Water Reliability Analysis in Industrial and Residential Area, Based on NRECA Method Using ArcGIS Software

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Abstract. In Purwakarta Regency there is a new area designated as a residential, commercial and industrial area, namely the Jatiluhur Estate Area. With the new area, it is necessary to know whether the availability of water can meet its water needs (water reliability) for the next 50 years. This research also carried out the water reliability mapping. Based on the analysis, both water availability with dependable discharge Q80% and Q90% overall and monthly, can fulfil the water needs of Jatiluhur Estate until 2070. However, with the regulation of water intake in the river, a ground tank is needed which takes into account the water loss of 19%, so that Q90% dependable discharge can fulfil the need while carrying out the regulation. From the results of monthly water reliability mapping, water reliability with Q80% and Q90% (overall) generate one color, four colors with Q80% (monthly), and three colors with Q90% (monthly). Whilst, the annual water reliability map generates one color for water reliability with Q80% and Q90% both overall and monthly.

Keyword: Water Reliability, Water Needs, Water Availability, NRECA, GIS

1. Introduction

Water is one of the important elements needed by humans. The level of water need in each place will vary. As the population increases, the water need will also increase. The increment in population, it will certainly have an impact on the population’s needs which are adjusted to the activities carried out by the population [1]. In addition, the existence of new industrial, residential and commercial areas such as Jatiluhur Estate Area will have major influence on the amount of water need in the area. Water needs in the Jatiluhur Estate Area are fulfilled by water from Citarum River (output of Jatiluhur Reservoir). The water in Citarum River itself is not only used to meet the water needs of Jatiluhur Estate, but also to fulfil the needs of domestic water, irrigation water, industrial water, etc in Purwakarta Regency and its surroundings. Therefore, it is necessary to know how reliable the water in Jatiluhur Estate for the next 10, 20, 30, and 50 years. By knowing the water reliability aims to determine whether the water availability from Citarum River can fulfil the water needs of Jatiluhur Estate. If it cannot be fulfilled, then a plan for water management in the area will be made. Water resources should be managed to ensure its availability and sustainability [2, 3]

The water used every day comes from a continuous hydrological cycle. According to Hidayat & Soekarni [4], through the hydrological cycle, the amount of water on earth is relatively constant, it’s just that the distribution and quality is uneven in each region. Therefore, the water availability is different in each places. In analyzing water availability, required continuous data of observed discharge. Meanwhile in Indonesia, data that measured continuously and lang is only rainfall data. Therefore, it needs a rainfall-runoff model to be able to convert rainfall into discharge data [5]. In this study, NRECA method is used to analyze the water availability, because it is a simple model and also very good at modelling low flows which is suitable for analyzing water availability.

From several previous studies, both regarding water availability, water demand, and water balance, such as those that have been carried out [6, 7, 8]. However only few were developing a water reliability map. However only few were developing a water reliability map. ArcGIS software was widely used to produce a map of to analyze water issue regarding temporal or seasonal condition [9, 10, 11]. Therefore, in this study, ArcGIS software was used to map water reliability based on Geographic Information System (GIS) in the Jatiluhur Estate. GIS-based information is needed by all groups, both the community
and government agencies [12], so it is hoped that the results of this research can be used for decision making related to the management of river water resources of Citarum in the Jatiluhur Estate Area.

2. Research Methodology

2.1 Research Location

The study was conducted in Jatiluhur Estate Area which located between 6°29'48" South Latitude and 107°24'09" East Longitude. The Jatiluhur Estate Area is a new area of ±1800 Ha that will be used as a residential, commercial and industrial area. This area is precisely located on Jalan Industri, Hegarmanah Village, Babakancikao District, Purwakarta Regency, West Java.

2.2 Stage of Study

Below are the stages that conducted for this study:

1. Preliminary stage
   In this stage, conducts problem identification and determine the purpose of the study, and also do some references that related to the topic of study, such as journal, books, and some standards applies in Indonesia.

2. Data Collection
   Data collection is the stage of collecting the required data, such as rainfall data, evapotranspiration data, observation discharge data, population data of Babakancikao District, and the map of study location.

3. Data Analysis
   After the required data was collected, data analysis can be carried out. Below are the stages of data analysis:
   a. NRECA modeling, which based on rainfall data, evapotranspiration data, watershed area, observed discharge data, and also the number of days in a month.
   b. NRECA calibration, was carried out using three objective functions, namely Nash-Sutcliffe Efficiency (NSE), Relative Volume Error (RVE), and correlation coefficient (r), also comparing the simulated discharge from NRECA modeling with observed discharge.

\[
\text{NSE} = 1 - \frac{\sum_{i=1}^{n}(Q_{\text{sim}} - Q_{\text{obs}})^2}{\sum_{i=1}^{n}(Q_{\text{obs}} - \bar{Q}_{\text{obs}})^2} 
\]

\[
\text{RVE} = \frac{\sum_{i=1}^{n}(Q_{\text{sim}} - Q_{\text{obs}})}{\sum_{i=1}^{n}Q_{\text{obs}}} 
\]

\[
r = \frac{\left(\sum xy - (\sum x)(\sum y)\right)^2}{\left(\sum x^2\right)\left(\sum y^2\right) - (\sum x)(\sum y)^2} 
\]

Where:
- \(Q_{\text{sim}}\): Simulated Discharge (m³/s)
- \(Q_{\text{obs}}\): Observed Discharge (m³/s)
- \(Q_{\bar{\text{obs}}}\): Average Observed Discharge (m³/s)
- \(n\): Number of Datas
- \(x\): Simulated Discharge (m³/s)
- \(y\): Observed Discharge (m³/s)

c. Calculate dependable discharge of Q80% and Q90% both overall and monthly using Weibull method.

\[
P\% = \frac{m}{n+1} \times 100\%
\]

Where:
- \(P\%\): Probability Percentage (%)
- \(m\): Serial Number of Data
- \(n\): Number of Datas

d. Determine the water availability based on the dependable discharge that has been obtained in previous step.
e. Calculate projection of population based on population data in Babakancikao District. The first thing to do in this step is calculate the rate of population growth, then determine the method to calculate projection of population, then calculate it with the predetermined method.

\[ i = \frac{P_t - P_{t-1}}{P_0} \times 100\% \]  

5. Arithmetic (\( P_t \)) = \( P_0 (1+it) \)

6. Geometric (\( P_t \)) = \( P_0 (1+i)^t \)

7. Exponential (\( P_t \)) = \( P_0 e^{it} \)

Where:
- \( i \) : Rate of Population Growth
- \( P_t \) : Population in year \( t \)
- \( P_0 \) : Population in base year
- \( t \) : Period of Time between base year and year \( t \)
- \( e \) : base number of the natural logarithmic system (\( \ln \)) = 2.7182818

f. Determine water needs (household, urban, industrial) for the next 10, 20, 30, 50 years using projection of population that have been carried out in the previous stage.

g. Analyse water reliability by comparing the water needs with the water availability.

h. Create water reliability map using ArcGIS software based on the result of the reduction between water availability and water demand.

Figure 1 shows a flow chart of the complete steps taken in this research.

3. Result and Discussion

3.1 NRECA Modelling and Calibration

The data needed in NRECA modeling and calibration are rainfall data, evapotranspiration data, and observation discharge data. In this study, NRECA modeling was carried out using rainfall data and evapotranspiration data from 2003-2015. In NRECA modeling, several parameters are used, the values of the parameters used in the modeling can be seen in Table 1.
In assessing the model used, calibration is carried out with three objective functions, namely Nash-Sutcliffe Efficiency (NSE), Relative Volume Error (RVE), and correlation coefficient (r). The results of these three objective functions can be seen in Table 2.

**Table 2. Objective Function Value**

| Function | Value |
|----------|-------|
| NSE      | 0.540 |
| RVE      | 0.288 |
| r        | 0.777 |

Based on model performance class according to [13], NSE value can be classified into “satisfied” class, because the NSE value is in the range of 0.50<NSE<0.70. If the model’s performance class is considered as “satisfied”, thus the next step of calculation can be carried out [14]. As for the RVE value which close to 0, the model is considered to have an acceptable small bias between the NRECA simulation discharge and the observed discharge. While the value of r can be interpreted that between NRECA simulation discharge and observed discharge has a good positive relationship. Which can also be seen in the comparison graph between the NRECA simulation discharge and the observed discharge in Figure 2, there is fairly good correlation in January to August 2004.

**Figure 2. Comparison Graph of Simulated and Observed Discharge**

### 3.2 Dependable Discharge

Dependable discharge is used to determine the water availability discharge. Based on SNI 6738:2015 [15], dependable discharge calculated using the Weibull Method. The Weibull method used here is to determine the probability of the occurrence of certain discharge from a list that have been sorted numerically [16]. In Indonesia, the probability of dependable discharge used for residential and industrial water needs is around 80% to 90%, thus the dependable discharge used are Q80% and Q90% both overall and monthly. Overall means the data used to obtain dependable discharge is the overall data that is sorted and then processed, meanwhile monthly means the data used is dependable discharge data in January every year (according to existing data). In Figure 3 and Table 3 below are the result of dependable discharge calculation of Q80% and Q90% both overall and monthly.
Based on the Figure 3 dependable discharge overall, Q80% is 5.96 m$^3$/s and Q90% is 4.27 m$^3$/s. As for dependable discharge monthly, it can be seen in Table 3 that the smallest dependable discharge of Q80% and Q90% occurred in October with 3.70 m$^3$/s and 2.45 m$^3$/s. Meanwhile, the largest of Q80% and Q90% occurred in February with 18.53 m$^3$/s and 12.85 m$^3$/s.

Table 3. Recapitulation of Dependable Discharge 80% and 90% (monthly)

|       | Jan | Feb | Mar | Apr | May | June | July | Aug | Sep | Oct | Nov | Dec |
|-------|-----|-----|-----|-----|-----|------|------|-----|-----|-----|-----|-----|
| Q80%  | 7.98| 18.53| 24.34| 20.92| 7.54| 5.84| 4.67| 3.74| 3.09| 2.45| 5.30| 6.33|
| Q90%  | 7.49| 12.85| 10.37| 11.61| 7.48| 6.04| 4.67| 3.74| 3.09| 2.45| 4.27| 4.61|

3.3 Projection of Population

In carrying out projection of population growth, there are several methods that can be used, which arithmetic, geometric, and exponential methods. In this study, the method chosen to project of population growth in 2020, 2030, 2040, 2050, and 2070 is the arithmetic method. The reason is from the calculation that have been done, the arithmetic method has the smallest standard deviation value and correlation coefficient value that is closest to 1 among other methods, which considered as the best method to describe population growth in the area. Table 4 shows the result of the projection.

Table 4. Total Projection of Population Growth

| Year  | P0   | Year- | i  | Total Projection |
|-------|------|-------|----|------------------|
| 2020  | 0    | 0     |    | 270840           |
| 2030  | 10   | 10    |    | 331568           |
| 2040  | 270840| 20    | 2.242%| 392296       |
| 2050  | 30   | 30    |    | 453025           |
| 2070  | 50   | 50    |    | 574481           |

3.4 Water Reliability

Water reliability is a comparison between water availability and water needs, whether it can fulfil the needs or not. The water needs were calculated are water needs of household, urban, and industrial, which calculated based on SNI 6728.1:2015 [17]. According to it, the household water need calculated based on the population, number of days, and water needs standard for household. The urban water need taken from 30% of total household water need. Meanwhile, industrial water need calculated based on industrial area, water needs standar for industrial, and number of days in a month. In this study, the amount of water availability and water needs are calculated per month, thus it is quite influenced by the number of day available. As for 2020, based on Figure 4a, the amount of water availability and water needs will be the same in months that have the same number of days. It also can be seen that the water availability, both with Q80% and Q90% overall, have much bigger number than its water needs (shown as purple
line) that tend to be constant every month. The highest water availability with Q80% and Q90% monthly occurred in February, while the lowest occurred in October. It also can be seen from the figure, the water availability can fulfill the water needs (shown as purple line) that relatively constant each month, even in October where the water availability is the lowest.

![Figure 4](image.jpg)

**Figure 4.** Water Reliability of Q80% Q90% Monthly in 2020 (a) and 2070 (b)

The water needs in 2070 from August to October by using Q90% for water availability, it takes more 50% of water from the river (Figure 4b). Thus, to be able to fulfilled the water needs in those months, it can be simulated a ground tank. As for the ground tank simulation, in November – July, water intake is carried out according to the amount of water needs which is rounded up. Meanwhile, in August – October, water intake is reduced little by little every month. So that the remaining water in the ground tank from November to July, can be used to cover the reduced water intake from August to October.

![Figure 5](image.jpg)

**Figure 5.** Ground Tank Simulation

Based on the result of the ground tank simulation that carried out by using water demand which takes into account a water loss of 20%, the ground tank still cannot fulfill the demand that indicated by the amount of water in the 300th day is below 0 as shown in green graphic line in Figure 5. Therefore, a re-simulation was carried out using water needs with water loss of 19%. It can be seen in the blue graphic line in Figure 5 that the amount of water stored in the ground tank is above 0, which means that the ground tank solution can be applied to the problem of water needs fulfillment in 2070 with water needs taking into account of 19% water loss.
3.5 Water Reliability Map

Water reliability mapping was carried out using ArcGIS Software based on SNI 6728.1:2015. On monthly water reliability map, the value of water reliability is obtained from the reduction between water availability and water demand per month. As for annual map, the value of water reliability is the total value of water reliability value each month in a year. Figures below are some water reliability maps was obtained. The color of maps below may differ each month or year, this is due to the difference in the amount of water availability and water need. The color range of water reliability that based on SNI 6728.1:2015 can also be the factor of it.

![Figure 6. Water Reliability Map February 2020 (Q80% Overall)](image)

![Figure 7. Water Reliability Map October 2020 (Q90% Overall)](image)

On water reliability map for February 2020 with Q80% overall and October 2020 with Q90% overall generates yellow (Figure 6 and 7). This can be interpreted that the surplus occurred in this month, which the amount of water remaining or the value of water reliability in the range 4,000,000 – 20,000,000 m$^3$/month.

![Figure 8. Water Reliability Map February 2020 (Q80% Monthly)](image)

![Figure 9. Water Reliability Map October 2020 (Q90% Monthly)](image)

On water reliability map for February 2020 with Q80% monthly generates light blue color and October 2020 with Q90% monthly generates orange color (Figure 8 and 9). This can be interpreted that the surplus occurred in this month, which the amount of water remaining or the value of water reliability in the range 40,000,000 – 60,000,000 m$^3$/month for February and in range of 0 – 4,000,000 m$^3$/month for October.

4. Conclusion

The conclusions that can be drawn from this research are as follows:
a. Water availability with dependable discharge Q80% and Q90% both overall and monthly can fulfill the water needs every year until 2070;
b. Annual water reliability map with Q80% and Q90% both overall and monthly generates yellow color. Monthly water reliability map with Q80% and Q90% overall produces a yellow color. With Q80% monthly generates yellow, light blue, green, and orange for 2020, 2030, 2040, and 2050. While, with Q80% monthly for 2070 and Q90 monthly generates yellow, green, and orange colors;
c. It is necessary to do a ground tank simulation using water demand that take into account water losses of 19%, this is in order to be able to carry out existing regulations related to water intake in rivers;
d. The highest water availability for Q80% and Q90% as a whole is in the months with 31 days. While the lowest water availability is in February. Availability of water for Q80% and Q90% monthly, namely February. While the lowest water availability is in October. The highest water demands are in months with 31 days. While the smallest water needs are in February. Overall, the water reliability is secured for the next 50 years.

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