Available online at www.sciencedirect.com

ScienceDirect

Agriculture and Agricultural Science Procedia 9 (2016) 538 – 550

Agriculture and Agricultural Science
Procedia

International Conference on Food, Agriculture and Natural Resources, IC-FANRes 2015

Preliminary Study on Baseflow Separation at Watersheds in East Java Regions

Indarto[a]*, Elida Novita[a], Sri Wahyuningsih[a]

[a]*PS Teknik Pertanian, FTP – UNEJ, Jl. Kalimantan no. 37 Kampus Tegalboto, Jember 68121*

Abstract

This research aims to determine the range of parameter value, baseflow index and the appropriate method for *base flow separation*. Seven (7) *recursive-digital-filters (RDF)* and two (2) graphical methods are used for this study. Discharge data from 8 watersheds in the administrative area of UPT PSDA Bondowoso in East Java were used to test the methods. Firstly, each method was calibrated using daily discharge data for each year (annually) to separate baseflow. Then, optimal parameter values are obtained by averaging the annual values. Calibration process produced optimal parameters value for each watershed. Furthermore, validation was performed using optimal parameter values from watershed having complete discharge data to other watersheds. The results show that optimal parameter values from calibrated watershed can be used to separate base flow in other watersheds. Principally, all methods can be used to separate base flow on this region, however three methods (EWMA, Line-Hollick and Local Minimum) perform better than others 6 methods.

Peer-review under responsibility of the organizing committee of IC-FANRes 2015

Keywords: baseflow; separation ; digital filter; digital graphic; east java.

* Corresponding author. Tel.: +62-85749797995
E-mail address: indarto.ftp@unej.ac.id

2210-7843
Peer-review under responsibility of the organizing committee of IC-FANRes 2015
doi:10.1016/j.aaspro.2016.02.174

1. Introduction

Hydrograph shows graphical representation of discharge or flow data on the river as function of time. The discharge is plotted as Y-axis and time series data (hourly, daily or monthly basis) is presented in X-axis. Commonly, Hydrograph is used as tool to interpret the response of watershed due to rainfall events. Hydrograph composed of two component, i.e.: quickflow and baseflow. Quickflow represent the rapid response of the river on the watershed caused by direct surface runoff, troughflow and rain event that fall directly to the river body. Baseflow represent the response of the river on the watershed supplied by groundwater flow and other type of flow that enter more slowly to the river streams, as defined by Hall (1986, 1971). Understanding and counting the contribution of these two components is essential for water resources management on the watershed (Brodie and Hostetler, 2007). In tropical region, the contribution of these two components may be significantly different between rainy and dry seasons. Quickflow contribute more dominant during the rainy or wet seasons. Contrary, during the dry season where no or less rainfall on the watersheds, the stream flow are significantly dominated by baseflow contribution to the river.

The quickflow is important to be considered when the objectives of water resources management are to collect, to store and to maintain the volume of water (e.g.: supply of reservoir, paddy irrigation, etc.). For disaster mitigation purposes the prediction of quickflow is also important to anticipate the potential discharge generated by flood event. However, during the dry seasons, majority of rivers in East Java are supplied only by baseflow. Furthermore, during the dry seasons, baseflow contribution are generally less than the demand of flows (for: residential, irrigation, industrial use, etc...). The lack of water supply during the dry season is more and more important problems to be solved during the last decades.

Debit or stream flow that usually observed on the river is actually composed by these two components (quickflow and baseflow). Practically, it is difficult to identify the portion of each component from measured discharge. However, some methods have been developed in order to interpret the portion and contribution of baseflow to river streams.

1.1. Baseflow separation methods from hydrograph

Analysis of baseflow component from hydrograph was reported since Boussinesq (1904), developed a theory from his empirical experience. After that, some related works are developed as published by Maillet (1905) and Horton (1933). Furthermore, literature reviews concern with the development of methodology for baseflow analyses are reported by Hall (1968; 1971), Nathan and McMahon (1990ab), Tallaksen (1995), Smakhtin (2001ab), Brodie and Hostetler (2007), Murphy et al.(2009) and Gonzales et al.(2009). Those examples of works and literature reviews show the development of divers' methodologies for baseflow analysis. Now, more practical methods based on digital filter and digital graphic separation are also developed (Gregor, 2010, 2012). These methods are more practice and more simple to be implemented in developing countries and on others watersheds worldwide.

1.2.1 Recursive digital filter (RDF)

The mechanism of how RDF work is similar to the method used on signal or in frequency analysis. In hydrograph analysis, the filter is use to separate the quickflow component that similar to high frequency signal and the baseflow component that analog to low frequency signal. The process is repetitive for the whole periods of record.

Some RDF algorithms have been developed and can be found, for example on the work of Pettyjohn and Henning (1979), Nathan dan McMahon (1990ab), Grayson et al. (1996), Chapman and Maxwell (1996), Chapman (1999), Furey and Gupta (2001), Tallaksen and Van Lannen (2004), and Eckhardt (2005, 2008). Detailed review of existing method for baseflow analysis (Including RDF methods) are reported by: Brodie and Hostetler (2007) and Murphy et al. (2009). Furthermore, Gregor (2010, 2012) developed practical tool named HydrOffice (http://hydrooffice.org) that serve baseflow separation easily conducted.

Table 1. Six RDF methods used for this study (Gregor, 2010, 2012)

Filter name	Equation	Reference
One-parameter	$q_{b(i)} = \frac{k}{2-k} q_{b(i-1)} + \frac{1-k}{2-k} q_{(i)}$ (eq. 1)	(Chapman dan Maxwell, 1996)
Boughton two-parameter	$q_{b(i)} = \frac{k}{1+C} q_{b(i-1)} + \frac{C}{1+C} q_{(i)}$ (eq. 2)	(Boughton, 1987, 1993; Chapman & Maxwell, 1996)
IHACRES three-parameter	$q_{b(i)} = \frac{k}{1+C} q_{b(i-1)} + \frac{C}{1+C} (q_{(i)} + \alpha_q q_{(i-1)})$ (eq. 3)	(Jakeman & Hornberger, 1993)
Lyne & Hollick	$q_{f(i)} = \alpha q_{f(i-1)} + (q_{(i)} - q_{(i-1)}) \frac{1+\alpha}{2}$ (eq. 4)	(Lyne & Hollick, 1979; Nathan & McMahon, 1990ab)
EWMA	$q_{b(i)} = \alpha\, q_{(i)} + (1+\alpha)\, q_{b(i-1)}$ (eq. 5)	(Tularam and Ilahee, 2008)
Chapman	$q_{f(i)} = \frac{3\alpha-1}{3-\alpha} q_{f(i-1)} + \frac{2}{3-\alpha} (q_{(i)} - \alpha q_{(i-1)})$ (eq. 6)	(Chapman, 1991; Mau & Winter, 1997)
Eckhardt Filter	$q_{b(i)} = \frac{(1 - BFI_{max})\alpha q_{b(i-1)} + (1-a)\, BFI_{max} \times q_i}{1 - \alpha\, BFI_{max}}$ (eq. 7)	*(Eckhardt, 2005)*

Note:

$q_{(i)}$	:	total flow (observed flow) at day i
$q_{b\ (i)}$	:	calculated baseflow at day i
$q_{f\ (i)}$	:	calculated quick flow/direct run off at day i
$q_{(i-1)}$	:	total flow at day (i - 1)
$q_{b\ (i-1)}$	:	calculated baseflow at day (i - 1)
$q_{f\ (i-1)}$	:	calculated quick flow/direct run off at day (i - 1)
k	:	filter parameter ~ recession Constant
α	:	filter parameter
C	:	filter parameter.
BFImax	:	maximum baseflow index (constant).

All RDF methods above (Table 1) calculate the baseflow for each interval (day i) using information of flow at day (i), day (i – 1), parameter value and constant. The parameter α, k and c are calibrated using daily discharge data empirically for each site (watershed). The BFI_{max} is determined by the user.

1.2.2 Digital Graphical Method (DGM)

Sloto & Crouse (1996) proposed three graphical methods to separate baseflow from the hydrograph, i.e : local minimum, fixed interval, and sliding interval. Local minimum method (Figure 1) search and use the minimum flow for each time-interval. Firstly, the interval is determined using [0,5 (2N*-1) day]. Value of **N** is determined empirically from Linsley et al. (1982), using N = $\mathbf{A^{0,2}}$, where A is watershed area in square miles (mil^2). Secondly, minimum flows for each time-interval is connected by straight line to describe the baseflow portion from the hydrograph. From Fig. (1), the minimum flow occurs at: 8, 13, 16 and 23 th January 1991.

The fixed interval method (Fig. 2) search the minimum flow for each time interval using interval (2N*day). **N** is the number of day when runoff finish and value of **N** is determined empirically from Linsley et al. (1982), using N = $A^{0,2}$, where A is watershed area in square miles. This method is illustrated by using bar chart that intersect with line hydrograph at the lowest point for each interval (Fig. 2). Baseflow for the next interval is determined by move the bar chart until intersect the lowest part of hydrograph. The process is continue for all interval available on

Hydrograph. Furthermore, Gregor (2010, 2012) developed those graphical methods as digital graphical method (DGM) in the form of BFI module on HydrOffice software package.

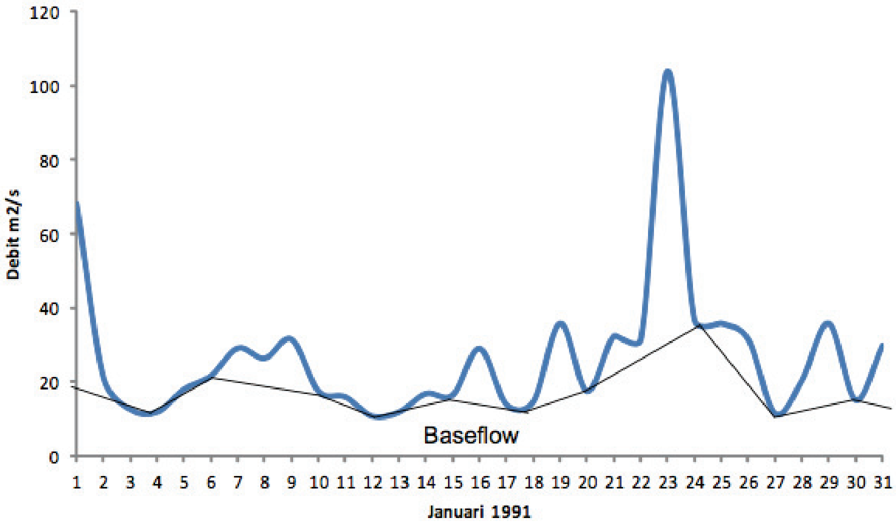

Fig.1. The local minimum method to separate baseflow of Kloposawit watershed for period of January 1991

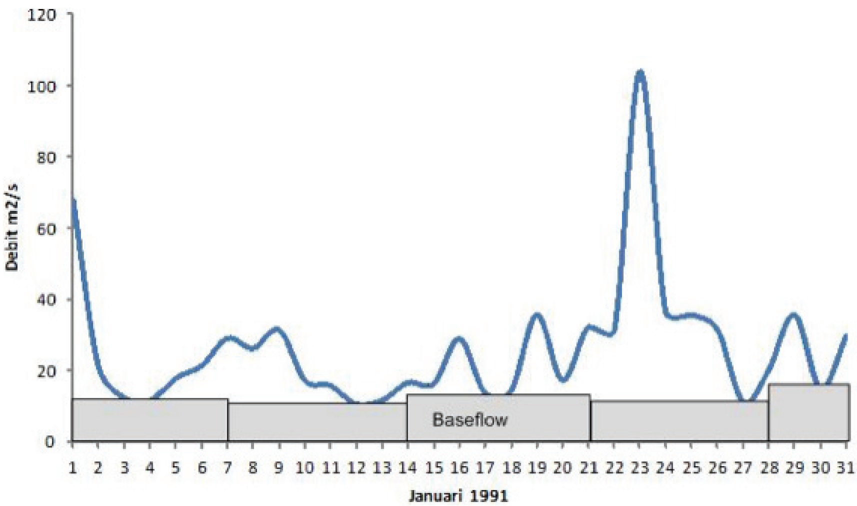

Fig.2. The use *fixed interval method to separate the baseflow of* Kloposawit watershed for January 1991

This study aims to evaluate and to search the appropriate method for baseflow separation. The performance of seven (7) recursive digital filters and two (2) graphical method are evaluated to separate baseflow.

2. Methodology

2.1. Study Site & Input data

The study was conducted at water administrative boundary of UPT PSDA *Bondowoso* (in East Java). Eight (8) watersheds on the regions (namely: *Bajulmati, Bomo Atas, Bomo Bawah, Stail-kradenan, Tambong-Pakishaji, Karangdoro, Kloposawit, and Deluwang*) are used to test the methods (Fig. 3). Table 2 summarized the main physical properties (i.e. area, form, and main river length) of the watersheds. Catchment area cover between ~66 km^2 up to 722 km^2, the watersheds can be distingue in two different form: wide triangle and elongated.

Table 2. Main physical properties of the watersheds

No	Name	Area (km^2)	form	Main river length (Km)
1	40_Bajulmati	203,1	Wide Triangle	19,31
2	41_Bomo_Atas	65,7	elongated	33,12
3	42_Bomo_Bawah	93,5	elongated	36,56
4	43_Karangdoro	477,8	Wide triangle	40,03
5	44_Kloposawit	722,1	Wide triangle	48,84
6	45_Stail_Kradenan	218,1	elongated	47,17
7	46_Tambong	53,9	elongated	17,21
8	47_Deluwang	162,7	elongated	35,12

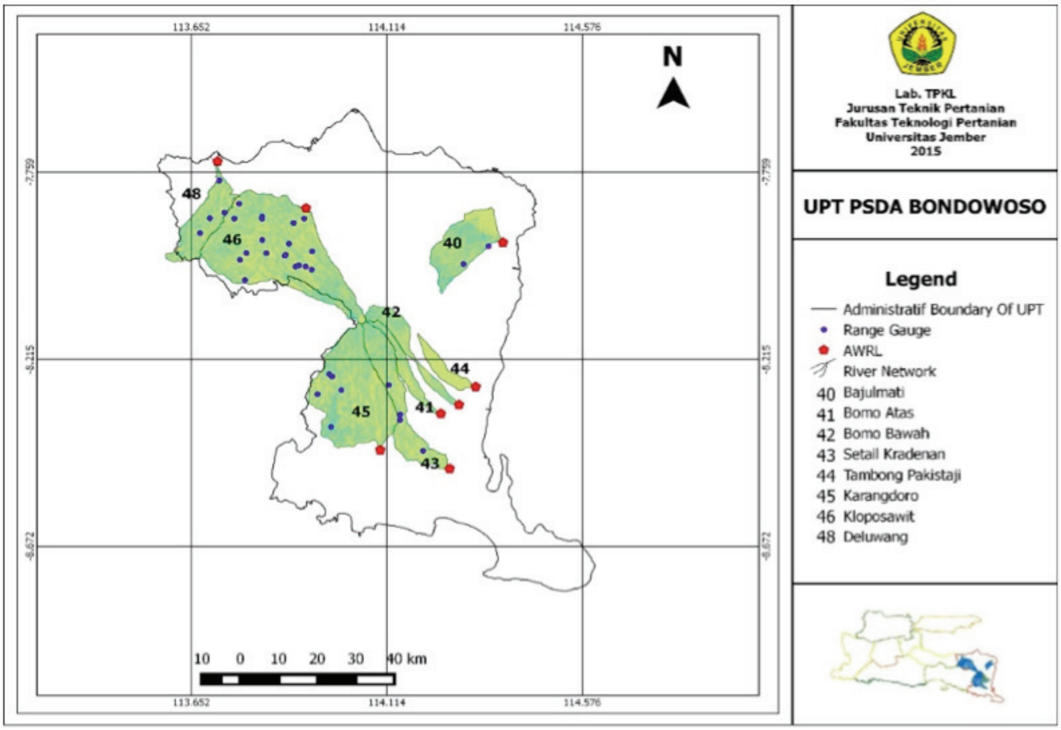

Fig. 3. Site location : 6 watersheds selected for baseflow separation test

Main statistical value of hydro-meteorological properties of the watersheds are presented in Table 3. The daily discharge data (flow data) is available only between 1996 up to 2005. Rainfall data is available from 1997 to 2005.

Table 3. Statistical value of hydro-meteorological properties of the watersheds.

No	Watershed	Daily discharge or flow in (m^3/s)					Rainfall in (mm)				
		Min	Max	MDF	Med	STD	Min	Max	MDF	Med	STD
1	40_Bajulmati	0,64	12,02	1,99	1,66	1,12	0,00	51,3	3,44	0,00	7,01
2	41_ Bomo Atas	0,02	15,4	1,45	0,96	1,1	0,00	96,7	2,8	0,00	7,18
3	42_ Bomo Bawah	0,20	63,8	1,28	0,71	1,42	0,00	149,8	7,29	2,8	11,05
4	43_Stail-Keradenan	0,13	498	9,98	4,81	19,11	0,00	118,8	4,23	0,3	8,01
5	44_Tambong	0,41	54	3,73	2,63	3,78	0,00	145	17,89	12,0	18,88
6	45_Karangdono	0,71	119	22,02	17,9	16,04	0,00	81,5	4,37	0,4	7,69
7	46_Kloposawit	1,29	97	9,21	7,82	6,27	0,00	67,4	4,09	0,5	6,77
8	47_Delulwang	0,00	15,4	1,28	0,71	1,42	0,00	62	3,00	0,00	6,68

Maximal daily rainfall data range from 98 up to 125 mm/day. Average flow for all watersheds are recorded between 5 to 36 m^3/day, maximum daily flow range from 23 to 588 m^3/day. Major land use are dominated by: (1) irrigated paddy field, (2) residential use, (3) plantation, (4) forest, and (5) other cultivation field. Three soil types (i.e.: mediteran, andosol and grumosol) are cover all areas of the watersheds.

2.2. Procedures

Daily discharge data from the sample watersheds above are prepared using OO-Calc/Excel, and then formatted to text (*.txt). Furthermore, the file (*.txt) are imported to Hydro Office for baseflow separation (Gregor, 2010, 2012). Baseflow separation from measured (observed) daily discharge data use seven (7) recursive digital filters (i.e.: (1) One parameter, (2) Bougthon – Two parameter, (3) Ihacres, (4) Chapman, (5) Lynie-Hollick, (6) EWMA and (7) Eckhardt filter and two (2) digital graphical methods, i.e : (1) fixed interval, and (2) local minimum (Gregor, 2010, 2012). Calibration and validation process are executed on the platform of Hydro Office (www.hydroffice.org) (Gregor, 2010, 2012).

More analysis, interpretation and visualization of result are prepared using Excel. Firstly, value of Root-Mean-Squares-Error (RMSE) method is used to compare the performance of calibration and validation process using several methods above. Then, Flow-Duration-Curves (FDC) are used to compare the baseflow separation results visually between dry season and rainy seasons. Furthermore, hydrographs that contain observed discharge vs baseflow calculated are also used to shows the separation results graphically. Finally, an index of baseflow (BFI) is used to compare between watershed and between seasons.

2.2.1. Calibration

Parameter values for each algorithm are entered by trial and error on a year basis (annually) (Figure 4). The process is stopped when the curve of calculated baseflow *(red-curve)* is close to the observed discharge *(blue area curve)* for dry period (Fig. 4).

In this case we use, periods between “July and September” to evaluate the performance of calibration process by assuming that between this period usually no or less rainfall on the region. This calibration process are realized for each watershed separately. All parameter values used to calibrate each watershed are presented in Table 4 as a range of parameter values explored in this study. The optimal values of parameters for each watershed and each method are obtained by averaging yearly values and resumed in Table (5a) and Table (5b).

2.2.2. Statistical Analysis

Statistical analysis of calibration result is conducted by comparing calculated baseflow and measured total flow for dry period (July until September), the period when no rainfall and no runoff for all most of the watersheds in East Java. In this period we can assume that *Quick-flow* or *Direct Runoff (DRO)* are close to zero value.

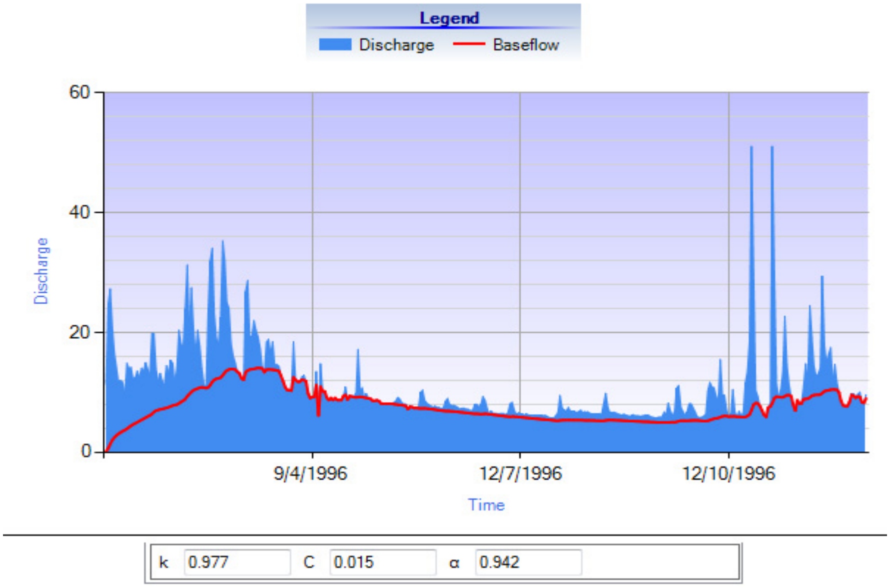

Fig. 4. Calibration process of parameter values

Furthermore, statistically this measured by Root Mean Square Error (RMSE) (eq. 8) to evaluate the goodness of fits between measured and calculated baseflow.

$$\text{RMSE} = \frac{\sqrt{\Sigma(Q_c - Q_0)^2}}{n} \quad \text{(eq. 8)}$$

Where:

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

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

n : number of sample.

Less values of RMSE indicate the strong correlation between measured and calculated base flow. Evaluation are also performed by means of scatter plot to obtain correlation coefficient. The results of RMSE and regression coefficient from scatter plot are presented in Table 6 for Kloposawit watershed.

2.2.3. Validation

Validation is realize to show how model performance by introducing the same parameter values for all watershed. In this case, “Kloposawit” watershed is selected and considered as “master watershed”. This watershed is more properly measured at sufficient length of recording period. The optimal parameter values obtained from calibration process at “Kloposawit”, are then used to evaluate the model performance on other watershed. The results are presented in Table (7) on the form of RMSE values obtained for each method at each watershed.

3. Result and Discussion

3.1. Calibration result

3.1.1. Range of parameter values

Table 4 resume the range of parameter value explored for each watershed and each model. The parameter value of Eckhardt filter (BFI-max) is set = 0,8. It is reasoned by the fact that most of the river in East Java regions are categorized as perennial river, therefore BFI-max is set to 0,8 (Eckhardt, 2005).

Table 4. Range of parameter values explored for calibration

Filter names	Range of parameter values explored for each watershed				
	k	**C**	**α**	**N**	**f**
One parameter	0,953 - 0,985				
Two parameter	0,961 - 0,989	0,017 - 0,022			
IHACRES	0,962 - 0,981	0,013 - 0,015	0,924 - 0,942		
Lynie-Hollick			0,961 - 0,985		
Chapman			0,988 - 0,993		
EWMA			0,011- 0,015		
Eckhardt			0,960 - 0,990	-	-
Minimum local				4,0 – 14,0	0,90 – 0,95
Fixed Interval				7,0 - 21,0	-

Table (5) and (6) show the optimal parameter values for each model and calibrated at each watershed. The optimal parameter values are the averaged value from yearly value. It is show that values of k, c and α are relatively similar for 5 RDF methods (i.e: one parameter, two parameter, Ihachres, Chapman, Lyne & Hollick). Table (5) also show that parameter values are relatively similar from one watershed to another. This appearance are show for all 7 RDF algorithms used in this study (ie: one parameter, two parameter, Ihachres, Chapman, Lyne & Hollick, EWMA and Eckhardt Filter). Table (5b) show the optimal parameter value obtained from two **D**igital **G**raphical **M**ethod **(DGM)**

Table 5. Optimal parameter values RDF methods

DAS	One parameter	Two parameter		IHACHRES			Chapman Algorithm	Lyne & Hollick	EWMA
	k	*k*	*c*	*k*	α	*c*	α	α	α
40_Bajulmati	0,983	0,989	0,022	0,981	0,929	0,014	0,981	0,989	0,015
41_ Bomo Atas	0,985	0,961	0,019	0,963	0,925	0,013	0,983	0,993	0,011
42_ Bomo Bawah	0,971	0,978	0,017	0,966	0,924	0,014	0,982	0,988	0,013
43_Stail-Kradenan	0,966	0,981	0,020	0,964	0,935	0,013	0,964	0,988	0,012
44_Tambong	0,953	0,984	0,018	0,962	0,941	0,015	0,974	0,990	0,011
45_Karangdono	0,955	0,982	0,018	0,967	0,935	0,013	0,967	0,991	0,012
46_Kloposawit	0,982	0,988	0,020	0,977	0,942	0,015	0,985	0,991	0,014
47_Delulwang	0,974	0,982	0,019	0,963	0,932	0,015	0,961	0,989	0,011

Table 6. Optimal parameter values for three methods

Watershed	*Eckhardt Filter*		*Fixed Interval Method*	Local Minimum	
	a	BFI-Max	N	N	f
40_Bajulmati	0,982	0,80	13,80	10,00	0,90
41_ Bomo Atas	**0,980**	**0,80**	**14,80**	**9,40**	**0,90**
42_ Bomo Bawah	0,980	0,80	13,00	6,00	0,90
43_Stail-Kradenan	0,982	0,80	14,20	9,00	0,90
44_Tambong	0,982	0,80	17,60	11,80	0,90
45_Karangdono	0,982	0,80	18,20	12,60	0,90
46_Kloposawit	0,980	0,80	15,21	10,79	0,91
47_Delulwang	0,982	0,80	13,20	8,00	0,90

3.1.2. Statistical analysis : RMSE and Scatter plot

Table 7 shows the statistical analysis results of RMSE values and coefficient of determination (R^2) for all methods at Kloposawit watersheds. The RMSE and R^2 are calculated using baseflow separation result for dry periods (July until September) of all year.

Table 7. RMSE and R^2 for Kloposawit Watersheds

Metode	Metode RDF							Metode Grafis	
	One parameter	*Bougthon*	Chapman	Ihacres	Lyne-Hollick	EWMA	Eckhardt	Min	Fixed
RMSE	0,033	0,023	0,015	0,033	0,005	0,005	0,081	0,086	0,079
Coef of determination	-1,287	-0,107	0,566	-1,185	0,939	0,939	0,590	0,545	0,610

Globally, Table 7 shows that all methods done the similar performances for calibration period at Kloposawit watershed. These are marked by RMSE value that close to ~ 0 , and the coeffient of determination (R^2) that close to ~1.

3.1.3. Parameter values substitution

Furthermore, table (7) shows RMSE values calculated from all methods tested on all watersheds using single setting of parameters values. In this study, optimal parameter values obtained for each methods from Kloposawit watershed were used to simulate baseflow at others watersheds. It is similar to from more gauged (known) to less gauge (unknown) watersheds. The RMSE values (in Table 7) are calculated for dry periods (from July to September of all years tested).

Table 7. RMSE values of each model tested on all watersheds using single setting of parameter values (optimal parameters of Kloposawit watershed).

	RDF methode							Graphical	
Watershed	*One parameter*	*Bougthon*	Chapman	Ihacres	Lynie & Hollick	EWMA	Eckhardt	Fixed	Min
40_Bajulmati	0,033	0,023	0,015	0,033	0,005	0,005	0,02	0,024	0,027
41_ Bomo Atas	0,055	0,054	0,052	0,056	0,051	0,05	0,048	0,057	0,06
42_ Bomo Bawah	0,178	0,175	0,171	0,181	0,170	0,168	0,13	0,117	0,122
43_Stail_Kradenan	0,349	0,34	0,33	0,353	0,325	0,322	0,241	0,273	0,288
44_Tambong	0,109	0,102	0,098	0,11	0,094	0,093	0,071	0,075	0,059
45_Karangdono	**0,405**	0,349	0,299	0,404	0,234	0,229	0,251	0,333	0,37
46_Kloposawit	0,081	0,058	0,04	0,079	0,018	0,018	0,079	0,086	0,081
47_Delulwang	0,007	0,005	0,004	0,007	0,001	0,001	0,004	0,004	0,004
Max	0,405	0,349	0,330	0,404	0,325	0,322	0,251	0,333	0,370
Average	**0,152**	**0,138**	**0,126**	**0,153**	**0,112**	**0,111**	**0,106**	**0,121**	**0,126**
Min	0,007	0,005	0,004	0,007	0,001	0,001	0,004	0,004	0,004
Standard deviation	**0,149**	**0,138**	**0,128**	**0,149**	**0,120**	**0,118**	**0,095**	**0,119**	**0,132**

Table 7 showed that transferring parameter values to surrounding watersheds (from Kloposawit to others watersheds) done the range of RMSE values results from (0,001 to 0,405). However, average RMSE values from one watershed to others for each method is relatively similar (between: 0,106 to 0,152). Location of watershed to other watershed may influence the RMSE results. Watershed that closes each other's tend to have similar input of rainfall characteristics. Similar rainfall characteristics on that region will propagate similar flow characteristics (Indarto et al. 2013).

3.2. Validation Results

3.2.1. Flow Duration Curve

In this study, *Flow Duration Curve* is used to show the model performance in separating baseflow between rainy and dry seasons. At dry season both observed flow and calculated baseflow are show similar in form at FDC graphics (Fig.7), due to no or less rainfall occur on this dry period (July to September). Therefore, the curve of observed and calculated baseflow are close to similar during dry periods (Fig 7). This is also show on the right-bottom corner of the FDC graphic areas (Fig.8) for all periods of flows (annual FDC).

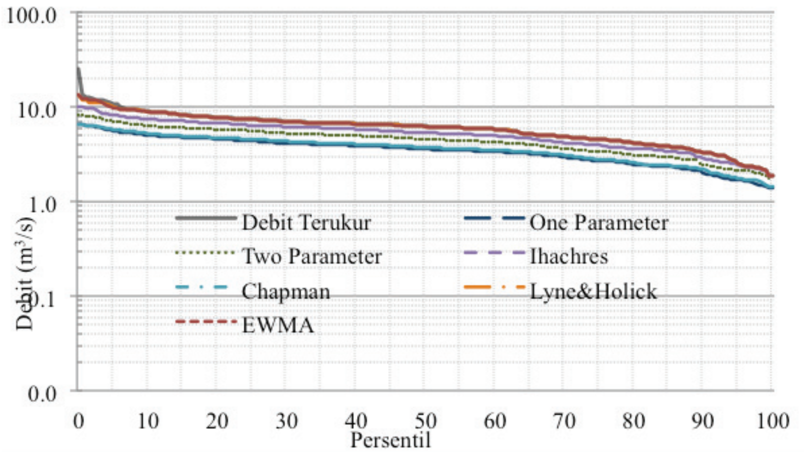

Fig.7 FDC curve of Kloposawit watershed for dry period only (July to September)

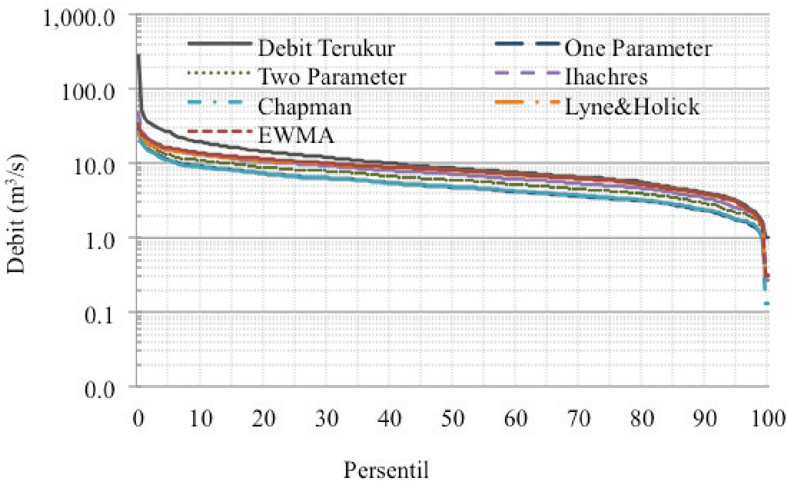

Fig 8. FDC Curve of Kloposawit watershed for all period (annual FDC)

However, for period of rainy seasons or high flows season, the calculated baseflow (separated baseflow component) by several methods above are relatively show below the observed flow, this appear on the up-left corner part of the FDC curves (Fig. 8). During, rainy season (between: October to Avril), the observed flow or total discharge is the sum of quick flow and baseflow. Quick flow component are more important than baseflow component during the periods of high flow. The FDC curves of Fig (8), could be used to shows the model performance visually in separating baseflow both on rainy and dry periods. Optimal baseflow separation method will show similar curve on the right-bottom corner and separated curve on the up-left corner to the observed flow curve on the FDC graphics.

3.2.2. Hydrograph visualization

Hydrographs in Fig. 9 to Fig.12 are used to illustrate the separated baseflow from total discharge for all periods of years. Fig. 9 shows the separated baseflow using 6 RDF methods zoomed for 01 January to 31 December 1991. Then Fig.10 visualized the separated baseflow by 6 RDF methods, zoomed for more length periods: 1991 to 1995.

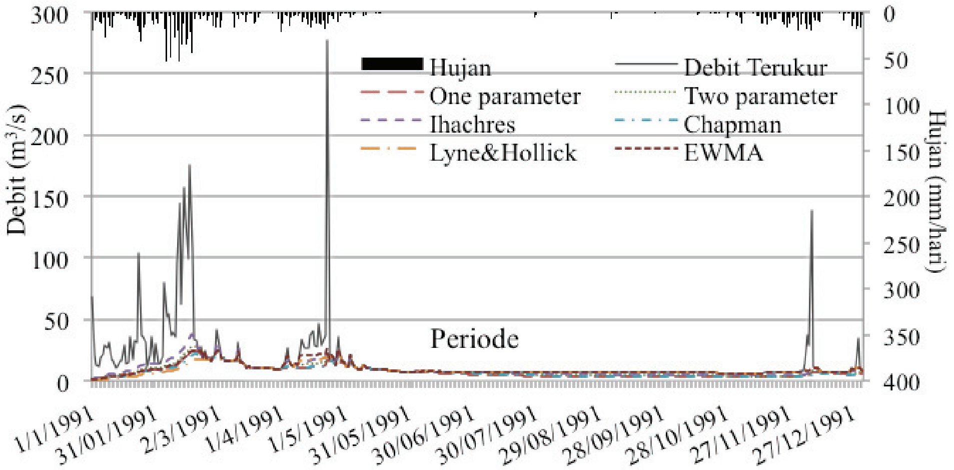

Fig. 9 Baseflow separation result using 6 RDF methods at Kloposawit Watershed (zoom: 01 Jan to 31 Dec 1991).

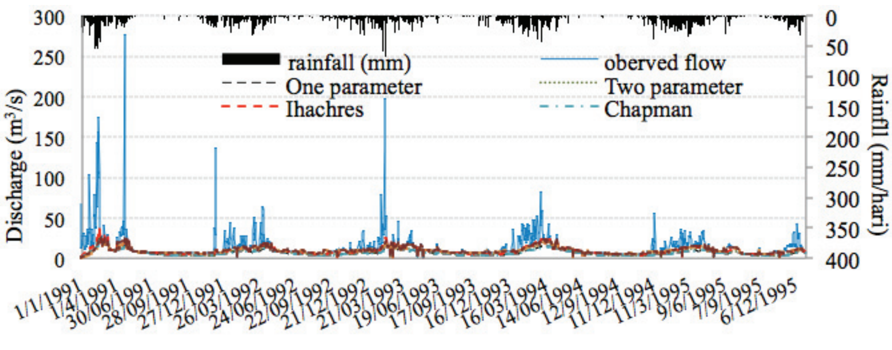

Fig.10 Baseflow separation results using 6 RDF methods at Kloposawit Watershed (zoom: 1991 to 1995).

Fig.7 to Fig.10 shows that Lynie-Hollick and EWMA filters estimated base flow in dry periods more precisely than 4 others RDF filters. Furthermore, this two method can also calculate baseflow higher than other methods. The two methods convert rainfall during the high flow to more infiltration areas during the rainy seasons that significantly add the groundwater. Furthermore, groundwater augmentation will contribute more to baseflow on the river. Contrary, one parameter method tends to estimated baseflow constantly both during dry and rainy seasons.

Others, three RDF methods i.e: Bougthon – two parameter, Ihacres, and Chapman) tend to estimate less baseflow during all periods.

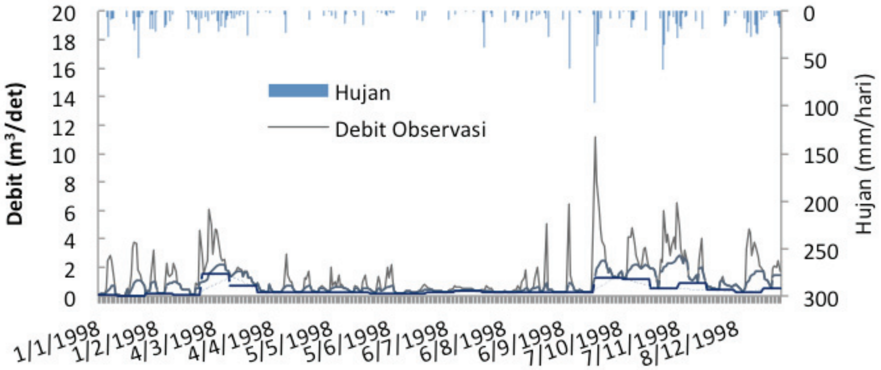

Fig.11 Baseflow separation result using 6 RDF methods at Bomo Atas watershed (zoom of : 01 Jan to 31 Dec 1998).

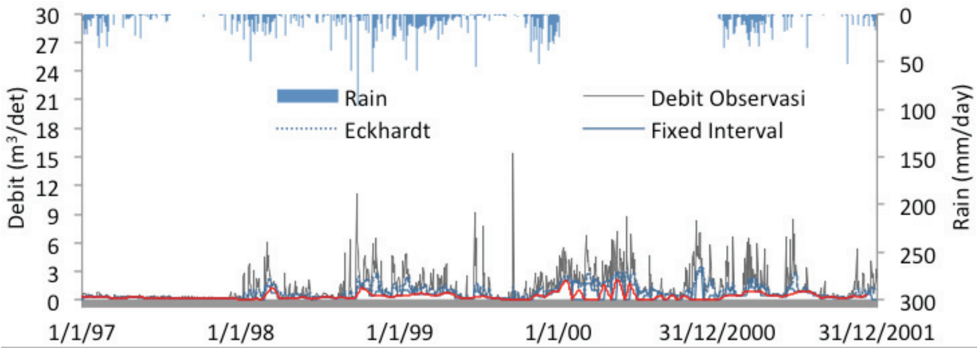

Fig.12 Baseflow separation result using 6 RDF methods at Bomo Atas watershed (zoom of : 1997 to 2001).

The same visualisations for baseflow separation result using two graphical methods and Eckhardt filters are shown in Fig.11 for year 1998 and Fig.12 for period of 1991 to 1995. It is also shows that Eckhardt filter and local minimum methods tend to estimate baseflow higher during the rainy seasons (period of: January to march). While, fixed Interval method estimate baseflow less than the two methods above.

4. Conclusion

Globally, all baseflow separation methods can be used to separate baseflow on this region, however three methods (EWMA, Line-Hollick and Local Minimum) perform better than others 6 methods. The results show that optimal parameter values from calibrated watershed can be used to separate base flow in other watersheds on the same regions.

Acknowledgements

The authors thank to: University of Jember, DP2M DIKTI, undergraduate students, and others stakeholders whose contribute to the data collection and during this study.

References

Brodie, R., and Hostetler, S., 2007. An overview of tools for assessing groundwater-surface water connectivity. Bureau of Rural Sciences. Canberra.

Boussinesq, J., 1904. Recherches theoretique sur l'rcoulement des nappes d'eau infiltres duns le sol et sur le debit des sources. J. Math. Pure Appl., 10(5th series), 5-78.

Boughton, W.C., 1987. Hydrograph analysis as a basis of water balance modelling. The Institution of Engineers, Australia. Civil Engineering Transaction CE29(1), 8 -33.

Boughton, W.C., 1988. Partitioning stream flow by computer. The Institution of Engineers, Australia, Civil Engineering Transaction, pp: 285 - 291.

Boughton, W.C., 1993. A hydrograph-based model for estimating water yield of ungauged catchments. Institute of Engineers Australia National Conference. Publ. 93(14), 317-324.

Chapman, T. G. and Maxwell, A. I., 1996. Baseflow Separation - Comparison Of Numerical Methods With Tracer Experiments. Water Resour. Hobart: Institute of Engineers Australia.

Chapman, T.G., 1991. Comment on evaluation of automated techniques for baseflow and recession analyses, by RJ Nathan and TA McMahon. Water Resources Research 27(7), 1783-1784.

Chapman T., 1999. A comparison of algorithms for stream flow recession and baseflow separation. Hydrological Processes 13, 710-714.

Eckhardt K., 2005. How to construct recursive digital filters for baseflow separation. Hydrological Processes 19, 507-515.

Eckhardt, K., 2008. A comparison of baseflow indices, which were calculated with seven different baseflow separation methods. J. Hydrol. 352, 168–173.

Furey, P.R., Gupta, V.K., 2001. A physically based filter for separating baseflow from stream flow time series. Water Resources Research 37(11), 2709-2722.

Grayson, R.B, Argent, R.M, Nathan, R.J, McMahon, T.A, Mein, R.G., 1996. Hydrological recipes: estimation techniques in Australian hydrology. CRC for Catchment Hydrology.

Gonzales, A.L., Nonner, J., Heijkers, J., Uhlenbrook, S., 2009. Comparison of different baseflow separation methods in a lowland Catchment. Hydrol. Earth Syst. Sci. 13, 2055–2068.

Gregor, M., 2010. HydrOffice User Manual version 2010. http://hydrooffice.org

Gregor, M., 2012. HydrOffice User Manual version 2012. http://hydrooffice.org

Hall, F.R., 1968. Baseflow recessions – a review. Water Resources Research 4(5), 973-983

Hall, A.J., 1971. Baseflow recessions and the baseflow hydrograph separation problem. Hydrology papers 1971, The Institution of Engineers, Australia.

Horton, RE., 1933. The role of infiltration in the hydrological cycle. Trans. Am. Geophysics. Union, 14, 446-460

INSTITUTE OF HYDROLOGY, 1980. Low flow studies. Res. Rep. 1. Institute of Hydrology, Wallingford, UK.

Indarto, Suhardjo W., Agung, P.S., 2013. Physical properties and flow Duration Curves of 15 Watersheds in East Java. Agritech. 33(4), 469-476

Jakeman, A.J., Hornberger, G.M., 1993. How much complexity is warranted in a rainfall-runoff model. Water Resources Research 29, pp: 2637-2649.

Linsley, R.K., Kohler M.A., Paulhus J.L.H., Wallace J.S., 1958. Hydrology for engineers. McGraw Hill, New York.

Lyne, V., Hollick, M., 1979. Stochastic time-variable rainfall-runoff modelling. Institute of Engineers Australia National Conference. Publ. 79/10, 89-93.

Murphy, R., Graszkiewicz, Z., Hill, P., Neal, B., Nathan, R., Ladson, T., 2009. Australian rainfall and runoff revision. Project 7: baseflow for catchment simulation. Stage 1 report – volume 1 - selection of approach. AR&R Report Number, P7/S1/004, ISBN: 978-085825-9218, Engineers Australia, Engineering House11, National Circuit, Barton ACT 2600.

Mau, D.P., Winter, T.C., 1997. Estimating ground-water recharge from stream flow hydrographs for a small mountain watershed in a temperate humid climate. New Hampshire, USA. Ground Water, 35(2), 291-304.

Maillet, E., 1905. Essais d'Hydraulique Souterraine et Fluviale. Hermann Paris, 218 p.

Nathan R.J., McMahon T.A., 1990a. Evaluation of automated techniques for baseflow and recession analysis. Water Resources Publications 26(7), 1465-1473.

Nathan R.J., McMahon T.A., 1990b. Estimating low flow characteristics in ungauged catchments. Water Res. Manage. 6, 85-100.

Pettyjohn, W.A., Henning R., 1979. Preliminary estimate of ground-water recharge rates, related streamflow and water quality in Ohio. Ohio State University Water Resources Centre Project Completion Report No 552, 323pp.

Sloto, R.A., Crouse, M., Y., 1996. HYSEP: A computer program for stream flow hydrograph separation and analysis. U.S. Geological Survey, Water-Resources Investigations, Report 96-4040 Pennsylvania.

Smakhtin V.U., 2001a. Estimating continuous monthly baseflow time series and their possible applications in the context of the ecological reserve. Water SA 27(2), 213-217.

Smakhtin, V.U., 2001b. Low flow hydrology: a review. J Hydrology 240, 147-186.

Tallaksen, L., M., 1995. A review of baseflow recession analysis. Journal of Hydrology 165:349-370.

Tallaksen, L., M., Vvan Lanen, H., A., J., van eds., 2004. Hydrological Drought – Processes and Estimation Methods for Stream flow and Groundwater. Developments in Water Science, 48., Elsevier Science B.V, Amsterdam

Tularam, G. A., Ilahee, M., 2008. Exponential smoothing method of baseflow separation and its impact on continuous loss estimates. American Journal of Environmental Sciences. 4(2), 136-144.