

THE RELIABILITY STUDY OF RAW WATER SOURCES IN THE DEVELOPMENT OF POTABLE WATER SUPPLY SYSTEMS IN INDONESIA

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ABSTRACT: To fulfill the demands of raw water for potable water purposes in various parts of Indonesia, dependable water resources, especially from surface water are needed. During the dry seasons, difficulties arise in fulfilling these demands. This study aims to identify dependable discharge in three locations with different rainfall types. The first step in fulfilling the raw water demand is analyzing the hydrological data using the theoretical and Markov model to determine the dependable discharge based on the type of rainfall. The calculation shows that the suitable distribution test for Cidurian River, Landak River, and Selindung River, respectively are Pearson III Logs, Normal Logs, and Normal Logs. The dependability of Cidurian River discharge with a watershed area of 9.38 km² in the Tangerang Regency with a monsoon rainfall rate is 0.325 m³/s, whereas Landak River, which is located in Pontianak City with an equatorial rainfall type and a watershed area of 624.27 km², has a dependability value of around 40.703 m³/s and for the Selindung River in Pangkal Pinang City with an equatorial rainfall type and a watershed area of around 14 km² has a discharge dependability value of around 0.145 m³/s. The rainfall intensity in each region strongly influences the input discharge. Rain potential in each region can be utilized by storing the rain during the rainy season to meet the demands of the surrounding community when the dry season arrives.

Keywords: Dependable discharge, Hydrology, Markov model, Rainfall, Raw water

1. INTRODUCTION

Despite its abundant water resources, Indonesia continually experiences water shortages due to climate variability, geographical condition and dry season [1]. The annual climate variation pattern may affect water availability unequally, possibly constraining the water use with its unbalanced conditions of demands and the available potential, particularly during the dry season [2]. To ensure that the supply of drinking water is met, concrete steps are needed to identify the potential for Potable Water Supply Systems development to be carried out by the Regional Water Supply Companies, including studies on the potential and feasibility of raw water sources for drinking water.

The anticipated object in this process is limited sources of raw water, especially during the dry season. Water sources; renewed through the hydrological cycle and influenced by climate and land conversion, form the components of the hydrological regime (rain and discharge) which are random and stochastic [3]. The two main elements of climate are temperature and rainfall. Indonesia as an equatorial tropical region has a small temperature variation, while the rainfall variation is quite significant [4].

The influence of physiographic factors in Indonesia and its surroundings, such as latitude, altitude, wind patterns (wind and monsoon winds) on climate/weather elements has resulted in 3 (three) types of rainfall, namely: equatorial, monsoon type, and local type [5]. This study proves the differences in rainfall patterns in three Indonesian rain areas represented by the regions of West Java, Kalimantan, and Pangkal Pinang. Many research has found that [6] many river basins in the world are labeled as “closed” or are on the verge of being closed; their flows no longer reach the oceans. Water demands and supplies are changing. Their future is uncertain, but it is certain that they will change. Demands are driven in part by population growth and higher per capita water consumption in growing urban, domestic, and industrial water sectors [7]. Strategies to mitigate the effect of climate change in the production of drinking water consist of providing new sources for drinking water production, and applying short-term storage concepts and drinking water treatment plants in the long term [8]. Characteristic differences among the regions in Indonesia can affect the dependability of the discharge in the raw water source of the watershed surface [9]. The purpose of this research is to describe the dependability of raw water on the three research areas based on the Markov hydrological model and

the continuous model based on differences in the characteristic of the existing hydrology regimes in the region.

2. RESEARCH LOCATION

The research was conducted in three locations: Rancasumur Discharge Post, Cidurian River Basin, Tangerang Regency, West Java Province, Indonesia. The watershed area is around 9.38 km². The data used in the calculation are the daily rainfall and discharge data from 2004-2013.

Manggu Discharge Post, Landak River, Kubu Raya District, West Kalimantan Province, Indonesia. The watershed area is around 624.27 km². The data used in the calculation are rainfall from 2002-2014 and daily discharge from 2002-2012.

Dipati Amir Rain Station, Selindung River Area, Pangkal Pinang City, Bangka Belitung Islands Province. The watershed area is around 14 km². The data used in the calculation are rainfall from 1980-2009.

3. RESEARCH METHODS & THEORETICAL BACKGROUND

The research method is based on the calculation of the theoretical and Markov rainfall data, combined with the concept of developing sustainable raw water reliability. This is an important aspect in the potable water supply component; by discussing the raw water design criteria and the foreseeable value of the raw water discharge using a series of hydrological statistical analyzes (Markov and continuous models).

The data used in the calculation are the discharge and random phenomena rainfall data, where the variables can be updated through the hydrological cycle. Components in the hydrological cycle can be stochastic and deterministic variables [10]. Therefore, the occurrence cannot be predicted by humans. Meanwhile, the output and saved components are influenced by human activities thus their occurrence can be estimated and controlled by humans [11].

3.1 The Concept of Discharge Planning in the Potable Water Supply System Plan

There are 4 (four) objective parameters/functions in a sustainable potable water supply system; quantity, quality, continuity and competitive selling price [12]. The success of clean water services is dependent on the availability of raw water sources and its quality and continuity of water sources [13]. The condition of raw water quality allows adjustments in the processing

production costs so that competitive water prices affect people's purchasing power for drinking water which is managed by the Regional Water Supply Companies. In term of continuity, the design criteria for the development of drinking water supply systems are shown in Table 1, where the concept of sustainable potable water supply development uses a planning discharge with a return period of 10-20 in dry years [14].

Table 1. Surface Raw Water Design Criteria

Raw Water Source	Raw Water Design			
Dry Water Flow	Domestic Municipally Industry (DMI)		Irrigation	
	1-7 days	10-20 years	15-30 days	5 years

The planning discharge is the discharge expected to be available throughout the year with the smallest possible risk of failure [15]. The discharge of raw water plant must fulfill the probability of success 95% with 5% probability of failure. This percentage is equivalent to the return period 20 years (R20). Thus it can be interpreted that in the 100 years, there will be five times the minimum extreme discharge is not met. This means there will be five droughts within 100 years.

3.2 Dependability Analysis of Raw Water Resources

In addition to using the historical discharge method, frequency analysis methods are often used in analyzing hydrological data. The continuous (theoretical) distribution function often used in hydrological data frequency analysis is a normal distribution, normal log, Gumbel, Pearson, Log Pearson, and so on [16]. To determine the critical discharge (extreme minimum discharge), the data must be processed through two stages of statistical tests: the distribution test and match test.

3.2.1 Analysis of Rainfall Characteristics

Rain characteristic analysis is done using five variables consisting of size, time, duration, frequency, and variability. The analysis was carried out through descriptive and analytic statistical, namely the calculation of (a) the amount of monthly and annual rainfall, and (b) the average monthly and annual rainfall. In this study, a study of rainfall data was conducted according to the Markov and theoretical method.

a. Markov Discrete Method

In the Markov process, the probability at a particular time is determined from the previous time event. The Chain of Markov concept is as follows [17].

- The probability of occurrence at a particular time is determined only from the previous time event.
- If $t_0 < t_1 < \dots < t_n$, ($n = 0,1,2,\dots$) > time points, then a collection of random variables $\{X(t_n)\}$ is the Markov Process if it satisfies the condition of $P_{ij} = P\{X(t_n) = j / X(t_{n-1}) = i\}$ > The probability of the j transition occurs if it is known that i occurs.
- If $t_0 < t_1 < \dots < t_n$, ($n = 0,1,2,\dots$) denotes time points, then a collection of random variables $[X(t_n)]$ is a Markov Process that satisfies the conditions: $P\{X(t_n) = X_n | X(t_{n-1}) = X_{n-1}, \dots, X(t_0) = X_0\}$, for all values of $X(t_0), X(t_1), \dots, X(t_n)$. Probability of $P_{X_{n-1}, X_n} = P\{X(t_n) = X_n | X(t_{n-1}) = X_{n-1}\}$ or $P_{ij} = P\{X(t_n) = j | X(t_{n-1}) = i\}$ is referred to as the transition probabilities stating the conditional probability of the system on condition (j) at the n time if it is known that this system remains stagnant everytime. In other words j occurs if i occurs.

The stages of class division in this research are one order for five classes. For this reason, the amount of rainfall is divided into five classes as follows:

- A very dry year is stated by (0)
- Dry Year is stated by (1)
- Normal Year is stated by (2)
- Wet Year is stated with (3)
- A very wet year is stated with (4)

Determining the class interval for each class division is obtained by dividing the probability curve from the selected population distribution into five equal parts, namely 0.2; 0.4; 0.6; 0.8; and 1. The value for each class is the value of the middle value of each class, namely on probability curve 0.1, 0.2, 0.3, 0.4 and 0.

3.2.2 Theoretical Method

a. Normal Distribution

Normal distribution or Gauss distribution is a data distribution that has symmetrical characteristics concerning the vertical and bell-shaped axis. A normal distribution has two parameters, μ which are a mean and standard deviation of σ from the population. The area covered by these limits can be found in the normal distribution table. The frequency factor in the

normal distribution (K_T) is the difference between data (x_T) with the mean of all existing values, divided by the standard deviation (σ):

$$K_T = \frac{x_T - \mu}{\sigma} \tag{1}$$

Calculation of frequency factors for normal distribution (and normal log) can be done through tables or calculated through an intermediate variable that depends on the value of w . The w value is a function of opportunity or return period.

$$K_T = w - \frac{2,15517 + 0,802853w + 0,010328w^2}{1 + 1,432788w + 0,189269w^2 + 0,001308w^3} \tag{2}$$

$$w = \left[\ln \left(\frac{1}{p^2} \right) \right]^{0,5} \tag{3}$$

$$p = \frac{1}{T} \tag{4}$$

b. Normal Log Distribution

Normal Log Distribution is used if the values of a random variable do not follow the normal distribution, but the logarithmic value meets the normal distribution. The discharge value (x_T) is obtained by looking for frequency factors (K_T). The difference is that the discharge value is obtained from the observation values that are transformed by the log.

$$y_T = \bar{y} + K_T s_y \tag{5}$$

$$x_T = 10^{y_T} \tag{6}$$

c. Gumbel type III

The Gumbel distribution is widely used for maximum data analysis, such as flood frequency analysis. In its use, Gumbel distribution uses alpha values (α) which is a function of standard deviation (s). The alpha value will be used in determining the distribution mode value (u). Calculation of the discharge value is a function of the mode value (u), alpha value (α) and frequency factor y_T .

$$\alpha = \frac{\sqrt{6}s}{\pi} \tag{7}$$

$$u = \bar{x} + 0,5772\alpha \tag{8}$$

$$y_T = -\ln \left[\ln \left(\frac{T}{T-1} \right) \right] \tag{9}$$

$$x_T = u + \alpha y_T \tag{10}$$

d. Log Distribution - Pearson type III

Of the 12 Pearson distribution types, only the Log Pearson III distribution is widely used in hydrology, especially in maximum data analysis. The use of the Log Pearson III method is done by compiling data in a table, calculating the logarithmic value of each data, calculating the average value (\bar{y}), standard deviation (s_y), coefficient of stability (C_{sy}) from the logarithmic value (y_i), frequency factor (K_T) which is a function of probability or return period. Then, value for various return periods is calculated by the equation:

$$y_T = \bar{y} + K_T s_y \tag{11}$$

The flood discharge value x_T for each return period is calculated using the exponential value of y_T :

$$x_T = e^{y_T} \tag{12}$$

3.2.3 Match Test

Two methods can be conducted to test whether the chosen type of distribution matches the data (the goodness of fit test), namely the Chi-Square test and Kolmogorov Smirnov [18]. The goodness-of-fit test aims to test Ho's hypothesis (the sample comes from the theoretical distribution tested against the H1 hypothesis, the sample is not derived from the theoretical distribution tested).

a. Chi-Square Test

Chi-Square test uses values of χ^2 which can be calculated by the following equation:

$$\chi^2 = \sum_{t=1}^N \frac{(Of - Ef)^2}{Ef} \tag{13}$$

Where:

χ^2 = Value of the calculated Chi-Square

Ef = frequency (number of observations) that are expected according to the class division

Of = frequency that is read in the same class

N = number of subgroups in one group

The obtained χ^2 value must be smaller than the value X_{cr}^2 (Critical Chi-Square), for a certain degree of significance, which 5% is often taken. The degree of freedom is calculated by the equation:

$$DK = K - (\alpha + 1) \tag{14}$$

Where:

DK = degree of freedom

K = number of classes

α = attachment (number of parameters). Chi-Square test has 2 attachments. It is recommended

that the number of classes is not less than 5 and the absolute frequency of each class is not less than 5.

b. Kolmogorov Smirnov Test (KS Test)

Kolmogorov Smirnov's suitability test is referred to as a non-parametric test because the test does not use a particular distribution function, through the observation of the curve and drawing data on the probability paper. KS test can be done by sorting the data and its opportunities, determining the value of each distribution opportunity and looking for the biggest difference (D) from the opportunities for observation and theoretical opportunities.

$$D = \text{maximum}[Fo(Xm) - SN(Xm)] \tag{15}$$

Do values can be determined based on a critical value table (KS). If the D value is smaller than Do , the theoretical distribution used to determine the distribution equation can be accepted, whereas if D is greater than Do , the theoretical distribution used for the sample distribution equation cannot be accepted.

If the theoretical distribution has been selected, the dependable discharge will be sought from the river. Dependable discharge is the minimum discharge that occurs or is exceeded on average at a certain return period. Determining the dependable discharge available in the water source can help identify the probability of failure of a design criterion in the drinking water supply business so that anticipatory action can be taken. This anticipation can be done with the construction of reservoirs.

4. RESULT AND DISCUSSION

4.1 Year Classification Based on Markov 5 Class

Classification for the type of year based on Markov's 5 class is: very dry (0), dry (1), normal (2), wet (3) and very wet (4). This classification is conducted to classify data to determine the type of year with a year forecast matrix. The data used are monthly rainfall data.

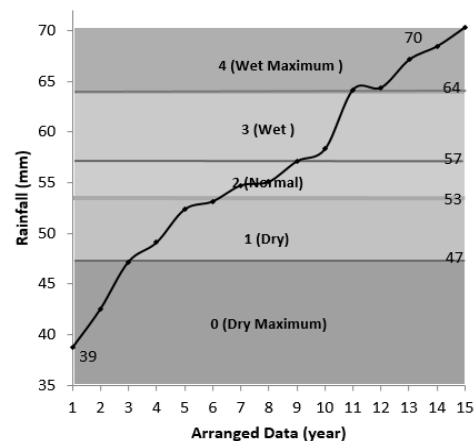


Fig.1 Year type classification based on Markov Class for Cidurian Station (2001-2015)

Based on Figure 1, the maximum dry year has the longest range between classes. This is supported by the type of monsoon rainfall more influenced by the monsoon breeze. Years with longer dry season than the rainy season generally occurs because the Cidurian River region (Tangerang Regency) is far from the equator line and is to the south and southeast.

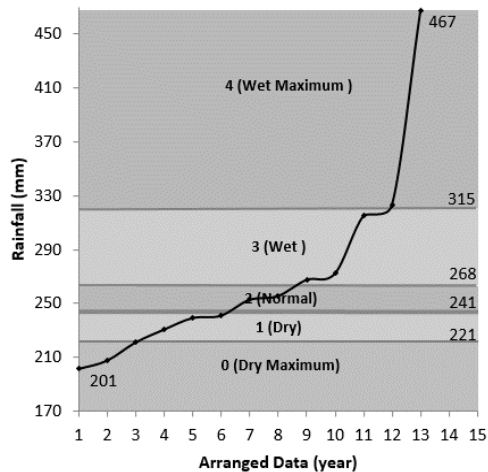


Fig 2. Year type classification based on 5 Markov Class for Ambawang Station (2002-2014)

Based on Figure 2, the maximum wet year has the longest range between classes. This is influenced by the type of equatorial rain found in Pontianak City, which is characterized by a short dry season and a long rainy season and occurs two rainy periods in a year.

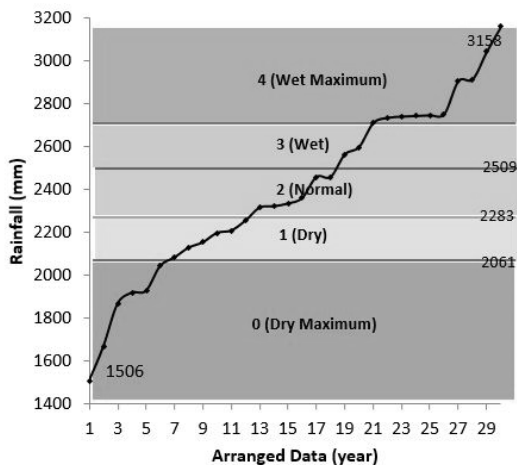


Fig 3. Year type classification based on 5 Markov Class for Adipati Amir Station (1980-2009)

Based on Figure 3, similar to Pontianak City, Pangkal Pinang City is part of the territory of

Bangka Belitung Province which has equatorial rainfall with a rainy season that is longer than the dry season.

4.2 Planning Discharge

The distribution test used to analyze the extreme dry discharge includes Normal, Log-Normal, Gumbel and Log Pearson type III; making four theoretical distributions tested on a minimum discharge data. The theoretical distribution matching test was conducted to examine the values of random variables from the discharge which are the minimum daily data discharge. To choose which distribution is suitable, a goodness-of-fit test is carried out with the Kolmogorov Smirnov (KS) type. Here are the results of the KS test on the theoretical distribution at the location of the Cidurian River.

Table 2. Selected Theoretical Distribution of KS Test Results for the Cidurian River

Duration (Day)	Dn from each distribution					
	Normal	Log-Normal	Gumbel	Log Pearson	Do	Chosen
1	0.171	0.018	0.096	0.068	0.56	Log Normal
2	0.071	0.006	0.096	0.003	0.56	Log Pearson
7	0.071	0.001	0.096	0.002	0.56	Log Pearson
15	0.071	0.003	0.096	0.003	0.56	Log Pearson
30	0.071	0.003	0.096	0.003	0.56	Log Pearson
60	0.071	0.009	0.096	0.001	0.56	Log Pearson

The discharge used in the calculation is the minimum daily discharge for a certain duration (1,2,7,15,30) days. Table 2 shows that the distribution of Log Pearson III represents the theoretical distribution test for the minimum daily discharge of the Cidurian River. The next step is to create a dependable flow curve based on the selected distribution test. The following is the dependable discharge table and curve for the Cidurian River.

Table 3. Dependability of Cidurian River Raw Water.

Duration (day)	Discharge (m ³ /s)			
	R2	R5	R10	R20

Duration (day)	Discharge (m ³ /s)			
	R2	R5	R10	R20
1	2.395	0.956	0.543	0.325
2	3.348	1.458	0.822	0.473
7	3.904	1.861	1.183	0.786
15	4.572	2.067	1.287	0.843
30	6.088	2.712	1.601	0.977

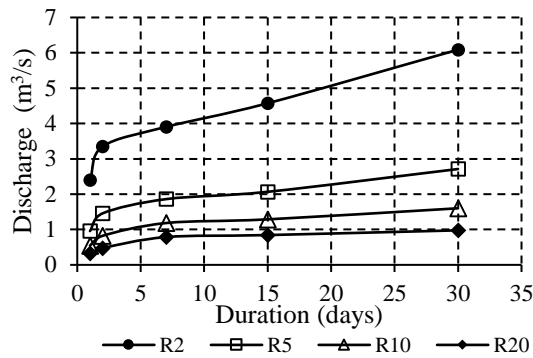


Fig 4 . Cidurian River Rancasumur Post Dependable Discharge Curve

In the second location, the Manggu Discharge Post, Landak River uses the same input discharge as the Cidurian River. The following are the results of the dependability of raw water for the Landak River.

Table 4. Selected Theoretical Distribution of KS Test Results for Landak River

Duration (Day)	Dn from each distribution					
	Normal	Log Normal	Gumbel	Log Pearson	Do	Chosen
1	0.071	0.039	0.096	0.051	0.56	Log Normal
2	0.071	0.039	0.096	0.049	0.56	Log Normal
7	0.075	0.039	0.096	0.060	0.56	Log Normal
15	0.037	0.039	0.096	0.051	0.56	Log Normal
30	0.071	0.044	0.096	0.049	0.56	Log Normal
60	0.071	0.044	0.096	0.044	0.56	Log Normal

In the Landak River, the theoretical distribution test represents the Normal Log because it is selected for each duration. After identifying the selected distribution test, the dependable discharge table and curve can be determined as follows:

Table 5. Dependability of Landak River Raw Water.

Duration (day)	Discharge (m ³ /s)			
	R2	R5	R10	R20
1	75.964	55.210	46.719	40.703
2	77.717	57.059	48.541	42.476
7	90.007	66.356	56.572	45.592
15	100.861	72.100	60.486	52.321
30	132.117	100.354	86.906	77.173

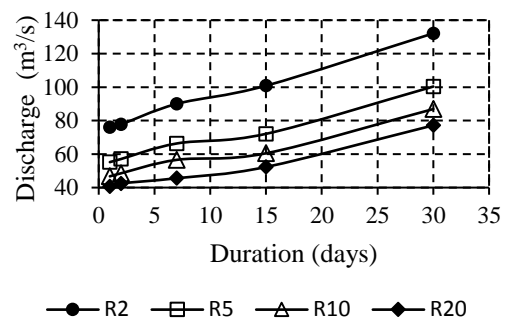


Fig 5 . Landak River Manggu Post Dependable Discharge Curve

For the third location, Selindung River, the input used is the minimum monthly discharge, due to the absence of historical discharge data in the post concerned.

Table 6. Theoretical Distribution of Selected KS Test Results for Selindung River

Month	Dn from each distribution					
	Normal	Log Normal	Gumbel	Log Pearson	Do	Chosen
Jan	0.54	0.46	0.58	0.47	0.56	Log Normal
Feb	0.54	0.40	0.58	0.40	0.56	Log Normal
Mar	0.53	0.49	0.58	0.49	0.56	Log Pearson
Apr	0.54	0.43	0.58	0.37	0.56	Log Normal
May	0.54	0.45	0.58	0.49	0.56	Log Normal
Jun	0.54	0.41	0.58	0.42	0.56	Log Normal

Jul	0.54	0.00	0.02	0.00	0.56	Log Pearson
Aug	0.54	0.46	0.46	0.46	0.56	Log Normal
Sep	0.54	0.45	0.10	0.10	0.56	Log Pearson
Oct	0.54	0.42	0.44	0.44	0.56	Gumbel
Nov	0.54	0.49	0.49	0.49	0.56	Log Normal
Des	0.54	0.46	0.47	0.47	0.56	Log Normal

Based on Table 2, the Normal Log distribution represents the theoretical distribution test for the minimum monthly discharge. Following are the results of the dependable discharge calculation for Selindung River based on the results of the selected distribution test.

Table 7. Monthly Dependability of Selindung River Raw Water

Month	Return Period			
	R2	R5	R10	R20
Jan	0.886	0.450	0.316	0.236
Feb	0.422	0.146	0.084	0.053
Mar	0.779	0.527	0.430	0.363
Apr	0.588	0.251	0.161	0.112
May	0.543	0.296	0.215	0.165
Jun	0.189	0.072	0.043	0.029
Jul	0.204	0.071	0.041	0.026
Aug	0.270	0.140	0.099	0.074
Sep	0.225	0.114	0.080	0.060
Oct	0.354	0.139	0.086	0.057
Nov	0.706	0.456	0.363	0.301
Dec	0.937	0.481	0.340	0.255

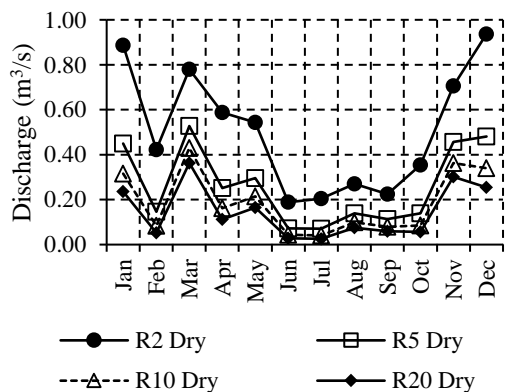


Fig 6. Selindung River Dependable Discharge Curve

In the dry conditions and the lowest ebb, the river still flows even though the discharge is not too large.

5. CONCLUSION

The theoretical distribution method is an appropriate method to analyze extreme dry discharge in the three locations. The calculation results shows that the selected distribution test for the Cidurian River in Tangerang Regency which has a monsoon rainfall type is a Pearson III Log distribution with a range of discharge dependability values of 0.325 m³/s (20 year return period with a duration of 1 day) with the influential area of Cidurian watershed about 9.38 km². Unlike the Landak River in Pontianak City which has a watershed area of around 624.27 km² with an equatorial type of rainfall, Cidurian River’s selected distribution test is Normal Log with discharge dependability for domestic raw water around 40.703 m³/s (20 year return period with a duration of 1 day). As for Selindung River which has a watershed area of 14 km² with similar rain type and selected distribution to Landak River, the average dependable discharge around 0.145 m³/s.

The difference in the value of dependable discharge is due to differences in watershed area in their respective regions, it is also influenced by physical factors such as latitude, wind pattern (wind and monsoon winds), the distribution of land and waters and other factors which supports variations and types of rainfall in each region. The difference in rainfall in the three research areas can be seen based on the type of year classification. Data processing results show that Cidurian Station has a long dry year characteristic compared to other classes, while for Ambawang Station with its equatorial rainfall types, has longer wet year characteristics compared to other classes. This is different from the Adipati Amir Station which has the characteristics of a dry year which is not much different from the wet year. The rainfall intensity in each region strongly influences the input discharge. Rain potential in each region can be utilized by storing the rain during the rainy season to meet the demands of the surrounding community when the dry season arrives.

The results show that the rainfall in every region of Indonesia has different characteristics that will affect the amount of flow in the watershed, where the flow is used as input to identify the planning discharges in the development of the Drinking Water Supply System in Indonesia.

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