Hydrograph separation method and baseflow separation using Chapman Method – A case study in Peusangan Watershed

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Abstract. Base flow is the portion of stream that is not run off and results from seepage of water from the ground into a channel slowly over time. Base flow is considered to be the groundwater contribution to stream flow. Estimates of the amount of base flow can be derived from stream records. This study is about groundwater recharge condition at two sub watersheds in Krueng Peusangan: sub watershed of Lut Tawar and sub watershed of Teupin Mane (Krueng Teumbo). The Krueng Peusangan Watershed is one of priority for watershed management because this watershed is in a critical condition. The Krueng Peusangan Watershed is an important water catchment area in Aceh where there are one million people depend on life from the water source watershed, such as drinking water, agriculture, and fisheries. The Krueng Peusangan includes four regencies, an upstream Aceh Tengah, a midstream area in Bener Meriah and downstream area in Bireuen and Aceh Utara. This research aims to get groundwater recharge using Seasonal Recession Method and Base Flow Separation Method. Both of methods were used to estimate groundwater recharge for each peak in stream flow during the period of record (2008-2012). The results showed that the trend pattern of the stream hydrograph could be explained using the exponential function where the dots lowest discharge that is the end of the recession (y) than any period of time on stream hydrograph semi logarithmic (x). The regression formula for the watershed of Krueng Peusangan is: y=1.3x^{-0.12} (Lut Tawar -Wih Nareh) and y=1.94x^{-0.42} (Teupin Mane-Krueng Teumbo). The filtering method (Base Flow Separation Method) by Chapman (1999) gave a lower percentage of the low flow component (base flow) for Sub Watershed of Teupin Mane (Krueng Teumbo): 2008/2009 (18%), 2009/2010 (3%), 2010/2011 (1%), 2011/2012 (1%). For Sub Watershed of Lut Tawar (Wih Nareh): 2008/2009 (1%), 2009/2010 (1%), 2010/2011 (4%), 2011/2012 (1%). Estimates using the two methods define a reasonable range of the base flow contribution to stream flow in the watershed.

1. Introduction

Groundwater is one of the most important natural resources, which supports human health, economic, development and ecological diversity. Challenges in the future are increasingly limited sources of surface water, and the ever increasing needs of water for purposes in supporting development.
Assessment of water resources available for both surface and groundwater flow is very important for optimal use and protection considerations, and also for the prediction of floods and low flows [1].

Based on the depth and density of surface drainage, groundwater flow systems can be categorized into three types: (1) shallow, (2) intermediate, and (3) regional flow systems [2]. For water resources management must understand the contribution of groundwater in the river so that good groundwater resource management techniques will reduce problems such as the disruption of the hydrological cycle balance and impact on groundwater contamination. One of the components of groundwater is base flow. It is a component of streams flow derived from natural aquifer storage. Availability of river water is influenced by surface runoff or base flow component directly. Stream flow can also be affected by direct flow disturbances, such as diversion of runoff and water harvesting mechanism.

A popular method by Meyboom (1961) [3] was used to determine the volume of recharge with seasonal recession and the recession curve displacement method by Rorabaugh. The method is a basic method used in the concept of river flow contributions from direct runoff and groundwater base flow [4]. The base flow recession curve is the lower part of the falling limb of a hydrograph and expresses the relationship between base flow and time. Recession constants describing the slope of the decline in stream following the dynamic movement of water in the basin fill [5]. Accurate estimation of the groundwater recharge is very important as an indicator of the proper management of the groundwater system [6].

A multitude of methods have been developed, which can be conveniently categorized into four basic approaches: graphical base flow separation, filtering algorithms, frequency analysis and recession analysis. In this research, we will use two methods for base flow analysis in Krueng Peusangan watershed, recession analysis and hydrograph base flow separation. The aim of this study is to determine the volume of the watershed recharge in Krueng Peusangan based on the available data using the both methods. The base flow is assumed to fluctuate (ups and downs) and the river discharge represents the integration of the physical condition of watershed and precipitation.

Hydrograph base flow separation is one of analytical methods developed for separate base flow from total stream flow. Although most procedure are based on physical reasoning, element of all separation technique are subjective. Manual separation of hydrograph stream into surface flow and groundwater flow is difficult and inexact. In this research, analysis of base flow using filtering method (base separation method) was only for two sub watersheds of Krueng Peusangan: downstream (Krueng Teupin Mane-Teumbo) and upstream (Lut Tawar-Wih Nareh).

2. Materials and Methods

The study was conducted in the watershed of Krueng (Figure 1). Precipitation data for the upstream and downstream areas were derived from Stations of Meteorology and Climatology of Lhokseumawe and Bebesan Takengon. The data as used in this study were stream flow data issued by the Office of Water Resources and Headquarter of Krueng Aceh Watershed, Aceh Province (NAD).

The hydrograph stream during the periods when all discharges are derived from groundwater sources is known as base flow recession curve. For analysis groundwater recharge using recession analysis.

Where \( Q \) is the discharge of the river at time \( t \) and \( e^{-a} \) is a constant defining the rate of recession. It is common practice to replace baseflow recession constant \( e^{-a} \) with \( k \). Thus, equation (1) becomes (2)

\[
Q_t = Q_0 e^{-at} \quad (1) \\
Q_t = Q_0 k^{-t} \quad (2)
\]

The pattern of groundwater recharge condition changes was obtained by connecting the dots of lowest discharge \( (y) \) in which it was the end of the recession from every period to the time \( (x) \) on flow semi-logarithmic hydrograph. The lines that formed as a particular curve which followed the end of the recession flow fluctuation. Trend was selected that had coefficient determination \( R^2 \) (8).

For base flow separation method, this study used the one that was proposed by Chapman (1999) [9]. It is given by equation (3).
Where:

\[ Q_{d}(i) = \frac{3\alpha-1}{3-\alpha} (Q_{d}(i-1) + \frac{2}{3-\alpha} (Q_{t}(i) - Q_{t}(i-1))) \]  

(3)

Where:

\( Q_{d}(i) \) = base flow \( (m^{3}/s) \),
\( Q_{t}(i) \) = total flow and \( \alpha \) is coefficient with value 0.925.

In this study, the discharge data at point D and point E will be used as observation points for hydrograph Method and Baseflow Separation Using Chapman Method. Point at (D) Wih Nareh representing sub watershed of Lut Tawar, (E) Krueng Teumbo representing sub watershed of Krueng Celala, Lut Tawar, Wih Balek, Bawang Gajah, Timang Gajah, Wih Bruksah, Wih Genengen.

3. Results and Discussion

Infiltration that occurs in an area is influenced by various factors, such as infiltration capacity, rainfall, climate, topography and geological structure. This can be seen from the conservation index of an area that is used to show the ability of an area to absorb rainwater that falls to the surface of the land. The infiltration process can occur if there is an unsaturated zone between the surface of the ground and the surface of the ground, so that water can infiltrate into the soil.

Infiltration can occur if there is no watertight space between the surface of the groundwater, so that the water on the surface can infiltrate into the soil. This infiltration process is influenced by soil structure, land use and climate. The Krueng Peusangan watershed is dominated by brown podsolic soil and yellow red podsolic and medium and rather fine soil texture which is a low absorption of water. In good vegetation conditions, the stability of water absorption can be helped by prisoners from the roots and
canopy of vegetation that covers the watershed area. But in this area research, there are about 33% land conversion functions as plantations.

Generally, the Krueng Peusangan watershed has a slope of 0.002 % and the lowest about 43-750 mpl in the middle and lower reaches of the watershed. While the highest point around 800-3000 mpl is located at the head or around the mountain Peutsagoe, Geureudong and mountains Gayo. The impact caused the physiographic Krueng Peusangan have a level slope were categorized grade flat slope-being. This means that the areas with the category of flat to being dispersed in the basin, especially the middle and lower reaches. While the steep watershed slopes to very steep generally found on the edge of the foothills of the upstream Krueng Peusangan. Either directly or indirectly, and topographic effect is most pronounced in setting rock are relatively high [2].

Changes in the distribution of river flow and groundwater recharge over space and time is also determined by changes in temperature, evaporation, and a significant rainfall [10]. One system is highly vulnerable to climate change are water resources. Climate change affect water availability, quality, and potential water damage. Many sectors and systems depend on the availability of water resources, so that changes in the hydrological regime and water quality due to climate change will have an impact on the social and economic fields. To overcome the negative impact of climate change on water availability, land use needs to be done. Rainfall analysis for 20 years (1992-2011) based climate classification of Smith Ferguson in Krueng Peusangan (Station Bebesan) was classified in type B with wet category 28.86%. In the same location had been a shift in climate over the past two decades due to the 1992-2001 was classified in type B category (23.68%), while in 2002-2011 was classified in type C category (34.25%).

The process of absorbing rainfall into the soil is strongly influenced by rainfall and watershed characteristics in the form of watershed morphology and morphometry. Watershed morphology is information on the physical shape of the watershed that is able to characterize watershed characteristics including watershed shape, watershed topography and drainage pattern, while the watershed morphometry states quantitatively the condition of river channel network which includes area, width, slope, river order and density. The extent of a watershed or sub-watershed functions as a reservoir of water flow from the surface water storage site. The wider the sub-watershed, the more water can be accommodated and the longer it takes for rain to reach the outlet.

Characteristics of drainage patterns in sub-watershed sub-locations are dendritic. The results of the analysis show that the Krueng Peusangan watershed has a tree-shaped flow pattern so that it can be classified into the dendritic flow pattern. Dendritic patterns are generally found in areas that have uniform rock and wide distribution.

The Krueng Peusangan watershed can be visually categorized into longitudinal watersheds with a northward orientation. The watershed roundness level using the circularity ratio method approach has a value of 0.31. The elongated shape is characterized by the presence of a main river that receives streams and creeks on the left and right sides which then flow into the sea. The Lut Tawar sub-watershed has a non-round shape with a value of circularity ratio 0.42 while the Teupin mane sub-watershed has circularity ratio 0.2 with a non-round category.

The shape of the sub-watershed in the Krueng Peusangan watershed is generally not rounded, indicating that the shape has a debit and centralized velocity is relatively small. This condition causes the water travel time of the tributaries to vary to the center of the flow because it experiences infiltration first. But the chance of water to erode the soil and disperse the soil material is getting bigger. If the effort to rehabilitate the land is not done, the chances of erosion and sedimentation are quite large.

The Krueng Peusangan watershed has a drainage density that can be classified into the medium category with a density index of 0.84. While the density index of the sub-watershed ranges from 0.37 to 1.39. The index of drainage density for Lut Tawar is 1.071 with a moderate category and for the location of krueng teumbo is 0.802 with a medium category. The density of drainage obtained for each watershed is smaller than 1.74, which means that the Krueng Peusangan watershed has features of poor surface drainage, many occurrences of inundation and often flooding is also a zone of sedimentation. Sub-watersheds that have a high drainage density will have better hydrological conditions when compared
with watersheds with low drainage density. This is caused by the increasing drainage density, the rainwater will be spread evenly into the creeks and before entering the main river the water has a longer time and more permeated into the soil which in turn will increase the availability of underground water.

![Figure 2. Trend of rainfall and air temperature at the research location](image)

In figure 2 shows the rainfall (2008-2012) continues to increase and the air temperature decreases at the research location. This will certainly cause increased air humidity. In addition to watershed physical factors, rainfall, climatic elements influence the pattern of water availability and temperature, air humidity, wind speed and duration of irradiation. These conditions will greatly influence to reduce river discharge and deposits of ground water.

This study in the Peusangan watershed is very difficult to determine the exact desires of the baseline which can then be analyzed for volume loss because there are no long dry months. Correcting the changing fluctuations from the recession line can change the unstable conditions of the refill area of the Teupin mane sub section at the measurement point in Teumbo. Therefore further analysis is needed for a longer period of time. For sub-watershed teupin Mane, this area is returned by Latosol soil types (33.89%) yellow red podsolic (48.68%), and Andosol (0.19%) (BP Krueng Aceh watershed, 2010) which is a type of soil absorbency. In conditions with agricultural land cover (68.72%) and secondary dryland forest (22.81%) covering forest areas that have been allocated to agricultural land through deforestation to be used as plantation gardens and fields in accordance with what is spent. Increased direct runoff in the rainy season, this causes the catchment volume of watersheds in this area to increase extreme fluctuations (unstable). Changes in the distribution of river currents and recharge soils above and time are determined by changes in temperature, evaporation, and importantly, precipitation [11]. Some of the effects of change on the hydrological process have been revised [12].

The line produces a regression equation (D) sub watershed of Lut Tawar, \( y = 1.3x^{0.12}, \ R^2 = 0.941, \) and (E) sub watershed Teupin Mane, \( y = 1.94x^{0.42}, \) with \( R^2 = 0.917. \) (figure 3 and 4). That was showed the pattern of groundwater recharge condition that occurred at some point in Krueng Peusangan watershed. It is obtained by connecting the dots lowest discharge that is the end of the recession than any period of time on stream hydrograph semilogarithmic. The lines that form a particular form of the exponential curve following the end of the recession flow fluctuation of each period of observations at the study site. Here, we can see the good relationship between the lowest discharge recession variable points with the time observation period. The figure also shows that at location E (Teupin Mane watershed) has a higher slope. This means reducing the water absorption pattern compared to the Lut Tawar watershed, while location (D) tends to have a horizontal slope. Instability of recharge that occurred will affect the amount of ground water reserves in the watershed [13]. The base flow recession was a function of topography, drainage patterns, soil type, geology of the watershed.
Figure 3. Hydrograph of Discharge, Baseflow recession and Pattern of Infiltration at Location D (Wih Nareh) Period November 2008 - October 2011

Figure 4. Hydrograph of Discharge, Baseflow recession and Pattern of Infiltration at Location E Period November 2008 - October 2011

The condition of absorption volume was also influenced by the characteristics of the rainfall in the region of the area. Conditions that occurred in both sub watersheds indicated that there had been an imbalance fluctuations of water seeped into the aquifer (groundwater catchment layer) on recharge area due to rainfall and high evapotranspiration in mid and downstream sections of Krueng Peusangan. Therefore, a clear direction needed for land use and functions of forests, especially in the recharge area to maintain the balance of the hydrological cycle and the quantity of groundwater properly. In the Upstream Krueng Aceh Watershed there had been some problem with decreasing direct flow because deforestation and sedimentation. Other side, in the downstream (Krueng Tepin Mane-Teumbo) there had also been some problem such as flooding.

3.1 Base Flow Separation Method by Chapman

The purpose of basic flow separation is to distinguish two streams base (use of groundwater inflow) and fast flow (surface runoff and interflow) [14]. Baseflow index (BFI) states the comparison of the base flow to the total discharge on the River. The baseflow index shows the ratio between the base flow to the total flow discharge in the River. According to [15], the baseflow index value that is around 0.9 indicates a permeable base. the high baseflow index value illustrates the bases that have a stable flow
regime and the das can provide water supply to the river, even though the dry season is quite long. A low baseflow index value (between 0.15 - 0.2) shows an impermeable watershed with a flashy flow regime.

Figure 5 is present one of sample the results of the base flow and direct flow component of the daily stream flow in Sub Watershed Teupin Mane (Teumbo) during 2008/2009 as calculated by Chapman (1999). According to the result, base flow is not the dominant value in the Sub Watershed Teupin Mane (Teumbo). The filtering method (Base Flow Separation Method) by Chapman (1999) gave Base Flow Index (BFI) of the low flow component (base flow) for Sub Watershed of Teupin Mane (Krueng Teumbo): 2008/2009 (18%), 2009/2010 (3%), 2010/2011 (1%) and 2011/2012 (1%). The Chapman method in this study used the empirical coefficient taken 0.95.

Many empirical methods and formulas for separating the base flow from the stream. Digital filter methods and digital graphic methods are two methods that are sufficient, it's easy to analyze [16]. Digital filter method (recursive digital filter works by processing discharges data for separating the base flow from the hydrograph. Chapman's Method tend to estimate lower base flow.

In general, the base flow contribution was very minimum than the direct flow. Based on [17], the Sub Watershed Teupin Mane (Teumbo) showed deteriorating watershed conditions (critical). In February 2016, Teupin Mane River flooded and some houses damaged while dozens of other inundated (Serambi Indonesia, 2016). It showed the sub watershed Teupin Mane (Teumbo) one of critical sub watershed of Kreung Peusangan.

![Figure 5. Base flow and direct flow components of Sub Watershed Teupin Mane (Teumbo) in 2008/2009.](image)

For upstream Sub Watershed Lut Tawar/ Wihnareh Figure 6 (one of sample), BFI was 2008/2009 (1%), 2009/2010 (1%), 2010/2011 (4%), 2011/2012 (1%) , respectively. In Sub Watershed Lut Tawar, it found that decreasing river flow and sedimentation. Where is important hydrological issue to be solved.

![Figure 6. Base flow and direct flow components of Watershed of Lut Tawar (Wih Nareh) in 2008/2009](image)
in the Krueng Peusangan Watershed. According to the result of BFI, the upstream was very minimum of base flow, because of deforestation in that area. Based on[10], the largest proportion of deforestation in Krueng Peusangan Watershed occurred in the upper catchment area.

The instability in the chapman method is also seen in the slope recession baseflow which tends to be flat (Lut Tawar) and steep for the Teumbo location. High average BFI values indicate watersheds with water availability both in the dry season and the rainfall is quite good, while the low BFI shows the watershed with the base flow contribution is quite low. Many methods for calculating the base flow index that is six methods (two parameters, ihacres, EWMA, Eckhardt, local minimums, and fixed intervals) resulted in an average BFI calculation of more than 0.7 and consistent across all watersheds. While the three methods (one parameter, Chapman, and lyne Hollick) tend to produce low BFI values and tend to be unstable [18]. Each method has a tendency to estimate the base flow higher and others tend to estimate lower. The instability in the chapman method is also seen in the slope recession baseflow which tends to be flat (Lut Tawar) and steep for the Teumbo location.

4. Conclusions
The pattern of absorption that occurred in the watershed area of Krueng Peusangan (D) sub watershed Lut Tawar for $y = 1.3x^{-0.12}$ and (E) sub watershed of Teupin Mane for $y = 1.94x^{-0.42}$. The location of E had a higher slope which decreased absorption pattern compared to watershed of Lut Tawar, while location of (D) tended to flat. The location measurement at points E showed infiltration volume fluctuated widely and unstable. Point D showed that the catchment volume increased, it was indicated Positive (good). The volume of absorption in the watershed of Krueng Peusangan midsection fluctuated sharply. Base Flow Separation Method by Chapman gave Base Flow Index (BFI) of the low flow component (base flow) for Sub Watershed of Teupin Mane (Krueng Teumbo): 2008/2009 (18%), 2009/2010 (3%), 2010/2011 (1%), 2011/2012 (1%). BFI was 2008/2009 (1%), 2009/2010 (1%), 2010/2011 (4%), 2011/2012 (1%) In this study, the result gave base flow value smaller than direct flow. In general, Krueng Peusangan watershed needs to do conservation and water resource management to solve the problem in this watershed.

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