Telaga Kenyamukan generating discharge analysis with Thomas-Fiering method for North Sangatta raw water needs

Febria Nur Risdina¹, Pranoto Samto Atmodjo² dan Sri Sangkawati Sachro²
¹ Civil Engineering Master Program, Diponegoro University. Semarang 50275, Indonesia
² Civil Engineering Department, Diponegoro University. Semarang 50275, Indonesia
E-mail: fnr090279@gmail.com¹

Abstract. The Telaga Kenyamukan as a raw source of Kudungga WTP is studied to determine the water availability. Historical data used in hydrological analysis are sometimes incomplete or have a short time period, so the results may not match the conditions in the field. Hydrological analysis in this study used rainfall data from Pit-J and AB Station from 2005 to 2016, and climatology data from the Sepinggan Meteorological Station from 2005 to 2016. The discharge was analyzed by Mock method, then generated up to year of 2038 with the Thomas-Fiering method and obtained the dependable flow with the monthly basic method in a 90% probability, resulting in 467 l/sec. The water requirements are calculated by projecting the population for the next 20 years, with the results of the RWC (Regional Water Company) total water demand in 2019 amounting to 259.99 l/sec and increasing up to 2038 to 630.32 l/sec. With a water balance analysis, the water availability in the next 20 years in meeting needs is in a surplus condition, but in RWC water supply systems which depend on Water Treatment Plant capacity, since 2028 the WTP capacity must be increased due to a deficit of -12.57 l/sec.

1. Introduction

The existence of Telaga Kenyamukan in the mining concession area of PT. Kaltim Prima Coal (KPC) provides opportunities for Regional Water Company (RWC) of Tirta Tuah Banua to increase water supply. Telaga Kenyamukan has a catchment area of 13.59 km². In non-technical terms, Telaga Kenyamukan is a source of water which gives many benefits to the RWC. Even though it is located in mining area, water sources do not originate from mining pit, but from infiltrated water from surrounding forests and rainwater, with water catchment areas that are not used in any activities, making the water unexposed to pollution.

The raw water sources of RWCs that have been used in advance, Sangatta River, have experienced a significant decrease in water quality and often get seawater intrusion, making it difficult for RWC intakes when taking raw water. This is one of the causes of Tirta Tuah Banua RWC until 2017 can serve only 61.98% in the area of Sangatta City. On the other hand, in accordance with the MoU between the East Kutai Government and KPC, KPC has the responsibility for taking raw water to the Kudungga Water Treatment Plant/WTP (which was built by the East Kutai Government), so sourcing raw water from Telaga Kenyamukan allows RWC to save on production costs.

This research is needed to analyze the water availability of Telaga Kenyamukan so that information supports the planned development of WTP raw water sources in the next 20 years in North Sangatta Sub-District can be prepared. Determining the term of the next 20 years is based on the Regulation of the Minister of Public Works No: 18 / PRT / M / 2007 concerning the Implementation of Procurement of Drinking Water Supply Systems Annex VII. In the estimation of water availability and water
requirements, long historical data is needed as an illustration of the phenomenon that occurs. But in the fact the existing historical data is incomplete and very short so that not much information is obtained. If the incomplete data is used in the analysis, the results obtained may be inaccurate compared to the conditions in the field. One solution to deal with the lack of data in hydrological analysis is to generate data, which means making new data sets based on historical data to obtain more complete data.

Data forecasting is made to predict time and systematic data that is likely to occur in the future based on information from past and present data[1]. Data on the availability of water resulting from subsequent generation can be used to determine the balance of water resources in the North Sangatta Sub-District. A data generation study was conducted by Afifah et al.[1], Pratiwi et al [2] and Suryanto [3]. This research aims to study water balance related to water supply systems in North Sangatta Sub-District for the next 20 years, with the expected results of being able to support the existence of measurable RWC services and can be the basis for developing and managing Telaga Kenyamukan water resources in a sustainable manner.

2. Methods

Research on the availability of water for RWC water supply systems with objects located in mining areas with limited access is new because most objects are located in areas where access is easily accessible. The research location is in North Sangatta Sub-District, with an area of 308.52 km², as shown in figure 1. The three main stage in this research procedure are shown on Figure 2.

Figure 1. A Map of North Sangatta Sub-District
Because there is no discharge data in Telaga Kenyamukan, the analysis of water availability consists calculations starting from hydrological analysis such as regional rainfall analysis, evaporation analysis, followed by discharge analysis, generating discharge then calculating dependable discharge. The main factor in calculating water requirements is the population in the research area. The number of domestic and non-domestic water sectors is calculated based on criteria from the Director General of Cipta Karya, Ministry of Public Works, 1996, as shown in Table 1.

In a study by Kurniawan [4], water balance is described as an illustration of the potential of a watershed in terms of the availability of water to the water needs in the watershed concerned. If the water balance shows a surplus, then the use of water can be maximized. Conversely, if the water balance shows a deficit, then water use should be regulated on a priority scale. This theory can be a basis for consideration in deciding strategies in water management. Based on research by Sri Harto [5], the basic concept of water balance can be described as a balance between the amount of water entering into, available at, and coming out of a particular system / sub-system.

**Table 1. Water requirement criteria.**

| No. | Description                                      | Metropolitan | Big City    | Medium City | Little City | Village |
|-----|--------------------------------------------------|--------------|-------------|-------------|-------------|---------|
| 1   | Home Connection units (HC) liter/people/day     | >150         | 120-150     | 90-120      | 80-120      | 60-80   |
| 2   | Public Hydrant (PH) liter/people/day            | 20-40        | 20-40       | 20-40       | 20-40       | 20-40   |
| 3   | Non-domestic units                               |              |             |             |             |         |
|     | a. Small business (litre/unit/day)              | 600-900      | 600-900     | 600         |             |         |
|     | b. Large business (litre/unit/day)              | 1000-5000    | 1000-5000   | 1500        |             |         |
|     | c. Industry (litre/second/day)                  | 0.2 - 0.8    | 0.2 - 0.8   | 0.2 - 0.8   |             |         |
|     | d. tourism (litre/second/day)                   | 0.1 – 0.3    | 0.1 – 0.3   | 0.1 – 0.3   |             |         |
| 4   | Losted water (%)                                | 20-30        | 20-30       | 20-30       | 20-30       | 20-30   |
| 5   | Maximum consumed factor                         | 1.15 – 1.25  | 1.15 – 1.25 | 1.15 – 1.25 | 1.15 – 1.25 | 1.15 – 1.25 *days |
| 6   | Peak hour factor                                | 1.75 – 2.0   | 1.75 – 2.0  | 1.75 – 2.0  | 1.75 – 2.0  | 1.75 – 2.0 *days |
| 7   | People per HC                                   | 5            | 5           | 5           | 5           | 5       |
| 8   | People per PH                                   | 100          | 100         | 100         | 100         | 100     |
| 9   | Remaining press in providing distribution       | 10           | 10          | 10          | 10          | 10      |
| No. | Description | City Category based on Population (people) |
|-----|-------------|-----------------------------------------|
|     |             | Metropolitan | Big City | Medium City | Little City | Village |
| 10  | Operation hours | 24 | 24 | 24 | 24 | 24 |
| 11  | Volume of reservoir (%) (max) | 15-25 | 15-25 | 15-25 | 15-25 | 15-25 |
| 12  | HC:PH | 50:50 s/d 80:20 | 50:50 s/d 80:20 | 80:20 | 70:30 | 70:30 |
| 13  | Service coverage (%) | *90 | 90 | 90 | 90 | 70 |

Source: Dirjen Cipta Karya Ministry of Public Works 1996 Planning Criteria

3. Analysis and Discussion

3.1. Water Availability Analysis
Water distribution in North Sangatta Sub-District has two sources of raw water; Sangatta river for Kabo WTP and Telaga Kenyamukan for Kudungga WTP. In this study, Sangatta river water availability data is compiled from the results of planning carried out by the East Kutai Public Works Office in Sangatta Dam Planning in 2009, namely the average dependable discharge \( Q_{95} \) of 18.138 m\(^3\)/s. Due to the absence of data on water availability at Telaga Kenyamukan, this study will use related data, such as rainfall, climatology, etc. to analyze water availability.

3.1.1. Rainfall Analysis in Catchment Areas of Telaga Kenyamukan. The Thiessen Polygon method is used to analyze rainfall in the Telaga Kenyamukan catchment area [5,6]. This method considers the area that influences one rain station as a point of observation. The equation of Polygon Thiessen is:

\[
P = \frac{\sum_{i=1}^{n} P_i A_i}{\sum_{i=1}^{n} A_i}
\]

In equation (1), \( P \) is regional average rainfall value (mm); \( P_1, P_2, ..., P_n \) is rainfall recorded in rain station 1, 2, ..., n; \( A_1, A_2, ..., A_n \) is an area of polygon 1, 2, ..., n; \( n \) is amount of rain station.

Data from 3 rainfall stations around the immediate vicinity of Telaga Kenyamukan water catchment area are the source of polygon data compilation, namely: Pit J station, AB Station and ARS station, as shown in figure 1. By Arc Map software, making Thiessen polygons can be done and it could be seen that Pit J station covers 90.07% of Telaga Kenyamukan catchment area and an area of 9.93% from the AB station.

3.1.2. Evaporation Analysis. To estimate available discharges (for long durations), loss of water due to evaporation must be taken into account. The modified Penman method can provide accurate results for analyzing evaporation of free water (Eo) if there is no water balance study conducted at the research site [6]. A study from Agus et al. [7] and Pratiwi et al. [2], shows that the calculation of monthly evapotranspiration with the Modified Penman method can be performed to analyze the availability of water using the Mock method. To complete some inadequate daily data, data from the stations around the station are used, with the Inversed Square Distance or Reciprocal method [8,9]. The equation of modified Penman method are (2) & (3)[10].

- \( \text{ETp} = \text{C.ETo} \) \hspace{1cm} (2)
- \( \text{ETo} = [w.(0.75R_s - R_n)] + [(1-w). f(U). (e_g - e_d)] \) \hspace{1cm} (3)

In equation (2), \( \text{ETp} \) is potential evapotranspiration (mm/day); \( \text{C} \) is Penman monthly correction number; and \( \text{ETo} \) is referral evapotranspiration (mm/day). In equation (3), \( w \) is table Penman I that deals with temperatures and regional elevation; \( R_s \) is shortwave radiation (mm/day); \( R_n \) is longwave radiation (mm/day); \( f(U) \) is function of wind speed at an altitude of 2 meters (m/s); \( e_g \) is actual vapor pressure whose magnitude is related to temperature function (mbar) and \( e_d \) is actual vapor pressure (mbar).
Climatological data from 2005 to 2016 consisting of air temperature, relative humidity, location of regional latitude, solar irradiation time and wind speed (BMKG meteorological station of Sepinggan, 2018) were analyzed by the modified Penman method.

3.1.3. Discharge Analysis. When there is no field discharge measurement data, the data can be obtained by changing the average rainfall data of the area as input into discharge data as output. The method used is Mock method [2,7,5,10,11,12], of which first step is to input rainfall data and potential evapotranspiration values. The final equation of Mock is: 
\[ Q = R_0 \cdot A \] (4)

Where Q is river discharge (m3/s); Ro is Runoff (mm); and A is catchment area (km²). To produce the availability of discharge data by Mock method, several parameters that need to be calculated, include limited evapotranspiration, water balance, ground water flow and storage (run off) and catchment area. For these calculations, some of the value factors needed are like the type of land outcrop (m), infiltration (i), slope of the drainage area, and monthly flow recession (k).

3.1.4. Discharge Data Generation for the Next 20 Years. The result of Mock method data is assumed to be historical data that will be used as input in forecasting water discharge in future. The Thomas-Fiering (TF) Method is commonly used and is considered a stochastic approach that is typical for forecasting in hydrology [13,14]. The basis of generating data is the calculation of the average value, standard deviation, correlation coefficient, regression coefficient, variance coefficient. The common equation of TF Method is:

\[ x_{i+1} = \bar{x}_{j+1} + b_j(x_i - \bar{x}_j) + t_i S_{j+1}(1 - r_j^2)^{1/2} \] (5)

In equation (5), which \( x_{i+1} \) is discharge on month \((i+1)\); \( \bar{x}_{j+1} \) is average of discharge on month \((j+1)\); \( b_j \) is regression coefficient for prediction of discharge on month \((j+1)\) based discharge on month \(j\) or regression coefficient between flowrate at month \(j+1\) with month \(j\); \( x_i \) is discharge during the month of synthetic data generation begins; \( \bar{x}_j \) is average discharge month \(j\); \( t_i \) is the number \(i\) of random number in a data series with zero mean and one standard deviation and follows a normal distribution; \( S_{j+1} \) is standard discharge deviation for month \((j+1)\); \( r_j \) is correlation coefficient between discharge on month \(j\) and discharge on month \((j+1)\); \( j \) is 1, 2, 3, ..., 12 (January until December) and \( i \) is \(j\), 12 month + \(j\), ..., month \(n + j\).

According to a study by Afifah et al. [1] and Pratiwi et al. [2], in calculations with a stochastic model, the data needs to be tested first to meet the normal statistical distribution requirements. The TF method for analysis is used by regressing the January discharge on December discharge, February discharge on January discharge rate, and so on for each month each year. A monthly regression relationship is used by assuming persistence caused by the effect of storing water as moisture and groundwater, as well as the inherent effects of seasonal weather patterns[15].

3.1.5. Analysis of Dependable Discharge. According to Limantara [17], Dependable discharge is defined as the flow available throughout the year with certain limits in percentage of failure. Drinking water and industrial needs demand a high probability, between 90% and 95% [11]. Calculations use the monthly basic method or based on monthly discharge. The steps are as follows:

- Sorted discharge data by ranking from the largest discharge to the smallest per each month, January until December.
- Calculated the percent of the dependable obtained from the value of \(m/(n+1)\) where \(m\) is the sequence number and \(n\) is the amount of data.
- Judging by the amount of discharge that has a reliability of 90%.
3.2. Analysis of Water Requirements

3.2.1. Population Growth Analysis. To analyze water requirements in an area, population growth analysis should be the first order of business since water is a primary need, especially in the domestic sector [18], of the community in the area.

![Figure 3. Projection of North Sangatta population growth for 2019-2038](image)

Population growth data is projected using the Geometric and Arithmetic methods [19], then the data is averaged to be used as projections for the number of residents from 2019 to 2038. Projections of population growth in North Sangattasub-district in 2019 amounted to 114,257 inhabitants and at the end of 2038 there will be 383,721 people, as shown in figure 3. Based on table 1, North Sangatta Sub-District is included in the category of medium-sized municipality, with a population of between 100,000 and 500,000.

3.2.2. Domestic and Non-domestic Sector Water Requirements Analysis. Water needs in the domestic sector consist of home connections and public hydrant connections. And non-domestic water needs consist of water requirements for education, health, house of worship, hotels, markets and restaurants, offices and rented houses, as well as industrial estates.

Water needs must also calculate water losses because this often occurs in RWC water production processes. According to a study by Silva et al. [20] and Alegre et al.[21], water loss is the amount of non-revenue water volume, and water loss is also the difference between the volume of raw water/treated water and revenue water. In addition, there is a need for non-RWC water which comes from mining companies as shown in table 2, KPC takes Telaga Kenyamukan water until 2021. Then after that, the use of Telaga Kenyamukan water is only for RWC water needs. This finding will affect the water balance analysis.

| No. | Source                | Mining water demand (PT. KPC & PT. Pama) |
|-----|-----------------------|------------------------------------------|
| 1   | Sangatta River         | 135                                      |
| 2   | Telaga Kenyamukan     | 30                                       |

3.3. Water Balance Analysis

Water Balance Analysis is needed to determine the potential of water that can be used in the future [17], therefore it is also necessary to look at the condition of existing infrastructure for water supply systems. The infrastructure for this research is Kabo WTP, with a capacity of 280 l/sec, and Kudungga WTP, which starting in 2019 has a capacity of 100 l/sec. The capacity of the two WTPs is expected to meet clean water needs in North Sangatta Sub-District.
This study calculates the water balance in two conditions, considering the use of raw water sources for two needs. The first water balance calculates the difference in the availability of raw water from Sangatta river and Telaga Kenyamukan with the total water demand in North Sangatta Sub-District. Dependable discharge of the two sources are used as the water availability value. The total water availability is derived from the sum of Q95 from Sangatta river and Q90 from the Telaga Kenyamukan, which is equal to 18,605 l/sec. The Water Balance II provides an overview of the balance of existing WTP capacity with RWC water needs that must be met. This is important in water supply, especially with piping systems. The capacity of WTP produces water that will be distributed to the community. In this study, it is assumed that WTP works with maximum capacity and the needs that must be met by RWC come from the domestic, non-domestic sectors as well as water loss during production. This water balance is also referred to as RWC Water Balance.

4. Results

The rainfall analysis with equation (1), obtained annual regional rainfall results as in figure 4. It determines the average rainfall in the catchment area of the Telaga Kenyamukan, ranging from 1594 to 2820 mm between years of 2005-2016 and the average rainy day in a year, which is 185 days. By using equation (2) and (3) so the Evapotranspiration are shown in Figure 5, the value between 3.06-4.94 mm in monthly average. Continued by calculation for Telaga Kenyamukan discharge that used the final equation (4) and rainfall data from 2005 to 2016 as an input made the availability discharge from 2005 to 2016 in monthly as shown in table 3. It used as historical data for generate longer data. The generated discharge from 2017 to 2038 using equation (5) was shown in table 4 that the highest monthly average of discharge is on June with 1.351 m³/sec.

![Figure 4. Annual regional rainfall (mm) and days of rain on Telaga Kenyamukan catchment area.](image)

![Figure 5. Monthly average potensial evapotranspiration.](image)
Generated data must have similar parameter characteristics as historical data, consisting of average values (as seen in Figure 6), standard deviation, correlation coefficient and variance. Figure 6 shows one comparison of statistical parameters, where it can be concluded that historical data and generated data have close statistical parameters, so the resulting data is considered accurate and can be used for calculation of reliable dependable flow analysis. The result of Pearson product moment correlation between historical data and generated data in the form of an average discharge shows a value of 0.897; which means that both data have highly correlate [16] and can be interpreted as valid data.

Table 3. Monthly average discharge of Telaga Kenyamanan year of 2005 to 2016 (m³/s).

| Year | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 |
|------|------|------|------|------|------|------|------|------|------|------|------|------|
| Jan  | 2.062 | 0.734 | 0.761 | 0.398 | 0.644 | 0.948 | 1.841 | 1.425 | 0.906 | 1.739 | 0.923 | 0.636 |
| Feb  | 1.586 | 0.779 | 1.525 | 0.759 | 1.931 | 0.501 | 1.409 | 0.798 | 0.773 | 0.790 | 1.048 | 0.565 |
| March | 1.516 | 1.068 | 1.179 | 0.592 | 0.789 | 1.810 | 0.733 | 1.382 | 0.407 | 0.866 | 0.544 | 0.747 |
| Apr  | 1.131 | 0.849 | 1.258 | 1.309 | 1.562 | 1.721 | 0.684 | 1.148 | 0.867 | 0.700 | 1.346 | 1.090 |
| May  | 0.571 | 0.765 | 1.560 | 1.355 | 0.991 | 0.965 | 0.747 | 1.849 | 0.743 | 1.220 | 0.920 | 1.170 |
| Jun  | 0.675 | 2.125 | 1.481 | 1.491 | 0.777 | 0.715 | 1.095 | 1.999 | 1.519 | 0.651 | 1.747 | 1.606 |
| July  | 0.774 | 0.257 | 1.860 | 1.863 | 0.853 | 0.830 | 0.488 | 0.674 | 1.357 | 1.221 | 0.365 | 1.110 |
| August | 1.643 | 0.734 | 1.007 | 1.197 | 0.689 | 0.701 | 1.731 | 0.972 | 1.904 | 1.343 | 0.301 | 1.321 |
| Sept | 1.107 | 0.630 | 1.559 | 1.434 | 0.305 | 1.033 | 0.765 | 0.490 | 0.709 | 1.037 | 0.013 | 1.524 |
| Oct  | 1.552 | 0.084 | 1.302 | 1.235 | 0.895 | 0.441 | 0.602 | 0.305 | 1.114 | 0.633 | 0.082 | 0.629 |
| Nov  | 0.725 | 0.958 | 1.614 | 1.246 | 1.765 | 0.586 | 1.715 | 0.758 | 0.555 | 1.875 | 1.235 | 0.500 |
| Des  | 1.460 | 0.619 | 1.617 | 0.810 | 0.838 | 0.750 | 0.908 | 1.595 | 0.555 | 1.675 | 0.886 | 1.086 |

Table 4. Generated discharge of Telaga Kenyamanan from 2017-2038
Calculation results of dependable discharge was shown in Figure 7. The highest value of Q90 was obtained in December with a value of 0.711 m$^3$/sec, and the lowest occurred in October with a value of 0.084 m$^3$/sec. And the dependable discharge is an average of 0.467 m$^3$/sec. This Q90 dependable discharge average is used as the value of water availability in Telaga Kenyamukan.

Table 5. Total water requirements of North Sangatta.

| No. | Year | Domestic Sector | Non-Domestic Sector | Water Loss | Mining needs | Total |
|-----|------|-----------------|---------------------|------------|--------------|-------|
| 1   | 2019 | 163.46          | 44.54               | 52.00      | 165.00       | 424.99|
| 2   | 2023 | 200.65          | 48.37               | 62.25      | 135.00       | 446.27|
| 3   | 2028 | 257.37          | 56.69               | 78.51      | 135.00       | 527.57|
| 4   | 2033 | 329.43          | 67.55               | 99.25      | 135.00       | 631.23|
| 5   | 2038 | 424.25          | 80.00               | 126.06     | 135.00       | 765.32|
Table 6. Water balance I

| No. | Year | Water Availability (l/sec) | Water Requirement (l/sec) | Δ (l/sec) | Result |
|-----|------|---------------------------|---------------------------|----------|--------|
| 1   | 2019 | 18,605.55                 | 424.99                    | 18,180.56| Surplus|
| 2   | 2023 | 18,605.55                 | 446.27                    | 18,159.28| Surplus|
| 3   | 2028 | 18,605.55                 | 527.57                    | 18,077.98| Surplus|
| 4   | 2033 | 18,605.55                 | 631.23                    | 17,974.32| Surplus|
| 5   | 2038 | 18,605.55                 | 765.32                    | 17,840.23| Surplus|

Table 7. Water balance II

| No. | Year | WTP Capacity (l/sec) | RWC Water Requirements (l/sec) | Δ (l/sec) | Result |
|-----|------|----------------------|-------------------------------|----------|--------|
| 1   | 2019 | 380                  | 259.99                        | 120.01   | Surplus|
| 2   | 2023 | 380                  | 311.27                        | 68.73    | Surplus|
| 3   | 2028 | 380                  | 392.57                        | -12.57   | Deficit|
| 4   | 2033 | 380                  | 496.23                        | -116.23  | Deficit|
| 5   | 2038 | 380                  | 630.32                        | -250.32  | Deficit|

5. Conclusions

By analyzing water availability, it shows that Telaga Kenyamukan has a dependable discharge with a 90% probability of 467 l/sec. RWC water requirements continue to increase along with population growth starting in 2019, from 259.99 l/sec up to 2038 at 630.32 l/sec. The water balance I shows the availability of raw water in a surplus status for the next 20 years. However, in the provision of clean water, the RWC needs WTP with adequate capacity that meets the water requirements. Water balance II shows the condition of surplus until 2027 and after that, RWC of Tirta Tuah Banua requires an increase in WTP capacity to serve the North Sangatta community starting in 2028, with a deficit of -12.57 l/sec to -250.32 l/sec in 2038 if production capacity is not increased.

From the values of the availability of Telaga Kenyamukan water with its dependable discharge, compared to the need for increasing WTP capacity (based on water balance II) where the demand increases to 250.32 l/sec in 2038, it can be concluded that Telaga Kenyamukan has reliability in terms of water availability for the next 20 years. Seeing the large availability of water from the Sangatta River, it looks able to meet the needs of North Sangatta community’s water requirements but knowing information that RWC’s services are not yet 100%, it is suggested that other research be able to study the causes.

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