Base flow identification using conceptual hydrology model

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Abstract. Base flow was a vital component in controlling the flow of a river. Base flow came from the groundwater flow. Base flow was the river flow that occurred during the rainless period. Conceptual hydrology model was a model that displays the hydrology process in mathematical formulation and separating the production and routing functions. The tank model was one of the conceptual models. The tank model simulated the watershed by replacing some reservoirs with several tanks. This research aimed to identify the base flow using conceptual hydrology model. The study was conducted in the Bango sub-watershed. The results exhibited that the tank model was dissatisfactory to simulate the surface flow compared to base flow. Surface flow model tended to be higher (overestimate) whereas the base flow tended to be lower (underestimate) compared to the observation data. The statistic test result displayed that the tank model could describe the base flow well.

1. Introduction
Base flow is a vital component in controlling the flow of a river. Base flow comes from the groundwater flow. According to Harto [1], base flow is the river flow that occurred during the rainless period. Factual, this definition was difficult to understand because, during the rainless period, the river contains interflow element. In his research, Harto stated the three watershed parameters that influenced the base flow: source frequency (ratio between total segment one rivers to total river from all segments), drainage density (total length of rivers in all segments per unit of watershed area), and drainage frequency (total rivers in all segments per unit of watershed area).

Limantara [2] defined base flow as the drainage result of the aquifer and is a minimum discharge. Similar argument by Viessman et al. [3] stated that base flow is the result of percolation water that cascades to groundwater reservoir and flows to the river as groundwater flow.

Base flow separation technique from the river flow hydrograph has a long history in the hydrology field and can predict low-flow and water quality. There are various methods to separate the base flow. There are three categories in the separation method: analytic, empiric, and chemical/isotopic or tracer [4]. The base groundwater and surface flow theory (for example, the analytical solution from Boussinesq approximation, unit hydrograph model, and reservoir yield-related theories from aquifer) is the base for the analytical method. The empirical method covers (1) recession analysis, (2) graphic method, (3) low-pass filter, and (4) using groundwater elevation to measure the base flow contribution based on the correlation between groundwater elevation and river flow. The tracer method uses dissolved chemical
and/or stable isotope to separate the hydrograph into components based on water mass balance and tracer.

Recursive Digital Filter (RDF) is a method of the low-pass filter, adapted from the signal-processing theory [5]. RDF method observes the surface discharge as a high-frequency signal, whereas base flow is a low-frequency signal. By filtering the high-frequency signal (surface discharge) from the flow, the method identifies the low-frequency signal (base flow) [6]. The filtered result depends on several specific parameters of watershed. The measured data in the base flow as the calibration base for these parameters. However, measurable data rarely available, and in practice, this parameter is often arbitrarily determined [7].

Many factors influences the base flow amount, for example, fluvial geomorphology, land, land use, and climate [8],[9]. Soil topography and properties have a relatively small influence on the base flow in a short period. Meanwhile, the changes in land use have various effects, especially the changes in forest land [10],[11]. Changes in forest land and others correlate with the changes in evapotranspiration, infiltration, and refilling the groundwater deposits in a watershed; and all influence base flow [9],[12]. Planning and managing watershed required practical knowledge about the correlation between changes in forest land on other land uses and base flow process. The most significant adverse effect on base flow change is by changes in forest land followed by agriculture and habitation. Grasslands, barren land, and shrubs did not have a significant impact [13].

Conceptual hydrology model is a model that displays the hydrology process in a mathematical formulation and separating the production and routing functions [1]. Some conceptual models of rainfall-runoff are NAM model [14], tank model [15], and HBV model [16].

The conceptual model position is between the physical-based model and the black box model. The conceptual model generally represents essential components that connected hydrology input and output. Usually, the term conceptual describes a simple arranged model from a small number of conceptual elements that are interrelated, and each represents the stage of the hydrological cycle in a part of the land. Most used element in the conceptual model is the storage component. Each storage has one input and one or more output to represent the watershed storage such as surface detention, soil moisture, and others. Routing uses storage and linear channel. The basic conceptual model consists of a series of moisture flow from one element to the next [17].

The conceptual model began for small and homogenous watershed modelling. However, this model could be in use in watershed with diverse topography and vegetations, and watershed with thousands of square kilometres. Input data for this model is simple and easy to obtain [17]. The conceptual model developed started from the 1950s when hydrology experts obtained a hydrology approach technique [18]. Then, in the 1960s, a conceptual model of lumped rainfall-runoff rapidly developed with a clear understanding of the physical hydrology cycle component (conceptual element). They connected each conceptual element and obtained rainfall-runoff correlation in a subsystem. The development of the hydrology model in 1980s led to a complicated model to predict the changes in land use and input-output spatial effect. That stage also developed the distributed parameter model with two and three dimensions displays. The hydrology model started to use the elevation model from a map or satellite image. After the 1980s, hydrology model evolved on a global scale that was macro-scale hydrology model.

The purpose of this study was to identify base flow using another alternative approach, the conceptual hydrological model. The conceptual hydrological model that will be used is the tank model. Hydrological tank model is a conceptual model of rainfall-runoff. Sugawara and Funiyuki introduced this model in 1956 [22]. This model consists of a series of linear tanks arranged in a series or parallel with output holes on the side and bottom side of the tank.

2. Research method

2.1. Research location

The study was conducted in the Bango sub-watershed. (Figures 1 and 2). The coordinates were between 112.56668° - 112.94181° East Longitude and 7.76549° - 7.87407° South Latitude with the elevation from
+500 m up to 1,800 m. The area of the Bango sub-watershed was 239.71 Km$^2$. The length of the main river was 12.5 Km. The average land slope in Bango sub-watershed was ±2.0% (sloping)

**Figure 1.** Research location.

**Figure 2.** Bango sub-watershed
Land use in the Bango sub-watershed consists of: 25% settlements, 43% plantations, 14% paddy fields and 18% forests. The land fraction in the location generally consisted of 26% sand, 51% silt, and 23% clay. Therefore, it belonged to a silt loam texture category with infiltration rate between 7.5–15 mm/hour [19] with moderate-slow classification [20]. This information affected low surface runoff potential [21].

2.2. Tank model

Hydrological tank model was a rainfall-runoff conceptual model. Sugawara and Funiyuki introduced this model in 1956 [22]. This model consisted of a series of linear tanks arranged in a series or parallel with output holes on the side and bottom side of the tank. The tank model connected discharge as the effect of rain, evaporation, and groundwater storage from the previous duration so that the developed conceptual model was deterministic non-linear. The tank model simulated the watershed by replacing some reservoirs with several tanks. There are two parameters in the tank model: 1) outlet coefficient at the side and the bottom of the tank parameter, 2) groundwater storage parameter. The parameters were calibrated automatically using the algorithmic genetic method. The excel macro program was developed for the development of genetic algorithms.

\[
\text{Figure 3. Design tank model scheme.}
\]

The total outflow from the side outlet (Q) of each tank, supposedly the water flow accumulation from the system in watershed, formulated as below:

\[
\begin{align*}
\text{Total}(t) & = Q_{\text{Surface flow}}(t) + Q_{\text{Total base flow}}(t) \\
Q_{\text{Total base flow}}(t) & = Q_{\text{Sub-surface flow}}(t) + Q_{\text{Intermediate flow}}(t) + Q_{\text{Sub-base flow}}(t) + Q_{\text{Base flow}}(t)
\end{align*}
\]  

The water balance equation in the tank model:

\[
\frac{d}{dt}H(t) = P(t) - Q(t)
\]

Where \(P\) is rainfall (mm day\(^{-1}\)), \(Q\) is total discharge (mm day\(^{-1}\)), \(H\) is water storage height (mm), \(t\) is time (day). The start \((t=1)\) determined the initial water level in tank A \((H_a(1))\), tank B \((H_b(1))\), tank C \((H_c(1))\), and tank D \((H_d(1))\). Next, at \((t+1)\), the renewed storage formula is as below:
\[ H_a(t+1) = H_a(t) + P(t) - Qa1(t) - Qa2(t) - Ia(t) \]  \hspace{1cm} (4)

\[ H_b(t+1) = H_b(t) + Ia(t) - Qb(t) - Ib(t) \]  \hspace{1cm} (5)

\[ H_c(t+1) = H_c(t) + Ib(t) - Qc(t) - Ic(t) \]  \hspace{1cm} (6)

\[ H_d(t+1) = H_d(t) + Ic(t) - Qd(t) \]  \hspace{1cm} (7)

2.3. Base flow separation method

This research used Recursive Digital Filter (RDF) with One Parameter Algorithm filter to separate the base flow. RDF method used Hydro Office BFI+ 3.0 software [23]. The equation of RDF with One Parameter Algorithm filter is:

\[ q_b(t) = \frac{k}{2-k} q_b(t-1) + \frac{1-k}{2-k} q(t) \]  \hspace{1cm} (8)

Where:

- \( q(t) \): The real river discharge value at t-day
- \( q_b(t) \): The actual base flow value at t-day
- \( q_b(t-1) \): The base flow value before t-day
- \( k \): Filter parameter with recession constant
- \( t \): Daily time interval

2.4. Model evaluation

Assessing reliability in a model to reproduce the nature phenomenon required some criteria. Principally, there are two criteria here: visual (graphics) and using a statistical analytical tool (Indarto, 2010 in [24]).

2.4.1. Visual or graphic criterion. Visually, reliability observes the coherency/similarity between measured and calculated output, for example, the scatter-plot result between measured and calculated discharge, making a difference residual graphic between measured and calculated discharge, and FDC graphic comparison between measured and calculated discharge (Podger, 2004 in [24]).

2.4.2. Statistical criteria. Quantitatively, model reliability to reproduce the natural phenomenon determined by a statistic with various parameters. One or several objective functions usually measured errors between the measured and calculated quantitatively. This research used several criteria:

2.4.2.1 The determination coefficient \( r^2 \). Formulated as below:

\[ r^2 = \left( \frac{\sum_{i=1}^{n} (O_i - \bar{O})(P_i - \bar{P})}{\sqrt{\sum_{i=1}^{n} (O_i - \bar{O})^2 \sum_{i=1}^{n} (P_i - \bar{P})^2}} \right)^2 \]  \hspace{1cm} (9)

the total observation data during routing period, \( O_i \) is the i-observed data, \( \bar{O} \) is the average observation data, \( P_i \) is the i-value of the surface model, \( \bar{P} \) is the average surface model. The range of \( r^2 \) is between 0 and 1 (perfect suitability). The value of 1 means the distribution of the surface model value is the same with observation.

2.4.2.2 Nash-Sutcliffe Efficiency (NSE) Coefficient. Nash and Sutcliffe (1970) suggested NSE coefficient and formulated as below:

\[ NSE = 1 - \frac{\sum_{i=1}^{n} (O_i - P_i)^2}{\sum_{i=1}^{n} (O_i - \bar{O})^2} \]  \hspace{1cm} (10)

The range of NSE is between 1.0 and \(-\infty\). The NSE value = 1.0 shows that the model reliability is excellent.

2.4.2.3 Root Mean Square Error (RMSE). RMSE equation is as below:
\[ RMSE = \sqrt{\frac{\sum_{i=1}^{n}(P_i-O_i)^2}{n}} \]  \hspace{1cm} (11)

The range of RMSE values is between 0 and \( \infty \). The RMSE value = 0 shows that the model reliability is excellent.

2.4.2.4 Percent Bias (PBIAS). PBIAS equation is as below:

\[ PBIAS = \frac{\sum_{i=1}^{n}(O_i-P_i) \times 100}{\sum_{i=1}^{n} O_i} \]  \hspace{1cm} (12)

The value of PBIAS < ±10 shows that model reliability is excellent.

2.4.2.5 Mean Absolute Error (MAE). MAE equation is as below:

\[ MAE = \frac{\sum_{i=1}^{n}|O_i-P_i|}{n} \]  \hspace{1cm} (13)

The range of MAE value is between 0 and \( \infty \). The value of MAE = 0 shows that the model reliability is excellent.

To summarize, Table 1 displays the statistical criteria to assess model reliability [25].

**Table 1. Criteria to Assess the Hydrology Model Performance.**

| Statistical Criteria                        | Value                              | Performance Classification |
|--------------------------------------------|------------------------------------|----------------------------|
| Determination coefficient \( (r^2) \)      | 0,00 \( \leq r^2 \) \( \leq 0,50 \) | Dissatisfactory            |
|                                            | 0,50 \( < r^2 \) \( \leq 1,00 \)  | Satisfactory               |
|                                            | 0,75 \( < \text{NSE} \) \( \leq 1,00 \) | Very good                  |
|                                            | 0,65 \( < \text{NSE} \) \( \leq 0,75 \) | Well                       |
|                                            | 0,50 \( < \text{NSE} \) \( \leq 0,65 \) | Satisfactory               |
|                                            | 0,40 \( < \text{NSE} \) \( \leq 0,50 \) | Acceptable                 |
|                                            | NSE \( \leq 0,40 \)                | Dissatisfactory            |
| Nash-Sutcliffe Efficiency (NSE) Coefficient | A value below half the standard deviation of the observation data | Satisfactory |
|                                            | PBIAS < ±10                         | Very good                  |
|                                            | ±10 \( \leq \text{PBIAS} \) < ±15 | Well                       |
|                                            | ±15 \( \leq \text{PBIAS} \) < ±25 | Satisfactory               |
|                                            | PBIAS \( \geq ±25 \)               | Dissatisfactory            |
| Root Mean Square Error (RMSE)              | A value below half the standard deviation of the observation data | Satisfactory |
| Percent Bias (PBIAS)                       |                                    |                            |
| Mean Absolute Error (MAE)                  |                                    |                            |

Source: [25]

3. Results and discussion

The tank model represented the surface flow in the top tank and the base flow in the tank below it consecutively. In this research, the surface flow and base flow models then compared to the results of the separation flow observation analysis using Recursive Digital Filter (RDF). Comparison between total flow, surface flow and base flow results from observations and tank model can be seen in Figures 4 to 6.

The results exhibited that the tank model was dissatisfactory to simulate the surface flow compared to base flow. Surface flow from tank model tended to be higher (overestimate) whereas the base flow tended to be lower (underestimate) compared to the observation data (Figures 5 and 6).

The analysis obtained a conclusion that tank model had dissatisfactory performance in simulating surface flow or extreme discharge, meanwhile it could give a satisfactory performance to simulate low-flow. Phien et al. [26] also stated a similar statement, that tank model could not simulate flood hydrograph (surface flow or surface runoff).
Figure 4. Comparison of observed total flow (surface flow + base flow) compared to the results of the tank model.

| Metric   | Value  |
|----------|--------|
| $r^2$    | 1.000  |
| RMSE     | 0.041  |
| MAE      | 0.012  |
| NSE      | 1.000  |
| PBIAS    | 0.103  |

Figure 5. Comparison of observed surface flow compared to the results of the tank model.

| Metric   | Value  |
|----------|--------|
| $r^2$    | 0.483  |
| RMSE     | 2.263  |
| MAE      | 1.563  |
| NSE      | -4.214 |
| PBIAS    | 300.181|
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\[ r^2 = 0.951 \quad \text{RMSE} = 2.271 \quad \text{MAE} = 1.570 \]

\[ \text{NSE} = 0.906 \quad \text{PBIAS} = 14.203 \]

**Figure 6.** Comparison of observed base flow compared to the results of the tank model.

The inaccuracy of the results of the surface and base flow models in this study was predicted due to the model not yet considering the level of soil moisture before the infiltration and surface flow processes in the first tank \([27],[28]\).

Overall, tank model performance could simulate rainfall-runoff well (Figure 4), in line with the research result of Suryoputro et al. \([29]\).

4. **Conclusions**

The conclusion from this research was that conceptual hydrology model could simulate base flow well. Based on the statement, conceptual hydrology model could be developed to predict the effect of the change in land use on base flow changes.

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