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RESEARCH ARTICLE

Comparing Master Recession Curves using Seven Baseflow Recession Models

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Abstract Baseflow recession analysis is an effective method for understanding catchment area releasing flow during dry season (without rainfall), thereby facilitating the management of water resources. Despite the availability of several theories on recession curves, there are limited studies on the comparison of different approaches. To overcome the limitation, several studies have reported the ability of master recession curves (MRC) modeling to combine automated methods for analyzing recession periods and curves shapes based on river flow data. Therefore, this study aimed to compare seven baseflow recession models for MRC characterization in small island watersheds. The Turkey test results showed that MRC visualization varied, particularly in terms of slope parameters and shapes. The seven recession models were grouped into two subsets based on their similarity. The first subsets consisted of Turbulent, Dupuit-Boussinesq aquifer storage, Depression-detention storage, Horton double exponential, Linear reservoir, and Exponential reservoir. Meanwhile, the second subset comprised Hyperbolic reservoir, Turbulent, Dupuit-Boussinesq aquifer storage, Depression-detention storage, Horton double exponential, and Linear reservoir. The findings also showed that the variability of MRC behavior depended on groundwater recharge, storage channel conditions, aquifer characteristics, and climate in the study area. These findings were also relevant to the development of MRC in other regions, such as hydrorecession tools, MRCPtool applications, sensitivity analysis-based Automatic parameter calibration of the VIC model for streamflow simulation over China, and spatial and temporal patterns in baseflow recession in the continental United States.

1. Introduction

Understanding long-term baseflow recession patterns is essential for developing new method to support future decision-making. This understanding is closely related to responses to climate variability and accelerated population growth, which significantly impact water distribution systems and watershed ecosystems (Latuamury *et al.*, 2021). In addition, an intensive comprehension of river flow recession periods is fundamental in effective water resource management. Several studies showed that maintaining riverbed flow within the groundwater component is essential. The analysis of riverbed flow can also clarify the characteristics of free aquifers, providing insights into the relationship between storage properties and flow discharge to the catchment area. However, the low quality of river flow data, the variability of recession curves, and the limitations of some mathematical approaches pose obstacles in determining baseflow recession characteristics in certain watersheds (Sujono *et al.*, 2004). To overcome uncertainty in determining the start time of recessions, several methods have been proposed to establish flow-release storage relationships based on the Boussinesq equation (flows from free horizontal aquifers). A solution to the problem of outflow from free aquifers in a horizontal impermeable layer into a fully penetrating flow channel was proposed by (Boussinesq, 1877), assuming the groundwater table is the free surface and ignoring the effect of capillarity above the groundwater table. The solution also relies on the assumption (Szilagyi & Parlange, 1998), that the flow is parallel to the slope of the base, the velocity is uniformly perpendicular to the base, and the hydraulic gradient is equal to the slope of the free surface. In this case, the slope of the impermeable layer is negligible and considered horizontal (Boussinesq, 1877; Posavec et al., 2010).

According to previous studies, the master recession curves (MRC) is a graphical method built on overlapping curves, where each segment is plotted and adjusted to form a single element representing a long set of recession data (Latuamury *et al.*, 2022; Posavec *et al.*, 2006, 2010). This method serves as an alternative for addressing variability across different recession periods due to the consideration of multiple curves extracted over prolonged durations. Among the various techniques within MRC determination, the matching strip is one of the most widely used in baseflow recession modeling, along with parameterization based on baseflow recession rate as a flow function (Carlotto & Chaffe, 2019; Lee et al., 2014). In addition, MRC graphical methods (Posavec et al., 2010) and analytic expression allow for a better understanding of periods of river flow recession (Stoelzle et al., 2013). MATLAB-based MRC parameterization tools have also been applied to different analytical models. These tools were reported to have graphical user interfaces that offer automated power sources to perform hydrograph splitting using numerical filters and automatically extract recession periods. For example, MRCP combines several automated resources to perform analysis based on river flow data (Carlotto & Chaffe, 2019).

In line with several reports, the MRC computational model developed by (Gregor & Malík, 2012; Gregor & Malík, 2012, 2014) utilizes HydroOffice 12.0 software, particularly the RC 4.0 module, to analyze complex recession curves from various computing methods and programs. The software uses the same graphical user interface structure, learns how to use one tool, and transitions to another variant effectively. The use of recession models can facilitate individual and MRC analysis, both manually and through innovative tools that combine powerful hybridization genetic algorithms and artificial immune system methods. The unique feature of the genetic algorithm program enables superposition analysis of 4 flow sub-regimes and 13 recession models most widely used in recent MRC modeling (Gregor & Malík, 2012). Therefore, this study aimed to calibrate seven recession models to compare the characterization of MRC for small island watersheds as an essential alternative for water resource management in the region.

2. Methods

Study area

The results of satellite image analysis for morphometric characteristics of the Wae Batu Merah watershed in Ambon City showed an area of 7.04 km^2, an average slope of 5.15 m, a river slope of 359.7 m, with a middle river length of 6.83 m, a drainage density of 3.28 km/km^2, a Circulation Ratio (CR) of 12.56, and a Bifurcation Ratio (BR) of 0.95, as well as a pinnate flow pattern. Drainage density was good, with Dd values ranging from 1–5, although, this condition was exacerbated by the ratio of river branches to abnormal watershed conditions with high flood peaks and short recession times. This led to high flood susceptibility and was characterized by high surface flow, low permeability, and infiltration. A branching ratio of 0.95 indicated a watershed shape tending to be rounded, indicating a high peak discharge (Qp) with rising time and rapid recession (Latuamury *et al*., 2021), as presented in Figure 1.

Study procedure

The MRC assembly procedure used the baseflow recession function found in hydrooffice RC4.0 software. The seven baseflow recession functions used in assembling MRCs in the study area were presented in Table 1.

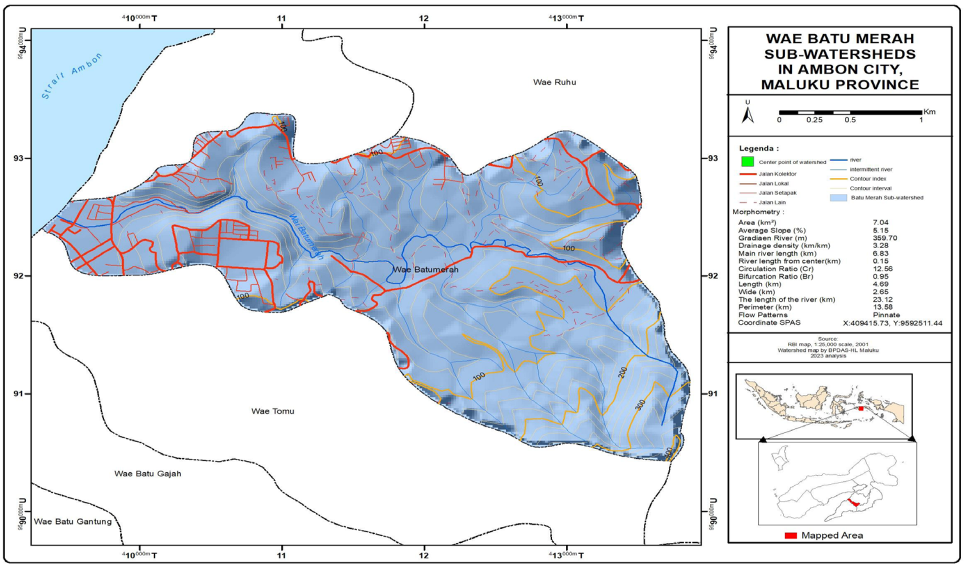

Figure 1. Morphometric map of the Wae Batu Merah watershed in Ambon City

Table 1. Recession functions used in RC 4.0

Conceptual model	Recession function	Storage type
Linear reservoir (Boussinessq 1877; Maillet, 1905)	$Q = Q_0 e^{-kt}$	General storage, Linearized Dupuit-Boussinesq equation, approximation for short periods
Exponential reservoir	$Q = Q_0/(1 + \emptyset Q_0 . t)$	Throughflow in soil, hydraulic conductivity assumed to exponentially decrease with depth
Horton double exponential model (Horton, 1933)	$Q = Q_0 e^{-\alpha_2 t^m}$	General storage, the transformation of a linear reservoir model
Dupuit-Boussinesq aquifer storage (Boussinesq, 1904)	$Q = Q_0(1 + \alpha_3 t)^{-2}$	Shallow unconfined aquifer, a special case of power-law reservoir for Dupuit-Boussinesq aquifer model
Depression-detention storage (Griffiths Clausen, 1997	$Q = \alpha_1/(1 + \alpha_2 t)^3$	Surface depressions such as lakes and wetlands, a variant of power-low reservoir
Hyperbolic reservoir (Toebes Strang, 1964)	$Q = \alpha_1 t^{-v} + b$	Ice melt, lakes
Turbulent model (Kullman, 1990)	$Q = Q_0(1 - \beta t)$	Karstic aquifers

Source: (Gregor & Malík, 2012)

Note, Q= discharge, t= time since the beginning of the recession, Q_0= discharge for t =0, k, n, α, β, $\emptyset$ - parameters to be determined by calibration.

The MRC assembly in this study employed a manual working mechanism using the matching strip method and genetic algorithm procedures. A total of 52 recession segments were selected, presented in a single graph, and subsequently adjusted along a horizontal timeline to generate a more compact significant recession curve. However, the main drawbacks of this method were a time-consuming process and subjective, and usually different recession outcomes depended on previous study experience. To address these limitations, an automated tool was developed in MATLAB to streamline the process of assembling prototype curves for the MRC assembly.

The procedures of genetic algorithms, along with neutral networks, expert systems, and Chaos theory methods, were assumed to be part of the group of artificial intelligence methods (Gregor & Malík, 2012). The main principle of the genetic algorithm had the following procedure, the creation of a preliminary population of random solutions to problems determined at the initial stage. Each solution in the population presented was a data structure (e.g. data array) that made it possible to store information about individual solutions effectively, and this was tested and evaluated to achieve defined goals. Furthermore, a new population was created from the existing solution population, and this had a higher probability of transitioning to the new generation. In creating a new generation solution, 2 individual solutions were randomly selected, but the better-rated solution was more likely to be selected. The highest-rated solution got a more significant cut than the others, and when the cross was determined, the newly created solution took properties from both solutions from the previous generation. This new individual solution presented a randomized genetic combination of parent generation properties, and during the process of crossing, random mutations also occurred. However, this mutational process occurred only with a very low probability, and gradually, with the help of the repetition of the evolutionary cycle, solutions that approach the ideal solution evolved. The described evolutionary process could be stopped by the number of evolutions previously described (Gregor & Malík, 2012; Gregor & Malík, 2012).

3. Result and Discussion

Baseflow recession average descriptive statistics

The calculation of the average baseflow recession calculation for 52 instances, employing 7 different models, highlighted the Hyperbolic function model with the highest baseflow volume of 3.09 m^3/second. Following closely were the Turbulent flow model (3.08 m^3/sec), Deput-Boussinesq aquifer storage (3.03 m^3/sec), Depression storage-detention storage (3.01 m^3/sec), Horton double exponential (2.96 m^3/sec), Linear reservoir model (2.95 m^3/sec), and finally, the Exponential reservoir model (2.81 m^3/sec) as presented in Table 2.

The descriptive statistical results of the seven recession models were relevant to the study conducted using the least squares regression method to estimate recession parameters at each percentile, also performed by (Thomas *et al*., 2015). However, this method was less sensitive to outlier data and needed to capture recession parameters effectively (Harman et al., 2009). Recession rates at different discharge magnitudes were treated as random variables using the exponential distribution with 2 parameters. Constructing a recession model involved assembling segments based on the probabilistic recession rate at each flow release interval. The method was deterministic due to its ability to reflect the variability of recessionary processes explicitly, and the same intervals used in calculating the pace of recessions and constructing their segments could cause significant errors and uncertainties. However, the exponential distribution needed to be flexible in overcoming the variability of recession rates.

Estimating model using seven baseflow recession model

MRC Visualization using reservoir linear model

The linear reservoir calibration resulted in a combination of recession parameters, which included initial recession discharge (Q0) of 4.75 m^3/sec, α value of 0.059, recession constant of 0.9427, and base flow volume of 4.4778 m^3/sec. The visualization of the linear reservoir model illustrated the slope of the gentle shape of the MRC recession curve, as presented in Figure 2.

Linear reservoir theory assumed that the outflow of Q from bedrock or riverside aquifers depended linearly on storage (S) (Tallaksen, 1995). Linear reservoir models (Hammond & Han, 2006, Wittenberg & Sivapalan, 1999) produced a model in the form of a straight line with the MRC shape decreasing exponentially. Additionally, it could also be seen that the overlapping recession segments represented the recession, interception, and slope parameters of the model curve. The model's ability to represent the segments was

Table 2. Descriptive statistics of baseflow recession for seven model

Baseflow recession model	N	Minimum	Maximum	Sum	Mean	Std. Deviation	Variance	Skewness	Kurtosis
Linear reservoir	19	1.64	4.75	55.87	2.95	0.97	0.93	0.42	-0.99
Exponential reservoir	19	0.90	4.72	53.37	2.81	1.20	1.43	0.00	-1.20
Horton double exponential	19	1.67	4.75	56.28	2.96	0.96	0.92	0.41	-0.99
Deput-Boussinesq aquifer storage	19	1.89	4.79	57.48	3.03	0.89	0.80	0.56	-0.80
Depression storage - Detention storage	19	1.83	4.78	57.19	3.01	0.91	0.83	0.51	-0.87
Turbulent flow model	19	2.07	4.79	58.51	3.08	0.82	0.68	0.68	-0.58
Hyperbolic function model	19	2.08	4.77	58.61	3.09	0.81	0.66	0.66	-0.60
Valid N (listwise)	19								

Source, Recession segment data using SPSS, 2007-2014 linked to different MRC slopes to describe the state of flow deposits. The recession curve formed a fitting line, and was joined together at the point of intersection, and characterized the model as a parameter of the recession function. Model visualization to display slope and suitability was subsequently used to show the condition of flow deposits in the catchment area (Hannah & Gurnell, 2001, Lázaro *et al.*, 2015).

The storage conditions of the catchment area, specifically the discharge at the beginning of the recession and soil moisture, were 2 critical factors affecting the recession rate. In addition, water storage in catchment areas also had a significant influence on variations in river flow recession behavior. Several low-flow hydrological studies had investigated this phenomenon extensively (Biswal & Marani, 2014, Shaw & Riha, 2012) and the rate of recession of river flows was observed to have doubled compared to the increase in previous storage. Therefore, it further confirmed that the base flow storage and discharge rates could control the observed dynamics of flow recession behavior (Biswal & Marani, 2010).

MRC visualization using exponential reservoir model

MRC visualization using the exponential reservoir model produced a combination of recession parameters, namely the initial recession discharge (Q0) of 4.77 m^3/sec, φ value of 0.015, recession constant of 0.0716, and base flow of 4.45 m^3/sec to produce a form of MRC that was relatively different from the linear reservoir recession model. The MRC slope of the exponential reservoir model had steeper recession parameters and lower baseflow volume than the linear reservoir model, as presented in Figure 3.

The relationship between temporal variation and recession characteristics of base flow theoretically suggested that inflow seepage per unit length of a river was assumed to be constant concerning time. The shrinkage of the river network was also considered regular and top-down, and the recession rate was directly proportional to changes in river flow (Biswal & Marani, 2014). In addition, temporal variations in the recession rate of injection flow were explained by the contribution of different reservoir variables to recharge and storage. The range of possible control over dynamic river flow recession also suggested that the process was relevant to watershed areas.

MRC visualization using Horton's double exponential model

MRC visualization using Horton's double exponential model obtained a combination of recession parameters, namely initial recession discharge (Q0) of 4.75 m^3/sec, α-2 value of 0.058, m parameter of 1, recession constant of 0.9437, and base flow volume of 4.48 m^3/sec. The slope of Horton's double exponential reservoir model was relatively the same as that of the linear reservoir model. However, the slope of the MRC was moderately different from the exponential reservoir model, which was relatively steep. The baseflow volume was lower than that of the linear reservoir model and Horton's double exponential model, as presented in Figure 4.

Reservoir models were assumed to help determine recession characteristics used as predictors in regional prediction models. Predictors derived from linear and nonlinear models were applied separately in regional base flow models and other predictors to represent physiographic and

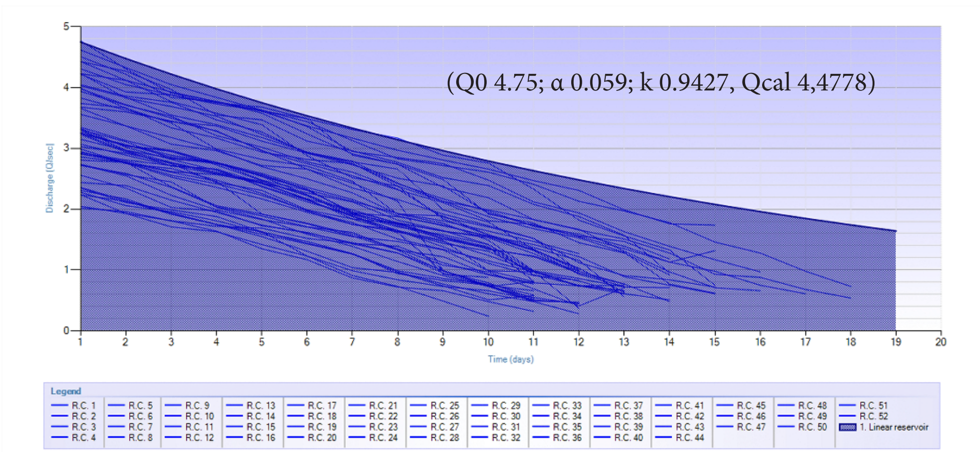

Figure 2. MRC using Linear reservoir model

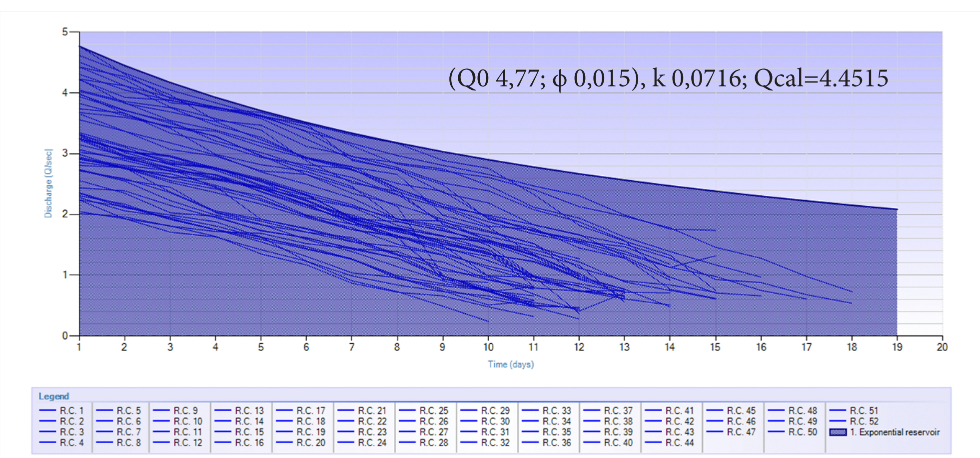

Figure 3. MRC using exponential reservoir model

meteorological characteristics. The model was applied to a specific measured catchment area, and the results showed that parameters from the nonlinear category performed better. Meanwhile, one disadvantage of using recession parameters for regional estimation was the likelihood of estimates with short river flow records. It was concluded that the recession parameter of the nonlinear model performed better than other recession parameters that only had physiographic and meteorological characteristics (Wittenberg & Sivapalan, 1999; Stewart, 2015).

MRC visualization using the Depuit-Boussinesq aquifer deposit model

MRC visualization using the Depuit-Boussinesq aquifer deposit model also produced a combination of recession parameters, including initial discharge (Q0) of 4.79 m^3/sec, α-3 value of 0.033, recession constant of 0.9371, and base flow volume of 4.4888 m^3/sec. The slope of the MRC for the Depuit-Boussinesq aquifer deposit model was relatively the same as that of the linear reservoir model and Horton's double exponential model, but the slope of the MRC was different from the exponential reservoir model, which was moderately steep and lower in volume compared to the previous three models, as presented in Figure 5.

The proposed recession analysis model (Brutsaert & Nieber, 1977, Latuamury et al., 2020) remained one of the few analytical tools for estimating aquifer hydraulic parameters at the field and other scales. In this method, recession hydrographs investigated the relationship dQ/dt=f(Q), where Q was the aquifer discharge and f was an arbitrary function. The observed F function was parameterized through analytical solutions following a one-dimensional equation (Boussinesq, 1877) for infinite flow in homogeneous and horizontal aquifers. Although attractive in its simplicity, it did not apply to conditions where the slope was an essential factor in moving the flow or hydraulic parameters that affected its depth (Boussinesq, 1877). Analytical solutions to one-dimensional initialized equations for inclined aquifers with numerical solutions of fully nonlinear equations. The behavior of the nonlinear equation (Boussinesq, 1877) was also assessed when the aquifer was heterogeneous, where the complete lateral hydraulic conductivity k varies as a power law with a height of z above the impermeable layer kZN, n constant 0. All analytical solutions differed from critical aspects of nonlinear solutions when plotted as dQ/dt=f(Q) and were unsuitable for type analysis (Basha, 2020, Brutsaert & Nieber, 1977). However, new analytical solutions for sloping aquifers were obtained empirically from numerical simulations that could be applied

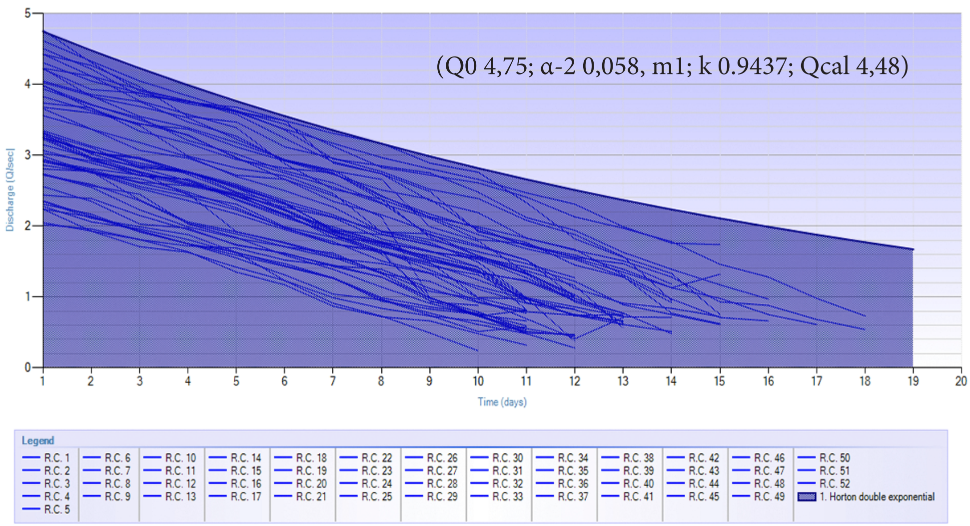

Figure 4. MRC using the Horton double exponential model

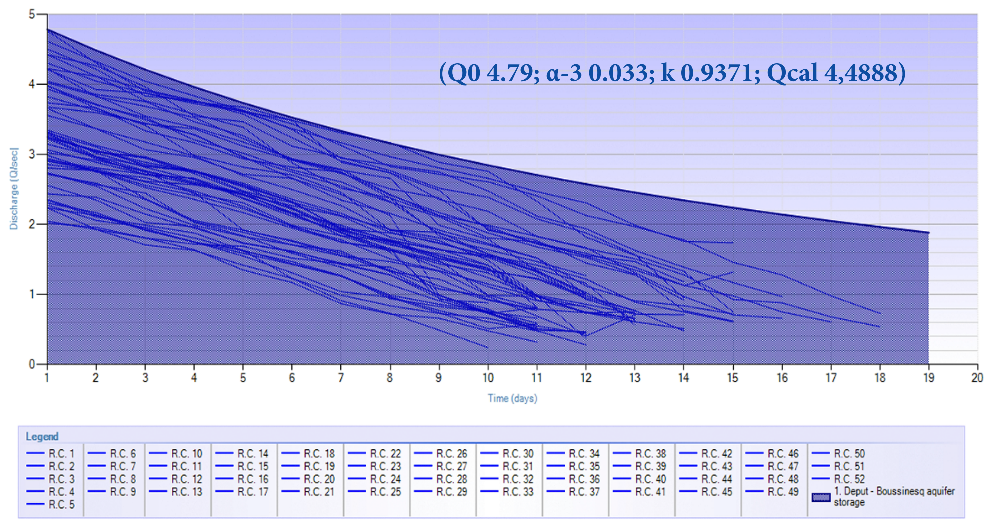

Figure 5. MRC uses the Depuit-Boussinesq aquifer storage model

during late recessionary periods when the recession curve met dQ/dt=aQb, where b=(2n+1)(n+1), and a was a function of the aquifer's dimensions and hydraulic properties.

The Depuit-Boussinesq model proved best suited for the observed parameterization of base flow recessions, reflecting generally nonlinear deposit declines. A previous report conducted by (Boussinesq, 1877) used recession curve observations to test a comprehensive theoretical analysis of watershed response mechanisms converging with unique MRCs at ever-increasing rates. The results showed that the characteristics of recession cannot be derived from one event alone but through a series of recession segments of different durations. The segment represented short-term recession events that differed from consecutive recessions due to storage conditions, evapotranspiration loss, and recharge rate. Meanwhile, MRC was described as a series of individual recession curves characterizing the average base flow response (Szilagyi *et al.*, 2007).

MRC visualization using the depression-retention store model

MRC visualization using the depression-detention deposit model resulted in a combination of recession parameters, which included initial recession discharge (α-1) of 4.78 m^3/sec, α-2 of 0.021, and base flow volume of 4.4911 m^3/sec. The slope of the MRC for the depression-retention store model was relatively the same as that of the linear reservoir, Horton's double exponential, and the Depuit-Boussinesq aquifer deposit model, but the slope of the MRC was different from the exponential reservoir model which was moderately steep and lower in volume compared to the previous 4 models, as presented in Figure 6.

The temporal variability associated with the base flow recession characteristic was evapotranspiration, which was identified as one of the main drivers of recession occurrence in the same catchment region. High evapotranspiration rates were observed to cause a faster decrease in discharge through the depletion of flow deposits (Posavec et al., 2006; Shaw & Riha, 2012). The recession rate of river flows was much faster during the growing season in forested watersheds than during the dormant season. Meanwhile, adjacent freshwater catchments showed increased recession rates during periods with higher evapotranspiration rates, and this could be due to other factors, such as the tendency of catchment flow storage conditions that were highly correlated with evapotranspiration (Fatchurohman et al., 2018, Shaw et al., 2013).

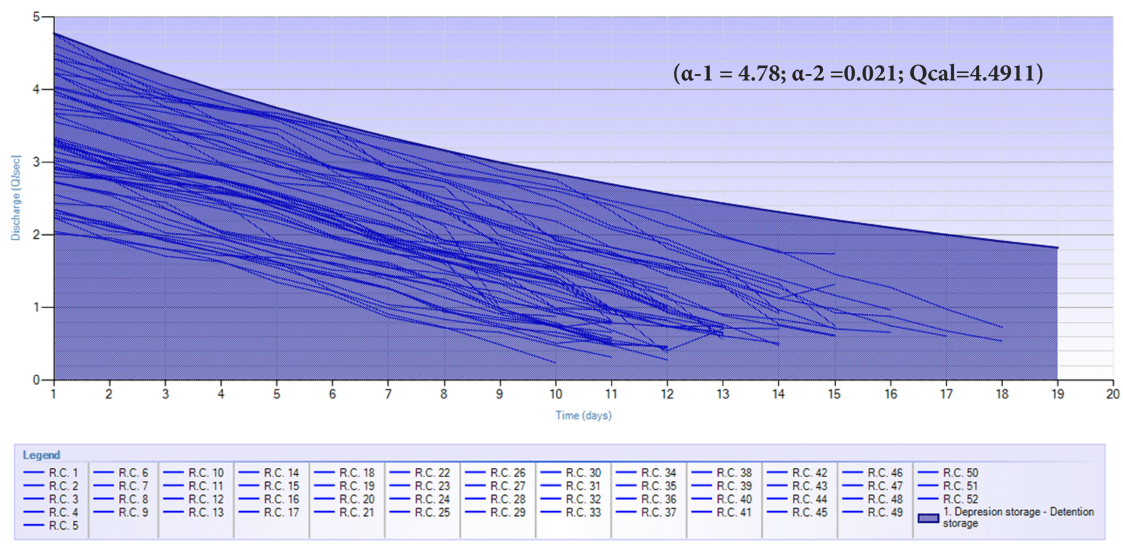

Figure 6. MRC using the Depression - -Detention storage model

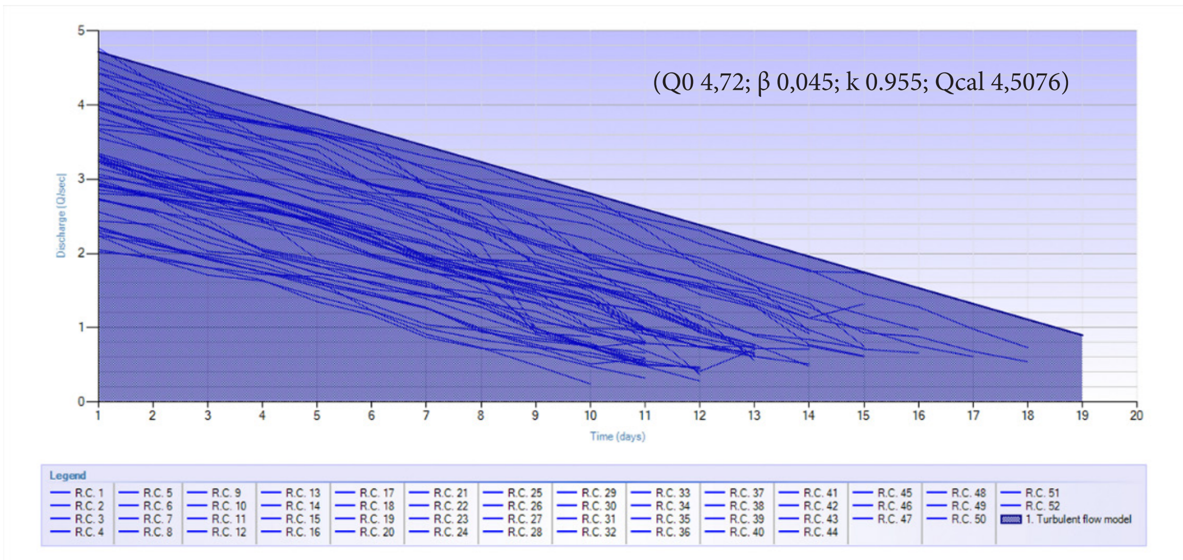

Figure 7. MRC using Turbulent flow model

MRC visualization using turbulent flow model

MRC visualization using a turbulent flow model produced a combination of recession parameters, including initial recession discharge (α-1) of 4.72 m^3/sec, β value of 0.045, recession constant of 0.955, and base flow volume of 4.5076 m^3/sec. The slope of the MRC for the turbulent flow model was relatively the same as that of the linear reservoir model, Horton's double exponential model, the Depuit-Boussinesq aquifer deposit model, and the depression-retention store model, but the slope of the MRC was different from the exponential reservoir model compared to the previous 5 models, as presented in Figure 7.

Groundwater drainage and evapotranspiration depleted water storage in catchment areas during dry weather (Szilagyi et al., 2007). This was recorded at different rates in space and time, known as the rate of recession or river draining, thus causing the discharge to decrease gradually. The gradual decrease in river discharge after runoff was closely related to the recession process in the catchment area. This suggested that the ability of watersheds to store and release water was a common trait to be considered in predicting reliable recession models when implementing effective water resource management systems (Latuamury et al., 2023).

MRC visualization using Hyperbolic function model

MRC visualization using a hyperbolic function model produced a combination of recession parameters such as initial recession discharge (α-1) of 4.91 m^3/sec, α value of 0.073, n value of 1, and base flow volume of 4.900 m^3/sec. The slope of the MRC for the Hyperbolic function model was relatively the same as that of the linear reservoir model, Horton's double exponential model, the Depuit-Boussinesq aquifer deposit model, the depression-retention store model, and the turbulent flow model, but the slope of the MRC was different from the relatively steep exponential reservoir model. This model was also observed to be similar to all 5 base flow recession models but different from the exponential reservoir model. The slope of the MRC further confirmed this trend, as presented in Figure 8.

The relationship between measured response and rate of change over time was explained by MRC and this occurred on a downward curve when there was no infiltration or other water input (Heppner & Nimmo, 2005; Rivera-Ramírez et al., 2002). MRC was developed using RC4.0 tools with structured procedures that provided a basis for validly measuring hydrological variables and characteristics with the ability to compare recession events in different recession periods. This was achieved through an iterative process applied to measure recession parameters and visualize the MRC shape for the study area (Chapmann, 1999, Latuamury et al., 2022). In addition, river flow recession models were used to understand the nature of aquifers in catchment areas by considering variations in climate, geology, and topography. The recession rate of river flow was significantly influenced by aquifer properties such as hydraulic conductivity and porosity. Evapotranspiration also affected changes in catchment reservoirs but did not directly affect the rate of river flow recession (Latuamury et al., 2020; Tallaksen, 1995).

Creating MRCs of recession segments for all seven baseflow recession models in the study area was difficult and time-consuming. However, the description of recession processes based on MRC (to formulate the corresponding equation or series of equations) was a process that could only follow the natural time series set of baseflow recessions predicted to occur (Gregor & Malík, 2014). New approaches and computational tools based on genetic algorithms allowed the creation of the most likely natural recession release circuit in time, from which MRCs could be built. Such shrinkage of recession release time series helped to avoid constraints such as limited data in long and incomplete time flow sequences, too many segments in many recession successions, and complicated hydrograph forms in some instances (Gregor & Malík, 2012).

One-way ANOVA test for seven baseflow recession model

Normality tests conducted on the seven baseflow recession models showed that these models met the normality requirements indicated by the Shapiro-Wilk coefficient value, which recorded more significantly than α 0.05. The turbulent model had the highest value of 0.587, followed by the Horton double exponential model (0.350), Linear reservoir model (0.341), Depression-detention storage (0.275), Dupuit-Boussinesq aquifer storage (0.235), Exponential reservoir model (0.180), and Hyperbolic reservoir model (0.169), as presented in Table 3.

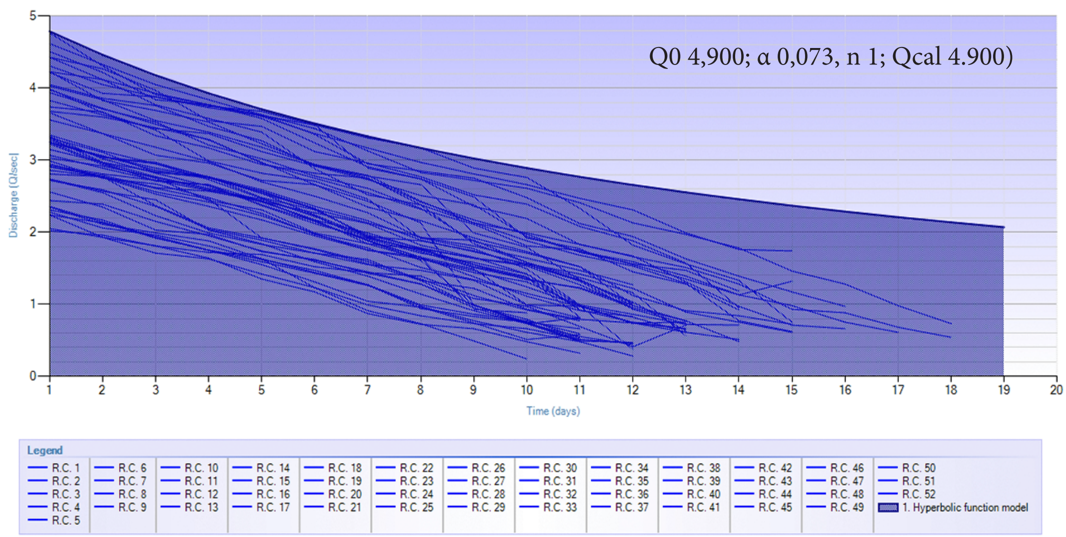

Figure 8. MRC using Hyperbolic function model

Table 3. Normality test results for seven baseflow recession model

Recession Model	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Linear reservoir model	0.104	19	0.200*	0.946	19	0.341
Exponential reservoir model	0.120	19	0.200*	0.931	19	0.180
Horton double exponential model	0.103	19	0.200*	0.947	19	0.350
Dupuit-Boussinesq aquifer storage	0.112	19	0.200*	0.937	19	0.235
Depression-detention storage	0.111	19	0.200*	0.941	19	0.275
Turbulent model	0.078	19	0.200*	0.961	19	0.587
Hyperbolic reservoir model	0.120	19	0.200*	0.929	19	0.169

Source, processing baseflow recession data using SPSS, 2023.

Table 4. Homogeneity Test of the Variances

Levene Statistic	df1	df2	Sig.
0.715	6	126	0.638

Source, processing baseflow recession data using SPSS, 2023.

Table 5. Results of a one-way ANOVA of all 7 baseflow recession model

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	14.011	6	2.335	2.315	0.037
Within Groups	127.075	126	1.009		
Total	141.086	132			

Source, Processing baseflow recession data using SPSS, 2023.

The homogeneity test also showed that the distribution of baseflow recession data for the entire model was homogeneous, which showed that the data's variance was the same. This was based on the Levene significance value of 0.638, more excellent than α 0.05. The results showed that the one-way ANOVA requirements were met, as presented in Table 4.

The results of the one-way ANOVA test showed a significant difference for seven baseflow recession models indicated by an F-calculated value of 2.315, which was more significant than the F-table value of 0.2700 at a significance level of 0.037 less than < α 0.05 as presented in Table 5. This suggested that all seven models' base flow recession characteristics differed significantly.

The results of Turkey's Test for seven models showed that these models were grouped into 2 subsets based on the value of the Turkish coefficient. The first subsets with the highest to lowest values were the Turbulent model, followed by Dupuit-Boussinesq aquifer storage, Depression-detention storage, Horton double exponential model, Linear reservoir model, and Exponential reservoir model. The second subset with the highest to lowest values was the Hyperbolic reservoir model, followed by the Turbulent model, Dupuit-Boussinesq aquifer storage, Depression-detention storage, Horton double exponential model, and Linear reservoir model. All models had a relatively gentle slope, while exponential reservoirs were different, as presented in Table 6.

The results of the characterization of the base flow recession of the Wae Batu Merah watershed MRC showed that the data were homogeneous and normally distributed, and the results of the one-way ANOVA test for all models also showed significant differences. The main advantage of recession curve analysis was that the output was a set of quantitative parameters associated with drainage mechanisms. The calculation of recession coefficients and initial discharge values, both total and partial runoff segments (sub-regimes), could be fully described in a typical MRC picture for the study watershed. The modeling built on this small island watershed also followed the development of MRC in other regions such as hydro recession tools (Arciniega-Esparza et al., 2017), MRC parameterization tools or MRCPtools (Carlotto & Chaffe, 2019), Sensitivity analysis-based Automatic parameter calibration of the VIC model for streamflow simulation over China(Gou et al., 2020), spatial and temporal patterns in baseflow recession in the continental United States (Tashie, Pavelsky, & Band, 2020, Tashie, Pavelsky, & Emanuel, 2020), Dynamic hyporheic and riparian flow path geometry through the baseflow recession in 2 headwater mountain (Ward et al., 2012), All models had a relatively gentle slope while the exponential reservoir was different. The variability of MRC behavior depended on groundwater recharge, storage channel conditions, aquifer characteristics, and climate in the study area.

Hydrorecession software development using Matlab by (Arciniega-Esparza et al., 2017) analyzed flow recession and hydrographs to extract information regarding outflow storage-discharge relationships in a catchment area. Results of calibration of the recession segment of the hydrograph by 3 different methods (Aksoy & Wittenberg, 2011, Brutsaert & Nieber, 1977, Vogel, Richard M. & Kroll, 1996) which were then analyzed with 4 models (Aksoy & Wittenberg, 2011, Arciniega-Esparza et al., 2017, Boussinesq, 1877, Maillet, 1905) as well as covering 4 parameter adjustment techniques (linear regression, bottom envelope, binning data and mean squared error). This study tool presented a linear and non-linear outflow deposit-release relationship, and this was helpful for regionalization, catchment area classification, baseflow separation, hydrological modeling, and low-flow prediction.

The study from (Thomas & Vogel, 2015) also investigated baseflow recession processes in slightly different hydrograph forms since runoff from a catchment area (or hydrogeological structure) was physically determined by static environmental processes and properties, such as geometry, aquifer hydraulic

Table 6. Turkey's Test for Model

Recession Model	N	Subset for alpha = 0.05	
		1	2
Exponential reservoir model	19	2.809	
Linear reservoir model	19	2.962	2.962
Horton double exponential model	19	3.010	3.010
Depression-detention storage	19	3.025	3.025
Dupuit-Boussinesq aquifer storage	19	3.079	3.080
Turbulent model	19	3.232	3.232
Hyperbolic reservoir model	19		3.884
Means for groups in homogeneous subsets are displayed			
a. Uses Harmonic Mean Sample Size = 19.000.			

properties, catchment area slope, which remained constant over time (Tashie, Pavelsky, & Band, 2020). The rough approach looked like recession discharge generally at the same period, however, the combination of recession parameters caused each series of recession discharges to be unique and differed in absolute value (recession coefficient, discharge) (Basha, 2020). The influence of the described dynamic parameters was projected on the complexity of recession processes even in simple watersheds and represented the main problem to be solved in the process of assembling the MRC. The proper preparation for a successful recession release was a significant task that must be completed before recession curve analysis (Nurkholis et al., 2019). Under simple conditions, the influence of static and dynamic physical properties of catchment areas or hydrogeological structures on baseflow recession characteristics was manifested in the considerable variability of relationships between individual release sequences over time. The dynamically changing physical properties resulting in a series of discharge recessions had different forms of MRC (Latuamury et al., 2021).

4. Conclusion

In conclusion, the results of the recession analysis of the seven recession models based on recession parameters such as initial discharge, constant, and base flow volume estimation showed that the visualization of MRC was relatively the same for all six models and differed significantly from the exponential reservoir model. The baseflow volume calculation results for the seven recession models from highest to lowest were the Hyperbolic function model, followed by the turbulent flow model, the depression-retention store model, Dupuit-Bossinesq, the Horton double exponential model, the linear reservoir model, and the exponential reservoir model. The results of Turkey's Test for seven models showed that each models were grouped based on similarity. The first group consisted of the Turbulent model, Dupuit-Boussinesq aquifer storage, Depression-detention storage, Horton double exponential model, Linear reservoir model, and Exponential reservoir model. The second group consisted of the Hyperbolic reservoir model, followed by the Turbulent model, Dupuit-Boussinesq aquifer storage, Depression-detention storage, Horton double exponential model, and Linear reservoir model. However, all 6 recession models had a relatively gentle slope, while the MRC slope exponential reservoir model was relatively steep. The variability of MRC behavior depended on groundwater recharge, storage channel conditions, aquifer characteristics, and climate in the study area.

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