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DROUGHT ANALYSIS IN BONDOYUDO WATERSHED, LUMAJANG REGENCY OF INDONESIA

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ABSTRACT

The aim of this study was to analyse estimation of duration and deficit drought. Location of study was at Kali asem and Umbul Sub-Watershed. These two sub-watersheds were parts of Bondoyudo Watershed, Lumajang Regency of Indonesia. The methodology consisted of collection and classification data of rainfall and discharge at Automatic Water Level recorder (AWLR) and dam, and then to analyse duration and deficit drought using statiscal method. Result was used as information on sharpeness of duration, deficit, and frequency of drought in location of study. These informations somehow would be used as consideration to develop watershed planning and management.

KEYWORDS: duration, deficit, frequency, drought.

INTRODUCTION

Human activity would increased climate change. It was included land use exhange, the use of gasoline, and others kind of activities. Therefore, climate change was indicated as global phenomena [1]. Acceleration of intensity and frequency on climate change was presented as drought, flood, and hurricane. Many indicators of climate exchange as drought, flood, sea level rising [2], and some problems in water resources development were be described by previous researchers.

In many countries, excisting water supplies were claimed largely for irrigation, growing minucipal, and industrial demands. Generally, remining flows were increasingly protected for stream flows and other enironmental purposes. Throughout the region, climate change and drought aggraated the water competitively [3]. Incidents of drought would had increasingly serious impact by the increasing demands. Droughts inflicted considerable social and economic worldwide due to their irregular occurrence and frequent which had been a prime reason in construction and planning of water resources [4]. It was intended to accelerate water supply in drought-prone area. Droughts exacerbated the scarcity of natural water resources. It was based on the understanding of drought severity, duration, occurrence, and frequency was of importance to water supply.

Droughts were a condition with very low of extremely rainfall depth or there was no rainfall for relatively a long time and it was longer than dry season [5]. Otherwise using rainfall data, drought analysis in a watershed was also suggested to base on discharge data [6]. This research was intended to estimate discharge both form rainfall and discharge data. Model of discharge prediction was based on flexible mathematical structure and it could identify a complexly non linier relation between inflow and outflow [7].

MATERIALS AND METHODS

This research was conducted in two sub-watersheds namely Kali Asem Sub-Watershed (area number of 276.43km^2) and Umbul Sub-Watershed (number area of 350 km^2). These two sub-watersheds were parts of Bondoyudo Watershed which located in Lumajang Regency of Indonesia with number area of 1.790,90 km^2 and it was 3.74% of number area of East Java Province.. Lumajang Regency was falls between south latitude of 7°52' and 8^{p}23' and east longitude of 112°5' and 113°22'. Map of location was as in Figure 1 below. Rainfall and discharge data used in this study was in the year of 1990 to 2005.

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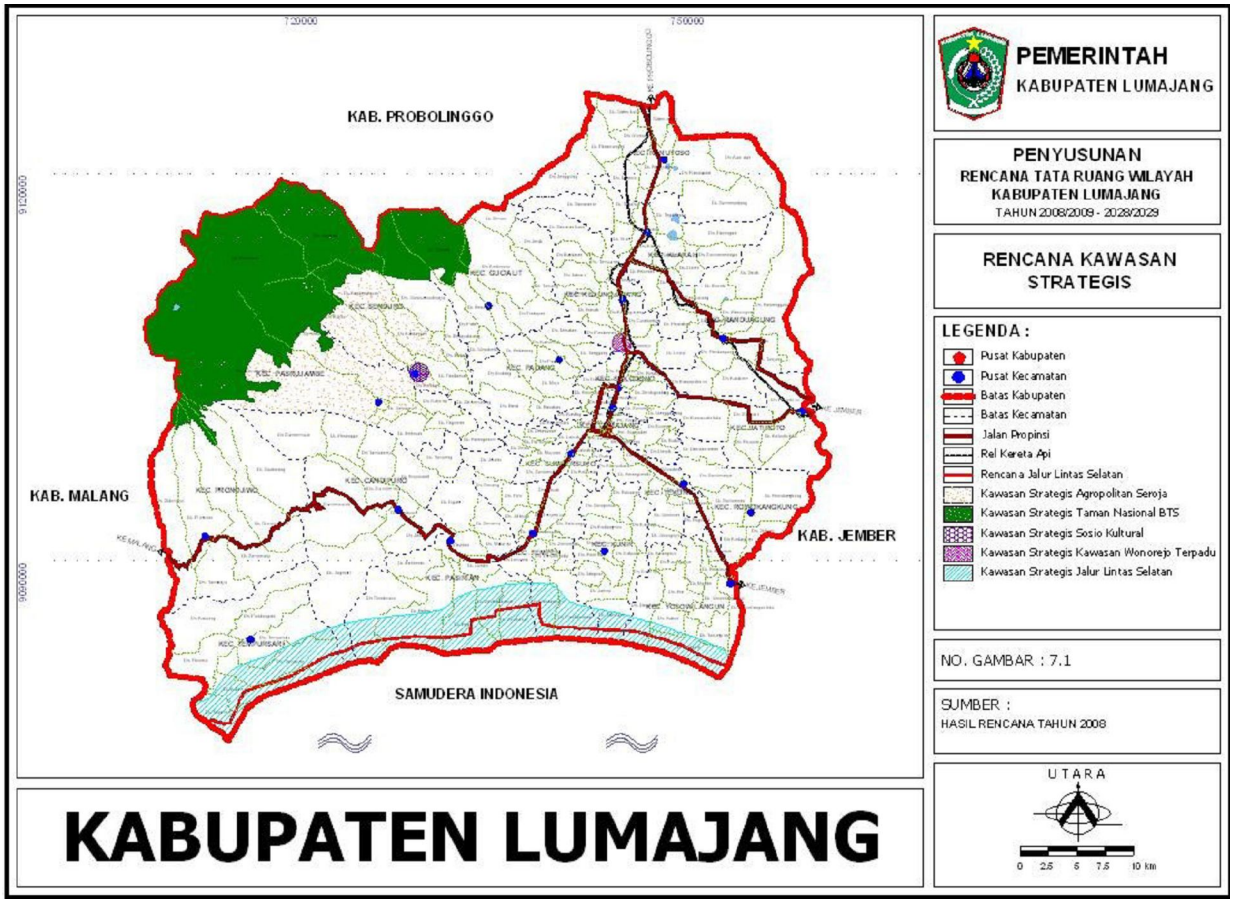

Figure 1 Map of Location

The characteristic of data could be classified using statistical characteristic of mean, deviation standard, skewness, maximum and minimum of series data in a period of time during analysis. The other statistical analysis was percentile or probability in normal distribution based on flow duration curve [8]. Parameter needed for analysis of rainfall data was P_{50} which was meant that 50% of rainfall was as medium in the period of 16 years and P_{50} was the interpretation of normal rainfall in this period. This value was used as threshold of drought analysis based on only rainfall data. Parameter needed for discharge data was Q_{50} and Q_{80}. Q_{50} was interpreted as normal discharge and Q_{80} was interpreted as dependable discharge which was 20% fail. These values were used as threshold of drought analysis based on Automatic Water Level Recorder (AWLR) as well as in Umbul Dam.

Analysis of Statistical Parameter

This analysis was intended: (1) to select distribution which was fit with distribution of observed data (historical data); (2) to determine threshold (Xo). It was as a boundary condition which was determined due to the analysis need. Xo was expressed as Q_{50} or Q_{80} because Q_{50} was Q_{normal} with probability of 0.5 or medium data but Q_{80} was Q_{base} with probability of 0.2 or $Q_{dependable}$. Based on the information as above, boundary condition of drought analysis was classified as follow:[9]

(1) Drought condition (K) if discharge (flow) was in the boundary of low flow [9] or $Q_{50} < Q < Q_{80}$
(2) Very drought condition (SK) if $Q < Q_{80}$

Drought analysis according to Tallaksen [10]:

- $$\sum_{1}^{t}\left(\bar{x} - X_0\right) = d = low\ flow \quad \text{.....} \quad (1)$$
  - Low flow, $d = \begin{cases} d \text{ if } d \le 0 \\ 0 \text{ if } d > 0 \end{cases}$

- Deficit,def = $\sum_{1}^{t}\left(\bar{\mathbf{x}} - \mathbf{X}_0\right)$; with t = duration of drought ..... (2)
  - Code = $\begin{cases} \text{def if def} \le 0 \\ 0 \quad \text{if def} > 0 \end{cases}$; with def = deficit

On the value of drought :

- Deficit, def = $\sum_{1}^{t}\left(X_0 - X_t\right)$ with t = duration of drought ..... (3)
  - Code = $\begin{cases} \text{def if def} \le 0 \\ 0 \quad \text{if def} > 0 \end{cases}$

Analysis of season

Classification of season was based on wet month and dry month [11]. According to Mohr, wet month was a month with rainfall not more than 100 mm and dry month was a month with rainfall less than 60 mm. Between dry and wet month was called as moisture month. According to Schmidt-Fergusson, the criteria of wet and dry was determined based on lq value. The value of lq was defined as the comparison between rainfall average in dry and wet month. It was formulated as follow [11]:

$$\text{lq} = \frac{\text{number of rainfall average in dry months}}{\text{number of rainfall average in wet months}} \times 100\% \qquad (4)$$

The value of lq was ranged between zero to one hundred. The criteria of very wet until very drought was based on analysis of 10 years historical rainfall data. According to Oldeman, wet month was the month with rainfall more than 200 mm and dry month was the month with rainfall less than 100 mm. According to Koppen, climate was divided into 5 types. The five climate types were included climate of tropical rainfall, dry, enough hot rainfall, snowy rainfall, and pole. Thornthwaite had classified wet and dry month based on the comparison between surplus or deficit water and water demand. Each method was used in different interest. Classification dry and wet month according to Oldeman was used for agriculture interest and this method would be used in this study. There were 5 main zones in wet months as follow [11]:

a. Zone A: wet months were more than 9 times in rotation
b. Zone B: wet months were between 7 until 9 times in rotation
c. Zone C: wet months were between 5 until 6 times in rotation
d. Zone D: wet months were between 3 until 4 times in rotation
e. Zone E: wet months were less than 3 times.

Dry months were also analysed due to the occurences in rotation. Dry main zones analogically as mentioned above were classified as follow:

a. Zone 1: dry months were more than 9 times in rotation (27 ten daily)
b. Zone 2: dry months were between 7 until 9 times in rotation (21-26 ten daily)
c. Zone 3: dry months were between 5 until 6 times in rotation (15-20 ten daily)
d. Zone 4: dry months were between 3 until 4 times in rotation (12-14 ten daily)
e. Zone 5: dry months were less than 3 times (< 9 ten daily)

Some assumptions used in this study were as follow:

- Occurrence climate was the same as 20 years of recent data (or it was fit to the period of analyzed data: 15 recent years in the years of 1990 to 2005.
- Drought in the boundary of maximum rainfall was 1.2 mm/jam [12]
- Monthly average evapotranspiration during 5 years was analysed in 5 recent years (in the years of 2002 to 2006)
- Precipitation was only in form of gauged run off in outlet of river at discharge measurement structure.
- Statistical test of data was analysed for determining the fit data parameter of model.

Level of drought was categoried due to the normal intensity with probability of 0.5 as follow: (www.*drought*.enl.edu/understanding and defining_*Drought*.htm)

- Mild drought (abnormally dry), included incipient dry spell, if P = 21-30% of P_{50}
- Moderate drought if P = 11-20% of P_{50}
- Severe drought if P = 6-10% of P_{50}
- Extreme drought if P = 3-5% of P_{50}
- Exeptional drought if P = 0-2% of P_{50}

Analogically with the criteria mentioned as above, the criteria of dry and drought was defined due to rainfall and discharge. The dry criteria was based on rainfall data with normally rainfall base (the same as P_{50}). Therefore, the criteria was classified as follow:\

- Dry (K) if P = 80-100% of P_{50}
- Very dry (SK) if P = 50-80% of P_{50}
- Very very dry (ASK) if P < 50% of P_{50}

According to Oldeman, dry criteria based on dry duration was classified as follow:

- Dry (K) zone 3 if dry duration was less than or the same as 20 ten-daily
- Dry (K) zone 2 if dry duration was as 21-26 ten-daily
- Dry (K) zone 1 if dry duration was more than 26 ten daily

Dry criteria based on discharge data was classified due to normally discharge (the same as Q_{50}) as follow:

- Dry (K) if $Q_{80} < Q < Q_{50}$
- Very dry (SK) if 71-100% of Q_{80}
- Very very dry (ASK) if Q < 70% of Q_{80}

RESULTS AND DISCUSSION

Yearly mean and timely series mean at the years of 1990 to 2005 was presented as in Figure 1 below. Statistical parameter timely series was described as in Table 1 below.

Table 1 Parameter of statistic in Kali Asem and Umbul sub-watershed.

Statistical parameter	P8005	P9005	Qaw	Qd
Mean	66,33	67,86	17,17	22,70
Median	50,00	51,00	15,69	20,26
St. Deviation	63,74	66,16	7,44	10,91
Kurtosis	0,56	0,06	8,73	25,77
Skewness	0,94	0,83	2,07	3,61
Minimum	0,00	0,00	4,26	0,00
Maximum	343,00	312,00	71,22	130,38

Note:

P8005 = rainfall data in the year of 1980 to 2005,
P9005 = rainfall data in the year of 1990 to 2005,
Qaw = discharge data of AWLR in the year of 1990 to 2005,
Qd = discharge data of Umbul dam in the year of 1990 to 2005.

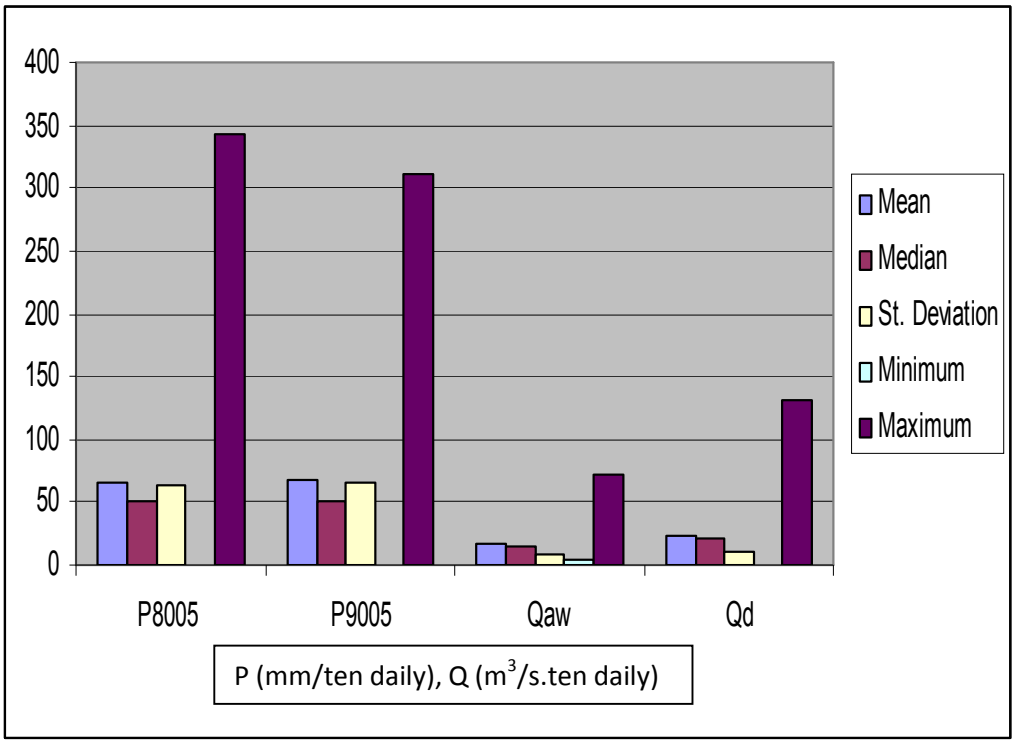

Figure 2 Parameter of statistic in Kali Asem and Umbul sub-watershed

Note:

P8005	= average of rainfall data in the year of 1980 to 2005 (mm/ten daily)
P9005	= average rainfall data in the year of 1990 to 2005 (mm/ten daily)
Qaw	= discharge if AWLR in the year of 1990 to 2005 (m^3/s.ten daily)
Qd	=discharge of umbul dam in the year o 1990 to 2005 (m^3/s.ten daily)

Curve of statistical analysis timely in the year of 1990 to 2005 presented that:

1. Rainfall data had relatively big range. The value of mean, median, and standard deviation in P8005 and 9005 was not significantly difference,
2. Discharge data of AWLR and dam had relatively small range. The value of mean, median and standard deviation on the Qaw and Qd showed that statistical character of discharge of the dam was higher than in the dam.
3. Median was statistical parameter which was used as threshold. It was a value with probability of 0.5 or 50% and P_{50} (= normally rainfall depth) was as dry threshold. Qaw_{50} for discharge of AWLR and Qd_{50} for discharge of Umbul Dam were as low flow threshold. Probability of 0.2 (Qaw_{80} or Qd_{80} was produced due to fitted distribution for determining drought threshold.
4. Standard deviation was used as base of predicted discharge data.
5. The value of minimum and maximum was used to estimate extremely value which had ever occurred in ten daily analysis..

Monthly dependable discharge had changed every month, but in the analysis of time series, it was simplified using constant $Q_{dependable}$ in the period of analysed time [13]. $Q_{dependable}$ used in this case was Q with probability of 0.2 or Q_{80} based on discharge data of AWLR as well as dam in the yeras of 1990 to 2005. Probability was calculated with cumulative distribution function (cdf) from selection of matching distribution. It was mentioned as fitted distribution if the distribution had Anderson Darling (AD) less than the other AD in statistical analysis. Figure 3 presented Gamma distribution test of discharge data in Kali Asem Sub-Watershed in the years of 1990 to 2005. This probability curve of discharge data showed that AD of Gamma distribution was less than normal distribution. It was meaned that this discharge data was fit to gamma distribution. It was also occured in Umbul Sub-Watershed. Then, treshold analysis was carried out using cdf and the result was presented as in Figure 3 below.

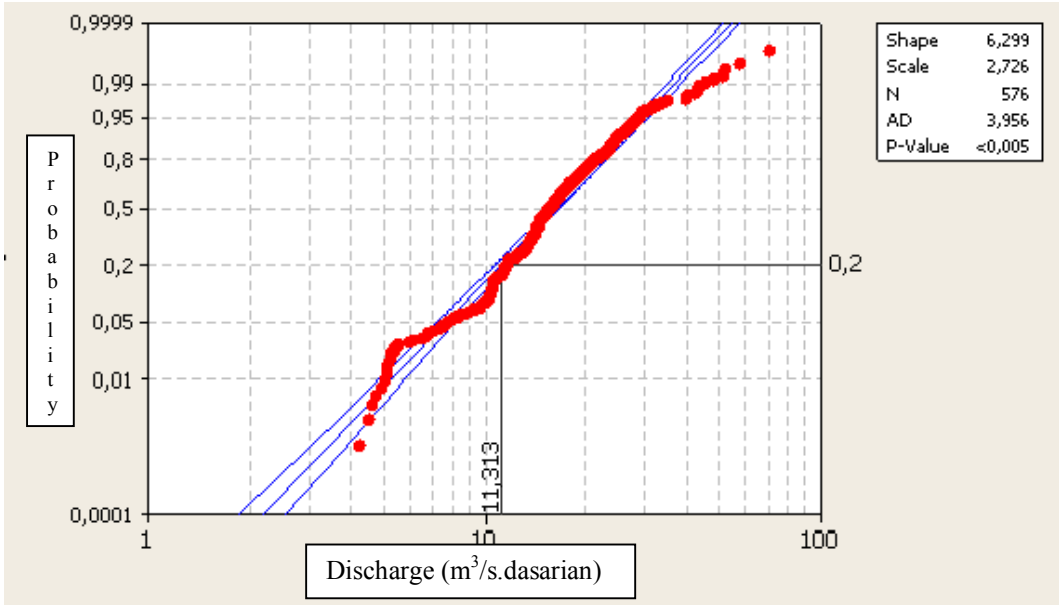

Figure 3 Gamma distribution test of discharge data in Kali Asem Sub-Watershed in the years of 1990 to 2005

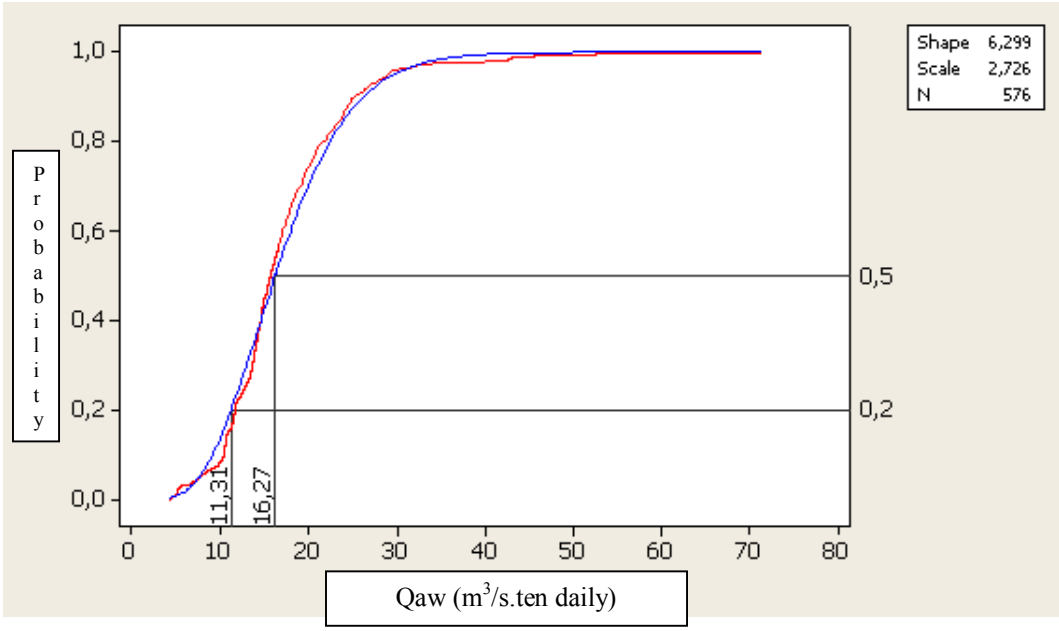

Figure 3 Treshold analysis (dry boundary condition) of AWLR in Kali Asem Sub-Watershed

Results showed that:

- Qaw_{50} = 16.27, interpretationed normally discharge of AWLR was 16,27 m^3/s.
- Qd_{50} = 21.31, interpretationed normally discharge of Umbul Dam was 21,31 m^3/s.
- Qaw_{80} = 11.31, interpretationed dependable discharge of AWLR was 11,31 m^3/s.
- Qd_{80} = 14.32, interpretationed dependable discharge of Umbul Dam was 14,32 m^3/s.
- P_{50} = 36.84 , interpretationed normally rainfall depth was 36,84 mm.

Based on the criteria as mentioned above, it was determined dry criteria due to the probability of 0.5 and 0.2 on rainfall data as follow:

- Category of dry (K) if P in the range of 29,47 < P < 36,84,
- Category of very dry (SK) if P in the range of 18,42 < P < 29,47,
- Category of very ery dry (ASK) if P < 18,42.

Criteria of dry based on discharge data was due to normally discharge (Q_{50}) as follow:

- Category dry (K) if Q in the range of 11.31 < Qaw < 16.27 on AWLR and Q in the range of 14.32 < Qd < 21.31 on Umbulan Dam.
- Category very dry (SK) if Q in the range of 7.917 < Qaw < 11.31 on AWLR and Q in the range of 10,.24 < Qd < 14.32 on Umbulan Dam.
- Category very very dry(ASK) if Q in the range of Qaw < 7.917 on AWLR and Q in the range of Qd < 10.024 on Umbulan Dam.

The primary results showed that the data was gamma distributed and the value of treshold was as follow:

- P_{50} = 36.84, it meaned that normally rainfall depth in the time series of analaysis was 36.84 mm/dasarian.
- Qaw_{50} = 16.27, it meaned that normally discharge on AWLR in the time series of analysis was 16.27 m^3/s.dasarian.
- Qd_{50} = 21.31, it meaned that normally discharge on Umbul Dam in the time series of analysis was 16.27 m^3/s.dasarian.
- Qaw_{80} = 11.31, it meaned that dependable discharge on AWLR in the time series of analysis was 11,31 m^3/s.dasarian.
- Qd_{80} = 14.32, it meaned that dependable discharge on Umbul Dam in the time series of analysis was 14.32 m^3/s.dasarian.

CONCLUSION

Duration and drought deficit was determined based on treshold. It was produced from historical discharge data due to analysis of pdf and cdf. If the discharge was over treshold it meaned that watershed condition was dry until wet, but if the discharge under the treshold it meaned that the watershed was drought.

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