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CALIBRATION OF SIX RECURSIVE DIGITAL FILTERS FOR BASEFLOW SEPARATION IN EAST JAVA

Indarto Indarto[1], Anik Ratnaningsih[2] and Sri Wahyuningsih[1]
[1]Department of Agricultural Engineering, University of Jember, Jember, Indonesia
[2]Department of Civil Engineering, University of Jember, Jember, Indonesia
E-Mail: indarto.ftp@unej.ac.id

ABSTRACT

This paper shows the calibration process of base flow separation methods. Six (6) base flow separation methods were used for this study. The main input for this research was discharge data from 54 watersheds in East Java. Firstly, each method is calibrated using daily discharge data for each year (annually) to separate base flow. Then, optimal parameter values are obtained by averaging the annual values. Calibration process produces optimal parameters value for each watershed. Furthermore, validation is performed using optimal parameter values from watershed having complete discharge data to other watersheds. The average RMSE values range for all methods are: 0.30 to 0.38 for calibration process, and 0.27 to 0.36 for validation process. It appears that the parameters values from calibrated watersheds are transferable to validation watersheds on the same boundary of UPT.

Keywords: base flow, separation, calibration, digital filter.

INTRODUCTION

During the dry season where no or less rainfall occurs on the watersheds, the stream flow is significantly dominated by base flow contribution. This phenomenon is commonly observed in the majority of the river in East Java region. Furthermore, the base flow contribution is generally less than the total demand of flows (for residential, irrigation, industrial use) during the dry season. The lack of water supply during the dry season is more and more important problems to be solved. Therefore, understanding and estimating the contribution of base flow is essential for water resources management. Hydrograph analysis to separate the river flow component into base flow and quick flow have been started since the empirical work of Boussinesq [1]. Further algorithms for separation process have been developed by Maillet [2], Horton [3], Hall [4-5], Nathan and McMahon [6-7], Tallaksen [8], Smakhtin [9-10], Gonzales [12]. Today, a grace of the advance of information and computer, those algorithms are available and shareable on the internet for the scientific community around the world.

This paper presents the calibration of base flow separation methods in East Java region. Fifty-four (54) watersheds on the region were used for this study. Six (6) algorithms of base flow separation based on recursive digital filter (RDF) method were tested on those watersheds. The six (6) RDF used in this study are: one-parameter [12], Boughton-two-parameter [13-15], IHACRES [16], Lyne & Hollick [17], EWMA [18], and Chapman algorithm [19-20].

Preliminary study on the application of these methods in part of East Java region has been published [21]. The mechanism of how RDF work is similar to the method used in signal processing. In signal processing the algorithm work as a filter to separate high signal (or extreme value) from their average (the common value) by using a certain filter based on a threshold or other deterministic values. However, in hydrograph analysis, the filter work to separate the quick flow component that similar to the high-frequency signal and the base flow component that analogue to the low frequency signal. The six algorithms are presented in Table-1.

Table-1. The Six RDF filters used in this study.

Filter name	Equation
One-parameter [12]	$q_{b(i)} = \frac{k}{2-k} q_{b(i-1)} + \frac{1-k}{2-k} q_{(i)}$ (1)
Boughton two-parameter [13-15]	$q_{b(i)} = \frac{k}{1+C} q_{b(i-1)} + \frac{C}{1+C} q_{(i)}$ (2)
IHACRES [16]	$q_{b(i)} = \frac{k}{1+C} q_{b(i-1)} + \frac{C}{1+C}(q_{(i)} + \alpha_q q_{(i-1)})$ (3)
Lyne & Hollick [17]	$q_{f(i)} = \alpha q_{f(i-1)} + (q_{(i)} - q_{(i-1)})\frac{1+\alpha}{2}$ (4)
EWMA[18]	$q_{b(i)} = \alpha\, q_{(i)} + (1+\alpha)\, q_{b(i-1)}$ (5)
Chapman [19-20]	$q_{f(i)} = \frac{3\alpha-1}{3-\alpha} q_{f(i-1)} + \frac{2}{3-\alpha}(q_{(i)} - \alpha q_{(i-1)})$ (6)

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The process is repetitive for the whole periods of record. Further explanation of the theory and the equation can be found on the document written by Gregor [22-23] and from the original researcher's works. This paper focuses on the application of RDF algorithms in more wide areas than previous study [21], by searching potentially transferable parameters values.

METHODOLOGY

Study site and input data

This study uses all discharge measurement sites available on the region. About 54 locations of discharge measurement are used for this study. Figure-1 show: the location of watersheds used for calibration and validation, UPTs administrative boundaries, rain gauges network, and discharge measurements sites.

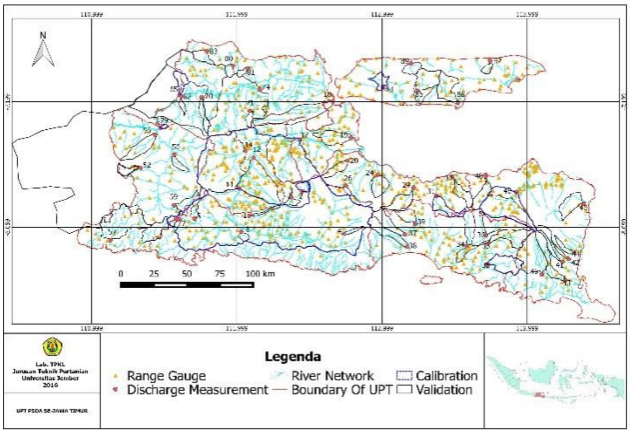

Figure-1. Study site 54 watersheds in East Java.

The East Java province consist of 9 administrative boundaries related to water resources management, named UPT (Unit Pelaksana Teknis). One unit of UPT covers between two to five regencies (Kabupaten). The daily discharge data (flow data) were available from 1996 to 2001/2005. Rainfall data were available from 1997 to 2001/2005.

The main land-use on the region was dominated by (1) irrigated paddy field, (2) residential use, (3) plantation, (4) forest, and (5) other cultivation fields. Table-2 summarized the main physical and hydrological properties of all watersheds. Catchment areas cover between ~14 km^2 to ~14000 km^2. The average daily discharge data range from 0.15 m^3/s to 361 m^3/s. Average daily rainfall range from 2.80 - 86.39 mm/day.

Procedures

Data preparation

Daily discharge data from 54 watersheds were prepared using Excel and then formatted to text format (*.txt). Furthermore, the file text (*.txt) were imported to Hydr Office [22-23] for base flow separation processes. The six RDF methods were used to calculate base flow from measured (observed) daily hydrograph data. Calibration and validation process were executed on BFI Module [22-23]. More analysis, interpretation, and visualization of the result were prepared using Excel. Calibration and validation processes are conducted at each UPT boundary.

Calibration process

Each watershed was calibrated manually. A range of parameter values was entered by trial and error, on a year basis (annually) from the Graphical User Interface (GUI) of BFI module's in HydrOffice package [22-23].

The trial is stopped when the curve of calculated base flow(red curve) is closely fitted to the observed discharge (blue area curve) for each dry period (Figure-2).

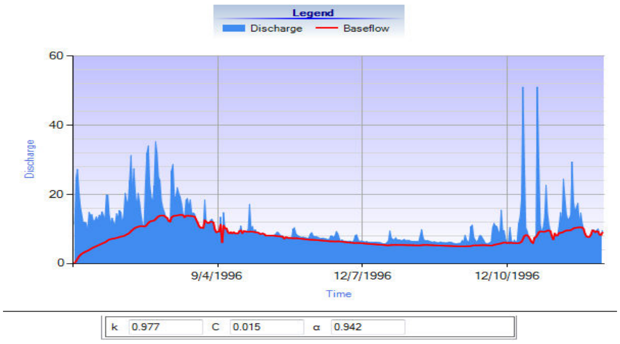

Figure-2. Example of calibration process of parameter values on BFI module.

In this case, we use the period between July to September of each year to evaluate the performance of calibration process by assuming that between this period usually no or less rainfall occur in this region. Therefore, for the dry period, we can assume that portion of quick flow or Direct Runoff (DRO) are less or close to zero value. Finally, the optimal values of parameters for each watershed are obtained by averaging yearly values.

Validation process

Firstly, one watershed was selected as calibrated watershed for each administrative boundary of UPT. The selection was based on the completeness of discharge data on each watershed. Furthermore, optimal parameter value from calibrated watersheds was used to separate base flow on other watersheds at the same administrative boundary of UPT.

Statistical analysis

Statistical analysis of calibration and validation result were conducted by comparing calculated base flow and measured total flow for all dry period. Statistically, this measured by Root Mean Square Error (RMSE) (equatio-7) to evaluate the goodness of fits between measured and calculated base flow.

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Table-2. Main physical and hydrological properties of the watersheds.

	Watersheds	Area (km^2)	Daily Rainfall		Daily discharge		Periods
			Average (mm/day)	Maximal (mm/day)	Average (m^3/day)	Maximal (m^3/day)	
1	1_Bacem	35.32	26.00	115.00	0.73	20.50	1996 – 2001
2	2_Coban Rondo	62.43	20.00	182.00	0.47	3.91	1996 - 2001
3	3_Jabon	5.67	21.00	162.00	0.46	10.70	1996 – 2001
4	4_Baros	9.96	20.00	150.00	0.15	1.21	1996 – 2001
5	5_Temon	16.94	23.00	143.00	2.93	57.30	1996 - 2001
6	6_Keser-Keser	7.42	17.00	125.00	3.28	69.60	1996 - 2001
7	7_Duren Kebak	6.54	22.00	160.00	0.35	24.70	1996 - 2001
8	8_Pundensari	11.34	16.00	145.00	110.13	988.00	1996 - 2001
9	9_Brantas Kertosono	6.499.50	26.00	109.00	135.41	829.00	1996-2001
10	10_Brantas Ploso	8.962.00	23.00	314.00	175,62	1168,00	1996-2001
11	12_Brantas Mojoroto	5.816.03	17.00	140.00	133,19	667,00	1996-2001
12	17_Brantas Mojokerto	9.993.67	21.00	139.00	191.82	863,00	1996-2001
13	18_lamong Simoanggrok	8.73	28.00	124.00	5,08	96,90	1996-2001
14	19_Brantas Perning	218.43	20.00	120.00	48,21	236,00	1996 - 2005
15	20_Rondodingo	135.30	58.90	134.00	4.99	101.00	1996 - 2005
16	24_Rejoso	168.10	30.26	80.00	12.52	110.19	1996 - 2005
17	26_Kramat	177.40	27.77	89.00	2.62	193.03	1996 - 2005
18	29_Welang	157.30	47.27	145.00	3.89	32.55	1996 - 2005
19	31_Kadalpang	113.20	61.41	95.00	2.91	69.04	1996 - 2005
20	32_Pekalen	165.20	86.39	178.00	10.94	94.30	1996 - 2005
21	33_Mayang	264.25	5,18	69,7	5,75	70,45	1996 - 2005
22	34_Rawatamtu	771.83	4,98	68,4	35,90	588,00	1996 - 2005
23	35_Sanenrejo	275.48	3,9	102,5	9,89	283,00	1996 - 2005
24	37_Karang Asam	179.16	14,35	104.00	14,35	104,00	1996 - 2005
25	38_Mujur	199.14	5,69	124,2	5,05	23,20	1996 - 2005
26	39_Wonorejo	116.84	4,79	99,3	18,57	196,06	1997 - 2005
27	40_Bajulmati	203.10	3,44	51,3	1,99	12,02	1997 - 2005
28	41_ Bomo Atas	65.70	2,8	96,7	1,45	15,4	1997 - 2005
29	42_ Bomo Bawah	93.50	7,29	149,8	1,28	63,8	1997 - 2005
30	43_Stail_Kradenan	477.80	4,23	118,8	9,98	498.00	1997- 2005
31	44_Tambong	722.10	17,89	145.00	3,73	54.00	1997 - 2005
32	45_Karangdono	218.10	4,37	81,5	22,02	119.00	1997 - 2005
33	46_Kloposawit	761.00	4,09	67,4	9,21	97.00	1997 - 2005
34	47_Delulwang	162.70	3,00	62.00	1,28	25,7	1997 - 2005
35	50_Nambangan	2126.00	17.00	101.00	38.26	397.00	1996 – 2001
36	52_Magetan	90.70	21.00	104.00	1.28	28.30	1996 – 2001
37	53_Kauman	5195.60	25.00	121.00	177.37	2035.00	1996 – 2001
38	54_Nepal	14.40	19.00	139.00	262.70	2141.00	1996 – 2001
39	55_Ngawi	213.38	30.00	129.00	92.23	972.00	1996 - 2001
40	57_Kedungpring	610.32	16.00	181.00	4.54	47.00	1996 – 2001
41	59_Ngindeng	109.85	20.00	105.00	4.54	47.00	1996 – 2001
42	65_Cepu	105.97	19.00	96.00	306.16	2481.00	1996 – 2001
43	70_Stren	93.73	27.00	141.00	2.04	19.20	1996 – 2001
44	71_Pejok	48.41	29.00	168.00	1.37	32.80	1996 – 2001
45	79_Gandek	11.18	27.00	129.00	2.91	132.00	1996 – 2001
46	80_Merakurak	29.28	22.00	92.00	0.53	27.20	1996 – 2001
47	81_Genaharjo	33.56	20.00	97.00	0.67	11.60	1996 – 2001
48	82_Singgahan	31.71	27.00	141.00	3.30	80.10	1996 – 2001
49	83_Belikanget	105.72	19.00	141.00	1.76	45.10	1996 – 2001
50	84_Blega Telok	99.83	21.59	163.00	1.78	68.10	1996 - 2001
51	85_Kemuning Pangilen	251.11	17.78	101.00	17.58	660.00	1996 – 2001
52	86_Samiran Propo	263.03	18.11	130.00	0.84	26.10	1996 – 2001
53	89_Nipah Tebanan	98.83	22.98	120.00	3.20	323.00	1996 - 2001
54	92_Klampok Ambunten	47.08	15.94	98.00	0.66	8.82	1996 – 2001

$$\text{RMSE} = \frac{\sqrt{\Sigma(\,Q_c - Q_0)^2}}{n} \qquad (7)$$

Where:

Q_c : calculated baseflow (m^3/s),

Q_0 : measured total flow (m^3/s),

n : number of samples.

If the values of RMSE close to zero (0), it shows the goodness of fits between measured and calculated base flow.

Visualization

Base flow separated from the total flow are then visualized by means of hydrograph and Flow Duration Curve (FDC) for selected discharge measurement sites. The FDC is a tool generally acceptable to visualize discharge time series [24].

The spatial distribution of base flow index (BFI) is visualized using quantum GIS [25]. A thematic layer of BFI can be visualized based on monthly average value. BFI is a proportion of base flow per total flow at specifics time interval (usually daily). In this case the BFI = Base flow(calculated)/ total-flow (observed discharge*).* The BFI concept uses the original form of BFI from Institute of Hydrology [26].

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RESULTS AND DISCUSSIONS

Calibration result

Range of parameter

Firstly, within UPT, each watershed was tested by a different range of parameters values. Table-3 presented the range of parameters values (from minimum to maximum) used for trial and error during the calibration process from all UPT's boundaries. For each UPT the minimum and maximum values may be different, that depend on parameters values obtained from the trial and errors process. The values as presented in Table-3 are the resume from all UPT values.

Table-3. Range value of parameters tested for calibration.

RDF Methods	Range of parameter values tested		
	k	C	α
One parameter	0,62 - 0,99		
Bougthon	0,72 - 0,99	0,010 - 0,360	
IHACRES	0,85 - 0,98	0,010 - 0,340	
Lynie-Hollick			0,94 - 0,99
Chapman			0,33 - 0,99
EWMA			0,001 - 0,04

Optimal parameter

Secondly, optimal values of parameters for each algorithm are determined by averaging yearly value. Furthermore, Table-4 shows the statistical resume (Min = minimum value, Max = maximal value, Ave=average value, St.Dev = standard deviation, CV= coefficient of variation) of calibration result and a range of optimal parameters value for each algorithm. The range parameter values in Table-3 are the resume for all 54 watersheds used in this study.

Table-4. Statistical value of optimal parameters obtained from calibration.

RDF Algorithm	Symbol	Optimal values obtained from calibration					
		Min	Max	Ave	St.Dev	CV	Range
One parameter	*k*	0.615	0.993	0.913	0.090	0.008	0.61 - 0.99
Bougthon	*k*	0.719	0.990	0.937	0.051	0.003	0.71 - 0.99
	C	0.010	0.360	0.106	0.123	0.015	0.01 - 0.36
Ihacres	*k*	0.850	0.981	0.947	0.030	0.001	0.85 - 0.98
	C	0.010	0.942	0.170	0.322	0.102	0.01 - 0.94
	α	0.013	0.910	0.445	0.339	0.113	0.013 - 0.91
Lyne-Hollick	*α*	0.940	0.998	0.980	0.016	0.000	0.94 - 0.99
Chapman	*α*	0.610	0.999	0.941	0.093	0.008	0.61 - 0.99
EWMA	*α*	0.001	0.998	0.025	0.135	0.018	0.001 - 0.99

Table-3 shows that "St.Dev" of parameters values obtained from calibration processes are range from 0.03 to 0.33, while the "CV" are less than 0.12 for different watersheds used in this study. It is shown that value of St.Dev and CV obtained from calibration are relatively small among watersheds.Furthermore, Table 3 also shows that parameter value is relatively similar among watersheds. In another word, the different watershed used in this study, show the relatively similar parameter values.

Statistical analysis of calibration

Thirdly, Table-5 show the RMSE calculated only for calibration watersheds.

Table-5. RMSE Value obtained from calibration.

Calibrated watershed	UPT boundary	RDF algoritms					
		One parameter	*Bougthon*	IHACRES	Lynie & Hollick	Chapman	EWMA
Coban rondo	UPT 1	0.011	0.011	0.011	0.009	0.011	0.009
Brantas Mojoroto	UPT 2	1.149	0.694	1.03	0.89	0.859	0.89
Brantas Mojokerto	UPT 3	0.71	0.79	0.77	0.84	0.51	0.77
Pekalen	UPT 4	0.11	0.04	0.1	0	0.1	0
Rawatamtu	UPT 5	0.109	0.236	0.239	0.051	0.09	0.077
Kloposawit	UPT 6	0.081	0.058	0.04	0.079	0.018	0.018
Nepal	UPT 7	1.204	0.983	1.19	0.863	1.081	1.042
Cepu	UPT 8	0.034	0.039	0.026	0.025	0.035	0.045
Blega Telok	UPT 9	0.023	0.02	0.024	0.023	0.017	0.019

The RMSE values (in Table-4) are calculated by comparing calculated base flow from the six (6) RDF methods vs the observed stream flow for the dry period (July - September). Table-4 shows that majority of the RMSE value obtained from calibration processes using different algorithms done the RMSE value less than 0.12. It indicates that different algorithm can perform similarly even tested in different watersheds. However, the exception results are for UPT2, UPT3, and UPT7, in this large sizes of watersheds such as in UPT2 and UPT3 may propagate the calibration results. Model performance is indicated by less value of RMSE (close to zero).

Validation result

Table-6 show the RMSE values obtained from validation watersheds using setting parameters from calibrated watershed.

Highlighted row (in Table-5) mark the calibrated watershed, which parameter values are used to simulated base flow on other watersheds (validated watershed) at the same UPT boundary. It is found that RMSE validation watershed can be quietly high or low compared to calibrated watersheds for all UPTs boundaries. This means that using parameter values from calibrated watershed is still suitable for the majority of the watersheds.

Furthermore, Table-7 show the statistical resume of the RMSE value obtained from calibration process (resume of Table-5).

Table-6. RMSE obtained from validation process.

UPT	Watershed	One parameter	Boughton	IHACHRES	Chapman	Lyne Holick	EWMA
UPT 1	Lahar bacem	0.011	0.011	0.011	0.009	0.011	0.009
	Coban rondo	0.005	0.005	0.005	0.004	0.004	0.004
	Sayang Jabon	0.008	0.007	0.008	0.008	0.007	0.008
	Sumber ampel	0.014	0.014	0.014	0.014	0.013	0.014
	Bagong	0.130	0.126	0.133	0.132	0.132	0.154
	Keser	0.406	0.547	0.419	0.588	0.391	0.588
	Duren Kebak	0.009	0.008	0.009	0.008	0.008	0.008
	Kali Brantas	1.587	1.407	1.602	1.175	1.461	0.177
UPT 2	Kertosono	1.129	0.681	1.015	0.256	0.787	0.870
	Brantas Ploso	0.711	0.853	0.630	0.513	0.436	0.513
	Mojoroto	1.149	0.694	1.030	0.890	0.859	0.890
UPT 3	Perning	0.640	0.780	0.760	0.920	0.500	0.500
	Mojokerto	0.710	0.790	0.770	0.840	0.510	0.770
	Lamong	0.940	0.820	0.850	0.980	0.550	0.970
UPT 4	Kadalpang	0.030	0.020	0.030	0.020	0.030	0.020
	Rejoso	0.210	0.080	0.130	0.010	0.210	0.010
	Welang	0.050	0.020	0.030	0.020	0.050	0.010
	Kramat	0.050	0.020	0.030	0.020	0.050	0.010
	Pekalen	0.110	0.040	0.100	0.000	0.100	0.000
	Rondodingo	0.050	0.020	0.030	0.020	0.040	0.020
UPT 5	Rawatamtu	0.109	0.236	0.239	0.051	0.090	0.077
	Mayang	0.030	0.055	0.056	0.014	0.025	0.026
	Sanenrejo	0.081	0.107	0.108	0.066	0.073	0.069
	Mujur	0.151	0.206	0.208	0.147	0.185	0.188
	Wonorejo	0.242	0.348	0.351	0.163	0.232	0.192
	Karang Asem	0.366	0.435	0.439	0.324	0.073	0.387
UPT 6	Bajulmati	0.033	0.023	0.015	0.033	0.005	0.005
	Bomo Atas	0.055	0.054	0.052	0.056	0.051	0.050
	Bomo Bawah	0.178	0.175	0.171	0.181	0.170	0.168
	Stail Kradenan	0.349	0.340	0.330	0.353	0.325	0.322
	Tambang	0.109	0.102	0.098	0.110	0.094	0.093
	karangdoro	0.405	0.349	0.299	0.404	0.234	0.229
	Kloposawit	0.081	0.058	0.040	0.079	0.018	0.018
	Deluwung	0.007	0.005	0.004	0.007	0.001	0.001
UPT 7	Madiun	0.713	0.532	0.708	0.722	0.836	0.838
	Gandong Mage	0.026	0.022	0.026	0.022	0.024	0.024
	Kauman	1.755	1.387	1.717	0.980	1.412	1.269
	Nepal	2.555	2.012	2.491	1.921	2.274	2.339
	Madiun Ngawi	1.204	0.983	1.191	0.863	1.081	1.042
	Kedungpring	0.005	0.004	0.005	0.003	0.004	0.004
	Ngindeng	0.076	0.058	0.075	0.060	0.070	0.072
UPT 8	Cepu	0.034	0.039	0.026	0.025	0.035	0.045
	Setren	0.016	0.017	0.016	0.012	0.016	0.014
	Babat	2.932	3.115	2.573	1.607	2.639	2.579
	Gandek	0.031	0.034	0.031	0.021	0.031	0.027
	Merakurak	0.004	0.007	0.004	0.001	0.003	0.005
	Genaharjo	0.007	0.008	0.006	0.003	0.006	0.005
	Singgahan	0.024	0.032	0.021	0.009	0.017	0.019
	Belikanget	0.024	0.030	0.021	0.009	0.019	0.019
UPT 9	Blega Telok	0.023	0.020	0.024	0.023	0.017	0.019
	Kemuning	0.066	0.065	0.068	0.059	0.039	0.039
	Samiran	0.006	0.004	0.007	0.006	0.002	0.003
	Nipah	0.014	0.012	0.015	0.014	0.010	0.010
	Klampok	0.004	0.004	0.004	0.004	0.001	0.002

Table-7. RMSE of calibration.

Statistic	One parameter	Boughton	IHACHRES	Chapman	Lyne Holick	EWMA
Min	0.011	0.011	0.011	0.000	0.011	0.000
Max	1.204	0.983	1.191	0.890	1.081	1.042
Ave	**0.381**	**0.319**	**0.381**	**0.309**	**0.302**	**0.319**
St.Dev	0.500	0.390	0.479	0.417	0.413	0.442
CV	0.222	0.135	0.204	0.155	0.152	0.174

Finally, Table-8 show the same statistical resume for all validation process.

Table-8. RMSE of validation.

Statistic	One parameter	Boughton	IHACHRES	Chapman	Lyne Holick	EWMA
Min	0.004	0.004	0.004	0.000	0.001	0.000
Max	2.932	3.115	2.573	1.921	2.639	2.579
Ave	**0.364**	**0.330**	**0.353**	**0.274**	**0.301**	**0.292**
St.Dev	0.633	0.577	0.596	0.442	0.552	0.538
CV	0.394	0.327	0.349	0.192	0.299	0.285

Tables 6, 7 and 8, show the average RMSE value for all methods ranges from 0.30 to 0.38 for calibration process, and from 0.27 to 0.36 for validation process. It appears that RMSE obtained from calibration and validation process are relatively similar. In another word, the parameters values from calibrated watersheds are transferable to validation watersheds where located at the same boundary of UPTs.

Visualization

Hydrograph and FDC

Figure-3 show the examples of base flow separation result in the form of the hydrograph.

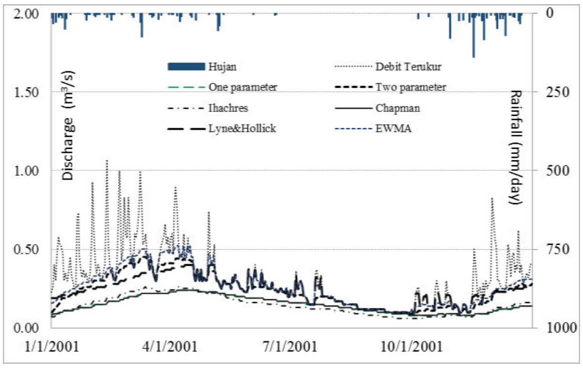

Figure-3. Hydrograph shows the separated base flow from total flow/observed flow (debit terukur).

Figure-3 visualize the hydrograph of the 86_Samiran_propo (UPT 9, row 52 in Table-1), zoom for 1 year period (1 January-31 December 2001). Furthermore, hydrograph of separated base flow can be visualized for each watershed and zoomed for specifics periods. This chart is useful to estimate the availability of flow as a function of time within the watershed area.

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Calculated base flow separated from the hydrograph can be visualized also in the form of Flow Duration Curve (FDC). Figure-4 present the example of FDC from 84_Blega_Telok (UPT9, row 50 of Table-1).

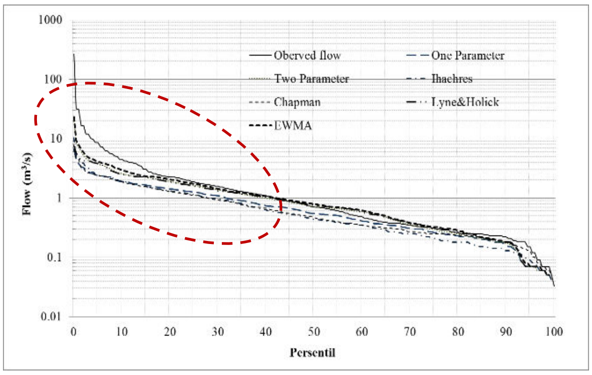

Figure-4. The FDC show the separated base flow from total flow/observed flow (debit terukur): for 84_ Blegatelok watershed.

The FDC curve in Figure-4 plots and shows the difference between observed flow (total flow = quick flow + base flow) on the river and the calculated (separated) base flow. This more clear, during the rainy seasons (from October to May) as showed in the upper left area of Figure 4. However, during dry seasons (July to September) the form of total flow curve (dashed-point-line graph) is relatively similar to the curve of separated base flow (bold-continue-line), as showed on the bottom right of the FDC plot (Figure-4). The same curve can be produced for each measurements sites to serve water resources management on the watersheds. Furthermore, hydrograph plotting as a result of base flow separation process can be visualized for each region.

Spatial distribution of BF*I*

Figure-5 and Figure-6 shows two thematic maps of an average monthly value of base flow index (BFI), which calculated using Lyne & Hollick method. The first map (Figure-5) show the spatial distribution of BFI for dry season (using a sample in July). The second map (Figure-6) show the spatial distribution of BFI for wet season (using a sample in January). It is shown that maximal BFI is greater for dry seasons than rainy seasons. Furthermore, BFI value for most of the watersheds ranges between 0.71 to 1.00 for the dry period and between 0.62 to 0.80 for the wet or rainy season. This shows that this region is strongly influenced by base flow contribution. In the rainy season the contribution of baseflow is more than 0.60 and in dry season baseflow contribution is more than 0.70.

CONCLUSIONS

The study shows the calibration and validation of six recursive digital filters (RDF) methods to separate baseflow from the total flow (observed flow) in the East Java region. The study shows that all method can be used, however, three algorithms (Ihacres, Lyne & Hollick, and EWMA filters) perform better than others methods. The result also shows the setting of parameters values from calibrated watershed is transferable to others watersheds at the same UPT boundary. Furthermore, most watersheds on this regions are considered influenced by strong contribution of baseflow both for rainy and dry seasons.

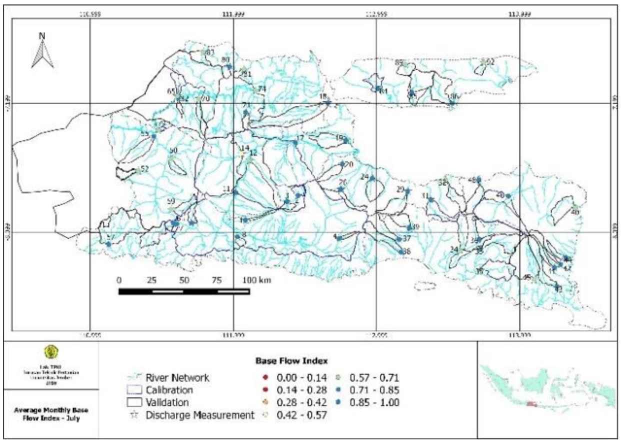

Figure-5. The average monthly value of BFI for July.

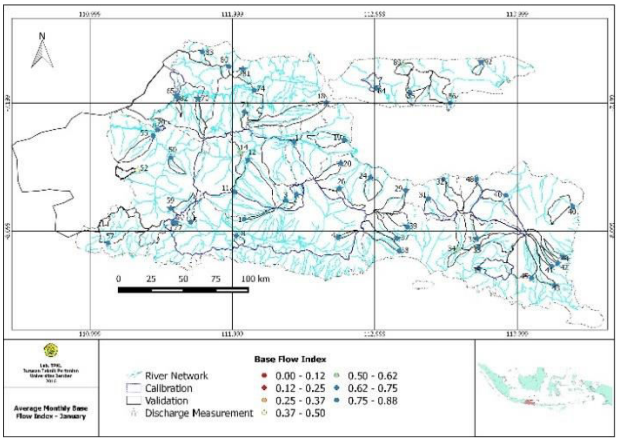

Figure-6. The average monthly value of BFI for January.

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