Quantifying the Reliable Discharges as an Incipient Analysis of Agricultural Planning and Developing in Ciujung Watershed

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Abstract. Rainfall-run-off modelling could estimate the surface water discharges according to the rainfall data record. The incremental rainfall derives the reliable rainfall in many probabilities, and then it becomes reliable discharges after rainfall-run-off modelling processes. The standard models to derive rainfall to discharges are F.J. Mock and NRECA. Both models use rainfall, meteorology, and climatology data as the primary information. Location of this research was in the Ciujung watershed, Banten province. The objective of this research was estimating the potential surface water in Ciujung watershed. Rainfall data recording from January 1997 until December 2018 will derive the reliable rainfall of 50%, 70%, 80%, 90% and 99% probability. The meteorology and climatology information were following the days of rainfall, sunshine ratio, wind velocity, air temperature, and relative humidity. The results give information about the potential of reliable discharges in the Ciujung watershed. As the agricultural planning and developing purpose, the 80% reliable discharges $Q_{80}$ becomes the fundamental consideration. It forecasts maximum discharges in a range of 60 m$^3$/s to 80 m$^3$/s and the minimum discharges in the range of 0.1 m$^3$/s to 0.6 m$^3$/s. These values become the threshold in agricultural planning and development. The advance analysis is quantifying the human needs of water, and the remaining value can be as the potential discharges for agricultural purpose. Further research will accommodate these analyses.

1. Introduction
The water resources management in a basin primarily employs the surface water [1]. That results in the main question of how much the surface water potential that available in a watershed. The surface water availability is depending on the stream discharges, and groundwater flows [2]. Surface water availability is an important thing to respond to the human needs of water and agricultural. The human needs then distinguished as domestic and non-domestic requirements. Occasionally, to forecast the potential of surface water in a region is exceedingly difficult due to unavailability of stream discharges record over the years. One of the solutions to this problem is the generation of surface water discharges according to the rainfall data record.

There are two standard models to generate rainfall data to become surface water discharges. They are F.J. Mock and NRECA model. Many researchers have applied these models to quantify the potential surface water discharges in many regions and intentions. Many regions such as upstream Barito watershed [3], Pacal-Sengaten sub-watershed [4], Malino watershed [5], upstream
Cikapundung watershed [6] and Cisadane watershed [7] have become the case study of quantifying the potential of surface water discharges. Moreover, F.J. Mock and NRECA model employ the other intentions such as to calibrate the watershed parameter [8], testing the reliability of the reservoir storage [9], and basic simulation in a dam [10].

This research employs the quantification of surface water discharges according to a rainfall data record in Ciujung watershed, Banten province. According to the Indonesia Central Statistics Agency (BPS), the Serang city, which is part of Ciujung watershed, has a population rate of about 1.91% over ten years [11]. Due to the increasing population rate, then the quantification of surface water discharges must be conducted in agricultural planning and developing.

According to the last paragraph, the main problem of this research was how much the rate of surface water in Ciujung watershed on any level reliabilities. Hence, the primary objective of this research was to obtain the estimation of reliable discharges in Ciujung watershed. The limitation of this research is only quantifying the potential surface water discharges without measuring the human needs of water. Therefore, this research is the initial analysis of agricultural planning and developing.

2. Methodology

2.1. Location

The location of this research was in Ciujung Watershed, which located in Banten Province, Indonesia. It has an area about 1900 km2. This research involved ten rainfall gauges as the rainfall data sources from 1997 until 2018. Figure. 3 conveys the location of Ciujung Watershed and its rainfall gauges spreading.

2.2. The rainfall data quality

Hydrology modelling concerns the quality and quantity of rainfall data series. The quality issue represented by the missing data series; on another hand, the quality issue regards to data consistency. In the entire of rainfall data recording, occasionally there are some unrecorded data due to the particular condition such as the gauges unavailable temporarily or moved to other places. The last condition also causes the rainfall data series are inconsistent [12]. As the introductory level, solving the quality data issues is the critical process as incipient analysis.

In order to comply with the complete rainfall data, the missing data can be estimated by the reciprocal method [12] through the equation

\[ P_x = \frac{\sum_{i=1}^{M} \frac{P_i}{L_i^2}}{\sum_{i=1}^{M} \frac{1}{L_i^2}} \]  

Equation (1) has some important variables. They are \( P_x \) as the missing rainfall data, \( L_i \) as the distance between the gauge of \( P_x \) to its neighbour gauges and \( P_i \) as rainfall data of the neighbour gauges. This analysis has to conduct at a corresponding time until the accomplishment of rainfall data is achieved.

Another issue of rainfall data quality is a concern to its consistency. Data consistency can be tracked by a double mass curve [13]. It is a curve in which the accumulated rainfall in specific gauges and accumulated average rainfall in its neighbour will meet graphically. Figure. 1 describes double mass curves, including its parameters to conduct the consistency analysis.

Consistency analysis results in the ratio between gradient to the theoretical condition of the double mass curve after its breaking point and denoted as \( C_{factor} \). \( C_{factor} \) is defined through the equation [13].

\[ C_{factor} = \frac{c}{a} \]
whereby $c$ denotes theoretical condition and $a$ denotes its gradient (Figure. 1 provides this explanation). All of rainfall data series after the breaking point in specific rainfall gauges have to multiply by its $C_{\text{factor}}$ as corrected data.

2.3. The rainfall representative

In an absolute watershed, usually, there is the spread of rainfall gauges and, each of them has a different result in rainfall measuring. Regarding obtaining the rainfall that represents entire of the watershed, the analysis of rainfall representative is necessary [14]. The rainfall representative rises through standard methods such as simple mean arithmetic, isohyet, and Thiessen polygon. This research employs the last method explained by equation [14].

$$P = \frac{1}{A}\sum_{i=1}^{N} A_i P_i,$$

where, $A$ denotes the watershed area, $P_i$ and $A_i$ denotes the rainfall of specific gauge, and the area stands for it, respectively. The all of Thiessen polygon terminologies explained by Figure. 2.

2.4. The reliable rainfall

Regarding governing the reliable discharges, the rainfall data over ten years are necessary to obtain a stable pattern of rainfall over the years. One of the methods to generate the reliability rainfall is govern the rainfall characteristic monthly [15]. It runs the probability distribution (for example Log-Pearson III distribution) monthly in entire series at many percentages of probability. Log-Pearson III distribution governs the parameter denotes as $K_T$ through equation [14]

$$K_T = z + (z^2 - 1)k + \frac{1}{3}(z^3 - 6z)k^2 - (z^2 - 1)k^3 + zk^4 + \frac{1}{3}k^5,$$

where,

$$z = w - \frac{2.515517 + 0.802853w + 0.010328w^2}{1 + 1.432788w + 0.189269w^2 + 0.001308w^3}$$

$w$ terminology quantified according to probability $p$ and equation
\[ w = \left[ \ln \left( \frac{1}{p^2} \right) \right]^{\frac{1}{2}}. \tag{6} \]

Special case for probability value excess about 0.5 or \( p > 0.5 \), then the \( z \) value from equation (5) has to given by the negative sign \((-)\) and the \( p \) variable of equation (6) is stated as \( 1 - p \) \([14]\). Equation (4) until equation (6) are assembling to open the curtain of the logarithmic rainfall as
\[ X_T = \bar{X} + \sigma K_T, \tag{7} \]
where, \( \bar{X} \) and \( \sigma \) are mean and deviation standard of logarithmic monthly rainfall data in the entire series. The level of reliability of discharges will vary upon 50\%, 70\%, 80\%, 90\%, 99\% and the minimum values \([9]\). For the agricultural purpose, the reliable discharges about 80\% are the typical value \([15]\).

### 2.5. Rainfall-run-off modelling

Water availability in a specific region can be forecasted quantitatively by interpreting the water balance in the regional system \([2]\). Rainfall-Run-off model transforms the rainfall into the run-off in the hydrological process in order to stream discharges monitoring and evaluating \([16]\). The discharges quantification is necessary to understanding the potential of surface water to meet human life, animals, and crop requirements \([4]\). Generally, computing the amount of run-off \( \forall Q \) from rainfall event using water balance \( WS \), deliberately conducted through equation \([17]\),
\[ \forall Q = P - E - G - WS, \tag{8} \]
where, the terminologies of \( P, E \), and \( G \) are precipitation, evapotranspiration, and groundwater flow. Equation (8) is the fundamental hydrologic model which the evapotranspiration term emerges from Penman approach, then the groundwater flows and water balance are deliberating F.J. Mock and NRECA model. Reliable rainfall value that appropriates to requirements threshold for agricultural planning and developing will be employed throughout equation (8) as the precipitation term.

The potential evapotranspiration (PET) relies on the meteorological and climate factor of a specific region \([15]\). The availability of regional meteorological and climate data such as the angle of latitude \( \phi \), daily sunshine ratio \( n/N \), wind velocity, air temperature \( T_a \), and relative humidity \( R \) has to satisfied during data collection process. Penman formulated the PET using the equation \([13]\)
\[ PET = \frac{\Delta H_n + E_a \gamma}{\Delta + \gamma}. \tag{9} \]
Equation (9) explains \( \Delta \) as the gradient of air pressure to saturated moisture \( e_s \) in average air temperature, and it is estimated through \([14]\)
\[ \Delta = \frac{4098 e_s}{(237.3 + T)^2}, \tag{10} \]
then \( H_n \) is the net radiation that calculated by \([13]\)
\[ H_n = H_o (1 - r) \left( a + b \frac{n}{N} \right) - \sigma T^4_a \left( 0.56 - 0.092 \sqrt{e_a} \right) \left( 0.10 + 0.90 \frac{n}{N} \right). \tag{11} \]
Equation (11) employs \( r \) as a coefficient of reflection, \( b \) is a constant value of about 0.52, and \( a \) is the latitude constant from the relationship of \( a = 0.29 \cos \phi \).

Eventually, after PET assessing, the analysis of reliable discharge can run using the F.J. Mock and NRECA model. F. J. Mock model has been introduced upon 1973, which this model simulates the water balance corresponding to rainfall, watershed characteristic and evapotranspiration \([9]\). The net rainfall \( \Delta S \) is stated by the difference of rainfall \( P \) and actual evapotranspiration (AET) or
\[ \Delta S = P - AET. \tag{12} \]
If the term of $\Delta S$ from equation (12) has a negative value, it means the fractional of groundwater will decrease [9]. Therefore, if $\Delta S > 0$, then the soil storage $SS$ will equal to zero, reversely $SS$ will equal to $\Delta S$ if another condition occurs.

F.J. Mock model is assembled by the following parameters (in mm unit) [8], [9]

1. The Actual Evapotranspiration (AET) that analyzed by equation

$$ AET = PET - E, \quad (13) $$

for $E$ parameter denotes the alteration of evapotranspiration and it rises from equation

$$ E = PET \frac{m}{20} (18 - n), \quad (14) $$

where, the $m$ and $n$ terms are the proportion of unvegetated land and the number of monthly rainfall days.

2. The soil moisture capacity (SMC) term as the equation

$$ SMC_n = SMC_{n-1} + SS(\Delta S), \quad (15) $$

where, as the incipient analysis, $SMC_{n-1}$ value commonly is about 50 to 250 mm [9].

3. The water surplus (WS) is the difference between $\Delta S$ and $SS$, thus

$$ WS = \Delta S - SS, \quad (16) $$

4. Soil porosity affects to infiltration rate ($I$), hence

$$ I = iWS, \quad (17) $$

where, $i$ is the infiltration factor depending on soil porosity and average slope (estimated is about 0 to 1) [9].

5. Ground water storage in the end of month ($V_n$) is explained mathematically by the equation

$$ V_n = kV_{n-1} + \frac{1}{2} (k + 1)I, \quad (18) $$

and $k$ parameter is a constant of run off recession which the value is about 0 to 1 [9]. Therefore, there are ground water storage alteration $dV_n$ as the equation

$$ dV_n = V_n - V_{n-1}. \quad (19) $$

6. The base flow ($BF$) terminology as the equation

$$ BF = I - dV_n. \quad (20) $$

7. Direct run-off ($DR_o$) explains the difference of water surplus and infiltration rate or

$$ DR_o = WS - I, \quad (21) $$

8. Eventually, total run-off ($R_o$) terminology will clear through the relationship

$$ R_o = BF + DR_o. \quad (22) $$

Another approach is the NRECA model which has developed since 1981. The approximation of discharges is conducted through three primary steps as PET analysis, watershed characteristic estimation and the run-off quantification [18]. NRECA model deliberates the primary watershed characteristic through NOMINAL, PSUB and iGWF parameter. NOMINAL parameter denotes the soil moisture capacity index in a watershed. PSUB parameter is the run-off fraction that flows, leaving the watershed as the groundwater flows or base flow. Then, iGWF parameter is the index that states the discharge is leaving groundwater storage [18]. Those parameters deliberate the following rules [18]:
1. NOMINAL gives soil moisture capacity index through equation
\[ Nominal = 100 + C\bar{X}, \]  
whereby, \(\bar{X}\) denotes the annual average rainfall, \(C\) is 0.2 if the rainfall occurs in the entire year and 0.25 if the rainfall occurs periodically. NOMINAL can reduce about 25% if the vegetation in the watershed is sparse.

2. PSUB parameter value is about 0.6 as the mean value. It can increase until 0.8 for the permeable watershed, and it can decrease by 0.3 for the impermeable watershed.

3. iGWF parameter value is about 0.5 as the mean value. Its value increases up to 0.9 if the flow in the watershed is unsustainable, decreases up to 0.2 for sustainable watershed.

The potential discharges, according to NRECA model, can be estimated through the analysis of parameters related to watershed. They are arranged by the following terminologies (in mm unit) [18]:

1. Moisture storage \((W_o)\), which its values depend on the storage alteration or delta storage (DEM) and provided by
\[ W_{on} = W_{on-1} + DEM. \]  
In incipient calculation, the initial value of \(W_o\) can be estimated as 10% of NOMINAL for the calculation which starts from dry season and 125% of NOMINAL for the calculation which start from wet the season.

2. Soil storage ratio \((f_o)\) explains the equation
\[ f_o = \frac{W_o}{Nominal}. \]  

3. The ratio of precipitation \((P)\) to the potential evapotranspiration (PET) \((f_1)\) or
\[ f_1 = \frac{P}{PET}. \]  

4. The ratio of actual evapotranspiration (AET) to the potential evapotranspiration (PET) \((f_2)\) quantification is depending on \(f_1\) value. If \(f_1 > 1\) then \(f_2 = 1\). Reversely, \(f_2\) quantification is following the equation
\[ f_2 = \frac{1}{2} f_o + (1 - \frac{1}{2} f_o) f_1. \]  

5. Determining the actual evapotranspiration (AET) value is through the relationship of
\[ AET = f_2 PET. \]  

6. The water balance \((WB)\) term is the difference between precipitation and AET, then
\[ WB = P - AET. \]  

7. Water balance \((WB)\) affects the excess moisture storage ratio \((f_3)\). If \(WB < 0\), then \(f_3 = 0\). The contrary of water balance condition or \(WB > 1\) encourages to \(f_3\) value as equation
\[ f_3 = 1 - \left(\frac{1}{2} (2 - f_o)^2 \right). \] Another condition or if \(WB = 0\), then
\[ f_3 = \frac{1}{2} f_o^2. \]  

8. Excess moisture \((EM)\) is quantified through equation
\[ EM = f_3 WB. \]
9. Delta storage (DEM) is the distinction of $WB$ and $EM$ or

$$DEM = WB - EM. \quad (33)$$

10. Recharge to groundwater (DGW) is formulated by the equation

$$DGW = PSUB(EM). \quad (34)$$

11. Initial groundwater storage ($GW_{n,1}$), in the incipient calculation, determined hypothetically. For the next time step, $GW_{n,1}$ is determined through equation

$$GW_{n-1} = GW_n - GWF. \quad (35)$$

12. The end groundwater storage ($GW_n$) is calculated by the equation

$$GW_n = DGW + GW_{n-1}. \quad (36)$$

13. Groundwater discharge (GWF) quantification comprises $GWF$ index or $iGWF$, therefore

$$GWF = iGWF(GW_n). \quad (37)$$

14. Direct run-off ($DR_o$) will compromise to the equation

$$DR_o = EM - DGW. \quad (38)$$

15. Eventually, total run-off ($R_o$) is the summation of $DR_o$ with $GWF$ or

$$R_o = DR_o + GWF. \quad (39)$$

2.6. Methods

This research was started from data collecting such as monthly rainfall data in ten gauges from 1997 until 2018 and climatology condition. The climatology condition which required to the analysis were follows the days of rainfall, sunshine ratio, wind velocity, air temperature, and relative humidity. They were collecting over ten years of recording.

After all required data are satisfied, the subsequent step is data analysis. Data analysis was initiated by the quality and quantity of data examination. The reciprocal method that explained by equation (1) employs the missing rainfall data analysis and to examine the rainfall data consistency, and the double mass curve provides it. The completed and qualified rainfall data will govern the Thiessen polygon to carries out the rainfall representative. Regarding the understanding of potential discharges, the rainfall representative has to derive into the reliable rainfall for 50%, 70%, 80%, 90%, and 99% probability through the equation (4) until equation (7).

The climatology conditions are assembling to quantify monthly potential evapotranspiration (PET) through the Penman equation. The other hydrological model parameters on equation (8) are accomplished by F.J. Mock and NRECA model analysis separately. Eventually, the reliable discharges for 50%, 70%, 80%, 90% and 99% probability are satisfied. Furthermore, the minimum discharges likewise obtained from these analyses.

The reliable and minimum discharges can subject as the forecast of surface water availability in entire Ciujung Watershed. Therefore, it becomes the necessary information on the threshold in agricultural planning and developing. For the agricultural purpose, the 80% reliability commonly will become the minimum threshold [15].

3. Result and Discussion

3.1. Quantity and Quality Data

Some of the missing data have been filled by using equation (1) as the reciprocal method. After the set of monthly rainfall data at ten rainfall gauges have been satisfied, then developing the double-mass curve gives the result as in Figure. 4 That figure gives the understanding that the set of monthly
rainfall data at each rainfall gauges fairly consistence. A particular case for Ciminyak gauges, there was a breaking point in the initial plot, and it seems inconsistency. However, it can be ensured due to the smooth at the trendline. This graphic shown the $R^2$ value as about 90% and this was the threshold of determination coefficient value.

3.2. The representative rainfall

The representative rainfall analysis results in the incremental monthly rainfall that representation of the rainfall in Ciujung watershed. The analysis run after the quantity, and quality data analysis terminate, then by using Thiessen Polygon as equation (3). Figure 5 concludes the representative rainfall from January 1997 until December 2018. Figure 5 also explains that the lowest rainfall occurred upon 1997 and the rainfall fluctuation along the data series tendency to stable. In period of 1997, the El Nino effect [19] given the significant effect to the incremental rainfall. Historically, the drought condition occurred prolonged in this period.

The reliable rainfall and potential evapotranspiration

The reliable rainfall analysis employed the equation (4) until equation (7) for 50%, 70%, 80%, 90%, and 99% reliabilities. Moreover, the minimum rainfall also involves in this analysis. For the potential evapotranspiration (PET) analysis, the Penman method will deliberate equation (9) until equation (11). The result of them gives the understanding of the condition of each of reliable rainfall compares to the potential evapotranspiration (PET). Figure 6 provides this information. The rate of PET exceeded the rate of reliable rainfall upon June until October annually. This condition could drive the arid season in Ciujung watershed. This was the initial signal denoted that the lowest surface water discharges in Ciujung watershed should be occurred approximately in June until October. In another hand, the wettest season would occur in January and February annually. Figure 6 described this condition for all of reliability level of rainfall.

3.3. The reliable discharges

The reliable rainfall with each of its reliability generates reliable discharges through F.J. Mock and NRECA method quantification. These methods, deliberate equation (12) until equation (39) and their result are precise separately through Figure 7 and Figure 8. Both methods given a similar characteristic of results. The low flow condition occurs in June until October. Focusing the $Q_{80}$, the maximum potential discharges were between 60 m³/s until 80 m³/s, while the lowest flows were between 0.1 m³/s until 0.6 m³/s. These are information that especially important as a fundamental consideration in agricultural planning and developing. In order to obtain the specific discharges that can be maintained as agricultural purpose, the quantification of human needs of water is necessary, then the remainder of discharges is the final threshold for agricultural purpose. The human needs (domestic and non-domestic), live stocks, industrial and fisheries will diminish the 80% reliability discharges to obtain how much the availability the surface water for agricultural purpose.

The fluctuation of reliable discharges in Ciujung watershed parallel with its PET condition. Either F.J.Mock and NRECA model given the similar characteristic. Both shown the lowest discharges were in June until October. After that, the discharges would bounce starting from November until the peak condition in February. This information could be primary consideration for the watershed planning and development. In the agricultural planning and developing, these reliable discharges information, especially 80% reliability level, must be diminished by the discharges would be used for human, live stocks, industrial and fisheries needs. The remaining discharges could be run in agricultural infrastructure planning such as irrigation channel, DAM, weir, and agricultural pattern of irrigation.
Figure 3. Ciujung Watershed (Google Earth, 2020)

Figure 4. The Double Mass Curve (Result Analysis)
Figure. 5. The Representative Rainfall (Result Analysis)

Figure. 6. The Reliable Rainfall and Potential Evapotranspiration (Result Analysis)
4. Conclusion
Quantification of potential discharges at Ciujung watershed through F.J. Mock and NRECA method given the similar characteristic of discharges fluctuation in entire of year. Both methods give information that the recession occurs in June until October, while it bounced starting from November until the peak condition in February. The maximum potential discharge was between 60 m$^3$/s until 80 m$^3$/s for general purpose. It was the 80% reliability level. The further research should to conduct the
quantification of human, live stocks, industrial and fisheries needs of water; hence the remain of potential discharges could deliberate as the threshold in agricultural planning and developing.

Acknowledgement
Universitas Sultan Ageng Tirtayasa had funded this research through the grant for the research of the beginner lecturer 2020. The number of contracts was 331/UN.43.3/PM.01.01/2020.

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