997), the four-parameter of kappa distribution is used in simulation. A Monte Carlo simulated program is used to generates random data. The region is “acceptably homogeneous” if $H < 1$, “possibly heterogeneous” if $1 \leq H < 2$, and “definitely heterogeneous” is$H > 2$.

Selection on regional distribution:

The robust distribution for the region is identified based on goodness of best fit criteria. It aims is to identify a distribution among the available candidates which is the best fit to the sample data. The goodness of fit is judged by how well the L-skewness and L-kurtosis of the fitted. In this study, the L-moment ratio diagram and $\left|Z^{dist}\right|$ statistic criteria are used as the goodness-of-fit measures for identifying the robust regional distribution as recommended (Hosking and Wallis 1997).

$\left|Z^{dist}\right|$ statistic is defined as

$$Z^{DIST} = (\tau_4^{DIST} - t_4^R + B_4)/\sigma_4 \qquad (8)$$

In whichτ_4^{DIST}isL-kurtosis of fitted distribution; $B_4 = N_{sim}^{-1}\sum_{m=1}^{Nsim}\left(t_4^{|m|} - t_4^R\right)$is the bias of t_4^R; and $\sigma_4$is the standard deviation of L-kurtosis regional (t_4^R) gained from several simulations (N_{sim}) on a region with homogenous distribution candidates, with some frequency distribution candidates, and several sites having the same length of data with the sample data.

The smallest value of$\left|Z^{dist}\right|$on one distribution candidate makes the candidate as the true frequency distribution for that particular region. The fit is considered to be adequate if $\left|Z^{dist}\right|$ statistic is sufficiently close to zero, a reasonable criterion being $\left|Z^{dist}\right| \leq 1.64$. Probably, more than one distribution candidates that have $\left|Z^{dist}\right|$ less of the criterion, the one with the lowest $\left|Z^{dist}\right|$is regarded as the most appropriate distribution.

Studi Area and Data:

The study area is located in the east of the Island of Java, administratively called as East Java province. The north-south landscape in the easternmost part is 80 km and 200 km to the west. It is surrounded by seas on three sides with a series of volcanoes located in the middle stretching east west this area is wet tropics. It is located at latitude of 6.83^o S and 8.48^o S and by longitude of 111.79^o E and 114.32^o E. The rainy season is in November until May. Flood peak is in February to March. Annual maximum flood peak is 63 streamflows of gauged catchments provided by the Center of Water Resource Research and Development, Bandung. Bulletin 17B suggests on the use of data from site with at least 10 years in the record, and considering that many projects have small catchment, and then we reduce the number of sites to 36 sites. At the site, mean of annual maximum flood varies from 3.57 m^3/s to 335.58 m^3/s. Annual rainfall data is provided by the Department of Water Resources of East Java Province, and the mean of annual maximum rainfall on gauged catchments range from 65.71 mm to 142.66 mm. The spatial hydrometric sites were mapped using Quantum GIS softwareVersion 2.4.0, then catchment boundary of each site was delineated. Based on delineated catchment, catchment area, perimeter, and river length could be obtained. Main river slope, Topographic Wetness Index and land cover runoff coefficient of each catchment were extracted from digital elevation models and digital land cover map using the tool box of Quantum GIS. Catchment area of sites varies from 6.39 km^2 to 956.45 km^2. Perimeter varies from 14.03 km to 161.45. Main river slope varies from 0.03 to 0.61.

RESULT AND DISCUSSION

Officially, the study area was divided into six regions by the Indonesian government. Region name is given in Table 1 together with catchment areas and the characteristics of the statistics that are calculated using L-moment statistics. WS Bengawan Solo has 12 sites,and the critical value for discordancy statistic is 2.757; WS Brantas has 8 sites, and the critical value for discordancy statistic is 2.140; WS BondoyudoBedadunghas 5 sites, and the critical value discordancy statistic is for 1.333. Therefore, the data from these three regions is acceptable.WS WelangRejoso only has three sites, too few and uninformative according to Hosking and Wallis (1997), so it should be considered a new composition by using objective technique, that is the application of cluster.

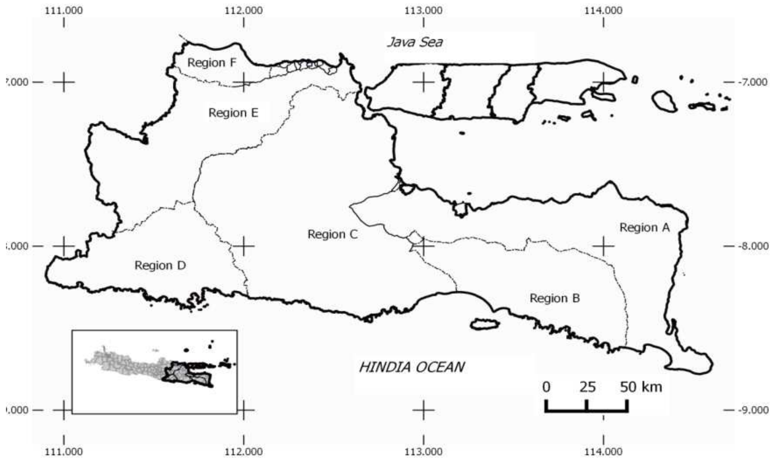

Fig. 1: Delineation of Regions.

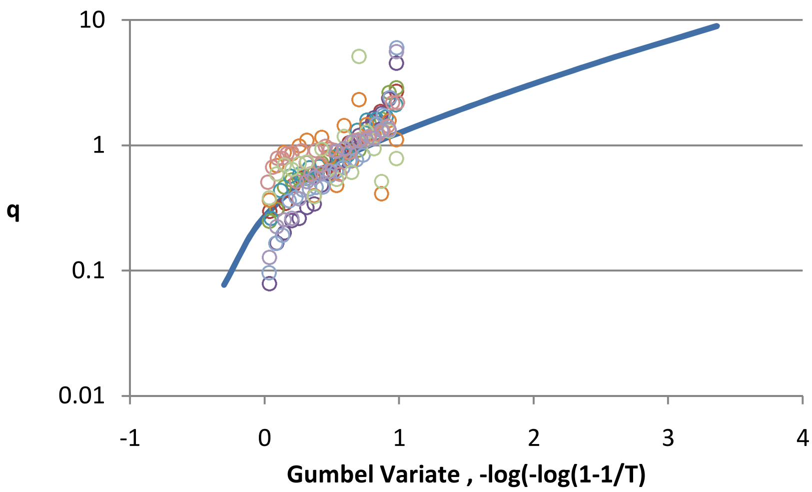

Fig. 2: Regional Growth Curve Fitted to Region A.

Six regions have been identified through cluster analysis but spatially multiple sites in a cluster arefar apart and surrounded by members of other clusters so subjective adjustment to the results of cluster analysis needs to be done. This modification is done to improve the geographical coherence and obtain homogeneous region as much as possible. Five regions have been identified as “possibly heterogeneous” i.e. Region A, Region B, Region C, Region D, and Region E; one region is “definitely heterogeneous” as shown in Table 2. Discordancy value in parentheses at sites in Region A is less than the critical value of the nine sites, i.e. 2.329; critical value of Region B is 1.333, Region C is 1.917, Region D is 1.648, Region E and F is 1. There is no discordant in each region. Figure 1 shows the location of the sixth region.

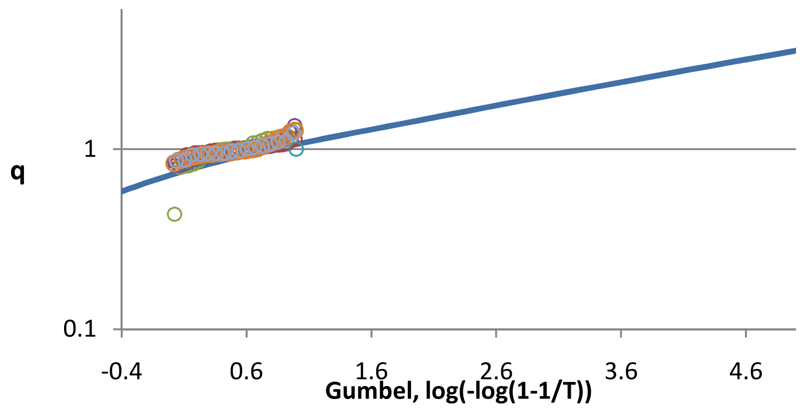

Fig. 3: Regional Growth Curve Fitted to Region B.

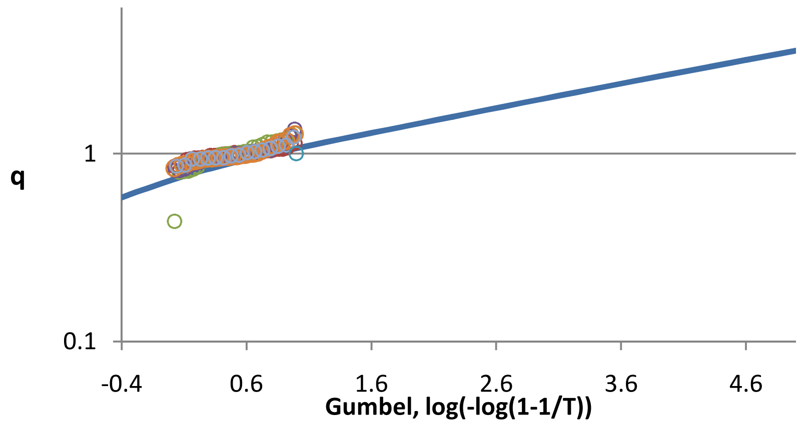

Fig. 4: Regional Growth Curve Fitted to Region C.

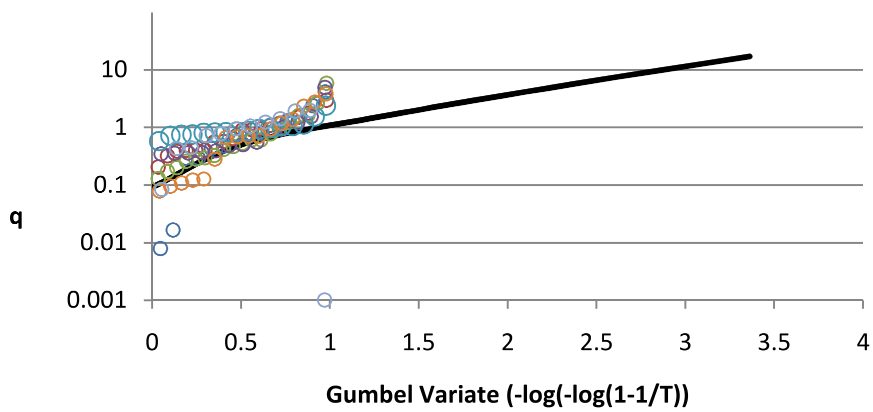

Fig. 5: Regional Growth Curve Fitted to Region C.

Region A is a combination of WS WelangRejoso Region, WS BaruBajulmati, and WS PekalenSampean. Region B is a modification of WS BondoyudoBedandung. Borderline of Region A and Region B which extends from east to west is a series of volcanoes along the Island of Java. Region C is largely WS Brantas, the biggest watershed in East Java Province. Region D, Region E, and Region F divide WS Bengawan Solo into three.

In Region F, Gembul site is a site with the highest L-CV and L-skewness than other sites. Examination of the data of Gembul site found one-year reference with enormous value which requires an examination of the validity of the data. However,it is not easy to gain sufficient access for inspection, and then the data is retained.

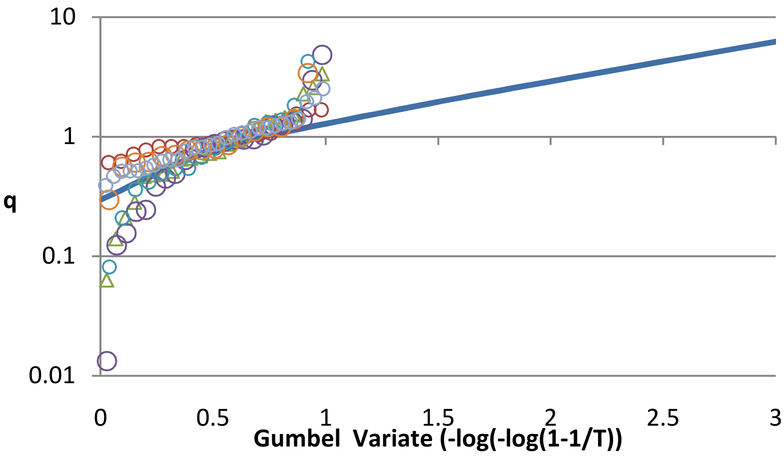

Fig. 6: Regional Growth Curve Fitted to Regional D.

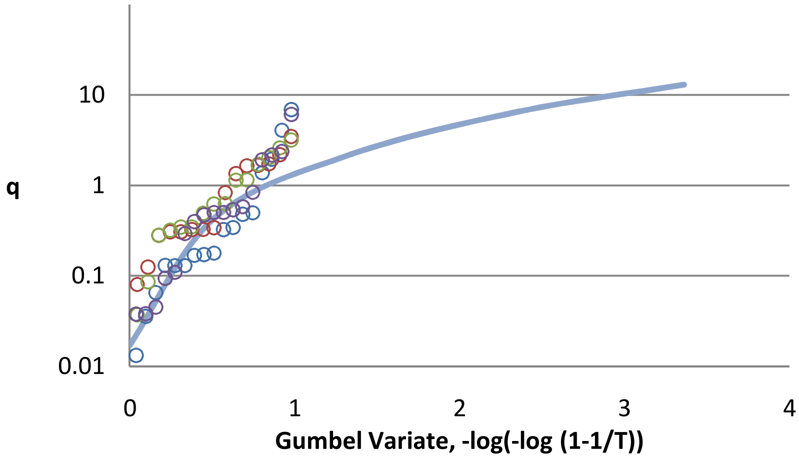

Fig. 7: Regional Growth Curve Fitted to Regional E.

Rejososite is excluded from the formation of region. This site is the cause of heterogeneity of regions formed, leading to no suitablefrequency distribution. The flow of the river at this site is regulated streamflow.

After ensuring homogeneity from the study area, the next step is to choose an appropriate frequency distribution for the regions. For the eastern part of Java, the distribution candidate is General Logistic (GLO), Generalized Extreme Value (GEV), Pearson type 3 (PIII), lognormal distribution (LN3), and Generalized Pareto (GPA), by 500 simulations for each region, the $|Z^{dist}|$has been calculated and is shown in Table 3. GEV and GLO are found to fit well to Region A base on the criterion of$|Z^{dist}|$, but the lowest is GLO. The same thing happened in Region B and Region C. GLO was found suitable for Region D. GPA is the lowest of four distributions to fit well to Region E.

GLO distribusion is identified as robust distribution for five region in study area, and GPA distribution is robust distribution for one region; therefore, regional distibution frequancy was developed using these distribution. The form of regional frequancy analisys for GLO distribution is expressed as follows:

$$q = \xi + \frac{\alpha}{\kappa}(1 - [T - 1]^{\kappa}) \quad (9)$$

and GPA distribution is expressed as follows:

$$q = \xi + \frac{\alpha}{\kappa}\left(1 - \left[1 - \frac{1}{T}\right]^{k}\right) \quad (10)$$

$q$is growth factor; ξ, α,and$\kappa$is parameter location, scale dan shape respectively; estimation value of each parameter can be seem in Table 3. The equation suitable with each region is presented as follows:

Region A

$$q \;\; = 0.771 - 0.75(1 - (T - 1)^{-0.393}) \quad (11)$$

Region B

$$\mathrm{q} \;\; = 0.868 - 0.742(1 - (\mathrm{T} - 1)^{-0.31}) \quad (12)$$

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Region C

$$q = 0.618 - 0.58(1 - (T-1)^{-0.526}) \quad (13)$$

Region D

$$q = 0.808 - 0.825(1 - (T-1)^{-0.349}) \quad (14)$$

Region E

$$q = -0.042 - 2.012\left(1 - \left(1 - \frac{1}{T}\right)^{-0.341}\right) \quad (15)$$

Tabel 1: Cathments, L-Moment Ratio, Discordancy Measure and Region.

Sample ID	Site Name	Catchment Area (km^2)	Sample Size (year)	Mean Annual (m3/s)	L -CV t	L-Skewness t_3	L-Kurtosis t_4	Discordancy Measure $D(i)$	Region Name
1	Prumpung	102.52	13	4.56	0.3462	0.3819	0.1998	0.54	WS Bengawan Solo
2	Klero	40.53	13	9.43	0.3139	0.3972	0.4669	2.4	
3	Ngilirip	92.11	15	24.41	0.3746	0.1456	-0.0687	1.46	
4	Kerjo	55.66	17	32.51	0.6667	0.573	0.3891	0.31	
5	Gembul	60.89	16	19.52	0.9363	0.8868	0.7339	1.97	
6	Lamong	194.17	16	92.73	0.1981	0.4826	0.4371	1.77	
7	Keang	139.57	18	25.58	0.1776	0.2876	0.1866	0.62	
8	Gondang_M	63.15	17	63.15	0.7655	0.7018	0.4755	0.88	
9	Gondang_S	66.65	15	40.61	0.5281	0.353	0.0812	0.68	
10	Gangseng	55.44	15	32.43	0.5304	0.3551	0.116	0.49	
11	Lorok	220.93	16	57.57	0.3096	0.459	0.4526	0.61	
12	Grindulu	601.83	28	245.4	0.2776	0.2777	0.1626	0.26	
13	Bagong	45.97	24	25.21	0.4231	0.3098	0.2216	0.6	WS Brantas
14	Keser	44.45	23	38.44	0.4732	0.3875	0.3814	1.06	
15	Sumber_Ampel	6.39	14	11.4	0.5576	0.4386	0.3341	0.62	
16	Cubanrondo	18.45	19	3.57	0.4067	0.3479	0.1752	1.47	
17	Sayang	10.61	19	6.4	0.5894	0.5964	0.401	0.72	
18	Duren	15.62	16	5.75	0.465	0.434	0.3755	0.4	
19	Lahar	34.59	16	5.35	0.5736	0.4112	0.1906	1.43	
20	Kadalpang	96.66	13	26.15	0.514	0.6797	0.4948	1.69	
21	Rondoningo	80.46	18	19.38	0.3852	0.6323	0.5806	1	WS Pekalen Sampean
22	Deluwang	167.41	18	42.77	0.4815	0.4801	0.4565	1	
23	Pekalen	168.73	28	43	0.2082	0.2753	0.2716	1	
24	Sampean	647.84	17	73.76	0.39	0.3581	0.1532	1	
25	Stail	286.82	18	66.89	0.3763	0.397	0.273	1	WS Baru Bajulmati
26	Tambong	117.85	18	31.73	0.5383	0.4436	0.2556	1	
27	Baru	655.01	31	116.31	0.1684	0.1278	0.2426	1	
28	Bomo Bawah	119.28	14	39.95	0.3192	0.2089	0.0583	1	
29	Sanen	181.37	27	111.65	0.3734	0.246	0.1351	1.32	WS Bondoyudo Bedadung
30	Asem	143.24	25	25.29	0.2443	0.3714	0.3175	1.26	
31	Bondoyudo	177.71	30	71.26	0.2773	0.4327	0.2646	0.96	
32	Mujur	130.01	12	36.96	0.7693	0.8456	0.838	1.32	
33	Bedadung	956.45	16	335.59	0.3288	0.4452	0.3271	0.14	
34	Welang	164.41	18	16.06	0.278	0.1606	0.1607	1	WS Welang Rejoso
35	Rejoso	210.13	19	34.56	0.2267	0.057	0.2732	1	
36	Kramat	191.11	20	61.83	0.5381	0.5785	0.4737	1	

Table 2: Final Delineation of Regions and Region Statistic.

Region	Site ID and Discordancy Measure (D) in Region	t^R	t_3^R	t_4^R	H_1	H_2	H_3
A	24(0.96); 25(0.14); 26(0.96); 28(0.77); 22(1.11); 36(0.74); 23(1.12); 21(1.75); 34(1.44)	0.3833	0.3925	0.3052	1.51	0.67	0.22
B	27(1.2); 29(1.27); 30(0.27); 33(1.05); 31(1.21)	0.2712	0.31	0.2502	1.45	0.77	0.08
C	15(0.78); 16(0.49); 17(0.44); 20(1.13); 6(1.75); 19(0.67); 32(1.75)	0.5057	0.5263	0.3868	1.94	0.75	-0.06
D	7(0.91); 13(0.59); 14(1.38); 18(1.37); 11(1.23); 12(0.51)	0.3552	0.3487	0.282	1.71	-0.15	-0.68
E	8(1); 9(1); 10(1); 4(1)	0.6285	0.5046	0.2759	1.2	1.08	0.89
F	1(1); 2(1); 3(1); 5(1)	0.5119	0.4649	0.34	4.74	3.2	2.39

Table 3: $|Z^{dist}|$ of Distribution and Parameter of the Best Fit Distribution in Each Homogenous Region.

	Region A	Region B	Region C	Region D	Region E
Generalized Logistic	1.29	0.5	1.09	1.11	0.95
Generalized Extrem Value	1.63	0.94	1.18	1.5	0.84
Generalized Lognormal	2.25	1.99	1.78	1.97	0.32
Pearson Type III	3.3	1.99	2.78	2.79	0.56
Generalized Pareto	2.8	2.17	1.77	2.67	0.28
location	0.771	0.868	0.618	0.808	-0.042
scale	0.293	0.23	0.305	0.288	0.686
shape	-0.393	-0.31	-0.526	-0.349	-0.341

Equation of each region plotted on a growth curve in Figure 2 to Figure 7 with the standardized empirical return period of number record data of at sites, where the plotting position formula $p = (j - 0.35)/n$. it is observed that estimate equation have reasonable agreement so the results are quite satisfactory.

Conclusions:

Six regions defined by the Indonesian government need to be modified in order to be acceptable to implement a regional frequency distribution. Based on data from screening, some regions simply have too few measuring stations that need to be merged. Selection on appropriate frequency distribution had been carried out based on appropriate statistical tests. Eastern part of Java Island is largely hydrologicallyhomogeneous. Region identified as heterogeneous is part of WS BengawanSolo covering parts of Central Java; thus, further research based on regional flood frequency analysis needs to be done. The methodology used in this study can be adopted for other regions in Indonesia if sufficient flood records are available.

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