Analysis of meteorological water availability and water demand in Cemoro River section area

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Abstract. About 69% of Cemoro River Section Area is dryland agricultures. Rain is the main source of irrigation for the dryland agricultures, but during dry season farmers use Cemoro River water for irrigation which is directly flowed using a water pump. The potential of water resources in Cemoro River Section Area is very important and determines agricultural products. The aim of this study is to analyze meteorological water availability and water demand in Cemoro River Section Area. Thornthwaite Mather method is used to calculate meteorological water, while the total water demand are calculated based on the domestic water demand, livestock water demand, and agricultural water demand. The result shows that discharge from 60% rain probability could meet total water demand stated as a surplus, but discharge from 80% rain probability could not meet total water demand and classified as deficit.

Keywords: meteorological water availability, water demand, Thornthwaite Mather

1. Introduction

Water resources is an important needs for all living things. Water is a daily need in human life for domestic, industrial, and agricultural. Water consumption in an area is not the same between one and another, it depends on water availability in each region. This condition affects humans in fulfilling water demand. One of strategic issue about water resources is the water balance between supply and demand, which the common problem is amount of water availability is not sufficient for water demand. Therefore, calculation and planning of water resources utilization is important to do as a mitigation effort to overcome its problem.

Amount of water availability depends on the hydrological process [1]. Meteorological aspects can be used to determine water availability. The availability of meteorological water is the availability of water from rain. Rainfall is the main determining factor, while other hydrological factors are topography, geology, soil, land cover and land use [2]. Changes in hydrological process and inappropriate use of water can affect water availability in an area.

Meteorological water availability can be presented as water balance graph. Water balance is a quantitative assessment of the components in hydrological process. Factors that affect water balance of a watershed are precipitation, inflow and outflow, groundwater inflow and outflow, evaporation, evapotranspiration, and changes in volume of water deposits [3]. Water balance is arranged based on climatological concepts and useful to know the occurrence of wet and dry periods in a region [4].
Based on the purpose of its use, water demand can be divided into domestic water demand, agricultural water demand, and livestock water demand [5]. Domestic water demand in an area is influenced by population, population activities, climate, and socio-economic conditions of the community. Agricultural water demand is calculated based on irrigation needs according to crop type and land use. Calculation of water demand for livestock is distinguished according to the types of livestock, specifically large ruminants (cattle/buffalo/horse), small ruminants (goat/sheep), and poultries.

Cemoro River Section Area is part of the Sangiran Ancient Site Area, which is a rural area and most of the population works in the agricultural sector. Potential of water resources are important because it determines agricultural product quantities. Dryland agriculture in Cemoro River Section Area has the main source of irrigation obtained from rain, but during the dry season farmers distribute water from Cemoro River for irrigating fields. In addition, there are many large chicken coops which need a lot of water every day. These conditions affect the consumption of daily water demand in accordance with the community’s lifestyle.

The importance of water supply for domestic, agricultural, and livestock water demand in Cemoro River Section is the main focus of this research. Inequality of water availability throughout the year can be compared with its water demand, so that it can be known the condition of water demand fulfilling in one year. Based on this background, the purpose of this study is to analyze meteorological water availability and water demand in Cemoro River Section Area.

2. Methods

2.1. Location and Time of Research

The Sangiran Site area is in Central Java Province with an area of 56 km². One of rivers flowing through this area is Cemoro River with upstream in Boyolali Regency. This study was conducted at Cemoro River Section Area which is limited by Sangiran Site Area in April 2019. This study site has an area of 19.81 km². The physiography of Cemoro River Section Area in the Sangiran Site Area included in the Solo Sub Zone [6]. Geological formations in the Cemoro River Section Area consist of Kabuh Formation, Kalibeng Formation, Notopuro Formation, Pucangan Formation, Alluvial Deposits and Mud Mountain Deposits. Study area is presented in figure 1.

Landuse in the Cemoro River Section is dominated by rice fields with a percentage of 68.89% of total area. Another landuse include pasture, plantations, settlements, rice fields, shrubs, and arable land. Agriculture that develops in the study area is dryland agriculture, which is irrigated by rain. The percentage of landuse in Cemoro River Section Area presented in Table 1.

2.2. Water Availability

Water availability was calculated with Thornthwaite Mather method. Calculation using this method can determine the quantity of water each month by considering the temperature, monthly heat index, and Water Holding Capacity (WHC) [7]. Required data include rainfall data, temperature data, median elevation data, surface material, and landuse. The data obtained from a relevant institution such as Badan Informasi Geospasial (BIG), Badan Pelestarian Manusia Purba Sangiran (BPSMPS), Balai Pengelolaan Sumber Daya Air (PSDA) Bengawan Solo, and Santa Barbara Climate Hazard Group, University of California.

2.2.1. Rainfall Data

The rainfall data used are from CHIRPS (Climate Hazards Group Infrared Precipitation with Station). The CHIRPS dataset is a climate database in the form of station rainfall and satellites covering the land of the earth. The advantage of this CHIRPS data is that high resolution reaches 0.05° while other global datasets generally have a resolution of 0.5° or lower [8]. CHIRPS rain data can be obtained through the web Climate Hazard Group (chg.geog.ucsb.edu/data/chrips). Rainfall data from CHIRPS was used in the form of monthly data from 2001 – 2016.
Sixteen-year data of rainfall was processed into rainfall pattern with isohyet method and two probability scenarios, 60% and 80%. Calculation of rainfall data begin with collecting monthly rainfall data for sixteen years. The data was processed using statistical analysis for probability of 80% and 60%. Result from statistical analysis then tested using chi square formula to determine the best rainfall data distribution. The process was repeated for all monthly rainfall data.

**Table 1. Landuse of Cemoro River Section Area.**

| Landuse     | Area (Ha) | Percentage (%) |
|-------------|-----------|----------------|
| Pasture     | 16.98     | 0.86           |
| Plantation  | 263.13    | 13.26          |
| Settlement  | 296.37    | 14.93          |
| Rice Field  | 1367.05   | 68.89          |
| Shrubs      | 9.58      | 0.48           |
| Arable land | 31.32     | 1.58           |
| **Total**   | **1984.43** | **100.00**    |

Rainfall data from statistical analysis was processed using isohyet to calculate average rainfall in study area. According to Triatmodjo [3] the isohyet method is used for mountainous regions with a large variety of elevations. This condition is suitable with the location of the study, which has various elevations. The equation of this method written in Equation 1.
\[ CH = \frac{CH_1 + CH_2}{2 \times A_1} + \frac{CH_2 + CH_3}{2 \times A_2} + \ldots + \frac{CH_n + CH_{n+1}}{2 \times A_n} \]

where in:
- \( CH \) = Rainfall pattern
- \( CH_1 \) = First rainfall contour line
- \( A_1 \) = Area in first rainfall contour line

2.2.2. Monthly Average Temperature Data
Temperature data was calculated by converting temperature data from Waduk Cengklik Climatology Station. Equation 2 is used to converting temperature data. Data used include contour data, as input for calculating the median elevation of Cemoro River Section Area.

\[ \Delta T = 0.006(z_1 - z_2) \]

where in:
- \( \Delta T \) = Temperature difference between the measurement station and location (°C)
- \( z_1 \) = Elevation of measuring station
- \( z_2 \) = Elevation of study area

2.2.3. Water Holding Capacity (WHC)
The WHC value was obtained by overlapping land use with soil material. Each type of soil texture has the value of the ability to store each water based on the Thornthwaite Mather classification in Darmanto [9]. Each texture and land use are multiplied broadly and averaged to get the WHC of Cemoro River Section Area.

2.2.4. Water Balance
Water balance is a quantitative assessment of the components in the hydrological cycle. Factors that affect the water balance of a region are precipitation, inflow and outflow, groundwater flow in and out, evaporation, evapotranspiration, and changes in the volume of water simulations [3]. Water balance is arranged based on climatological concepts and is useful to know the occurrence of wet periods (surplus water) and dry periods (lack of water) in a region in general [4]. The surplus condition is illustrated if the amount of rainfall exceeds the potential evapotranspiration value and changes in soil moisture, whereas if the rainfall value is smaller, then a deficit will occur. Systematically calculations are carried out according to Equation 3.

\[ \Delta s = P - PE \]

where in:
- \( \Delta s \) = Surlus and Deficit Value
- \( P \) = Rainfall
- \( PE \) = Evapotranspiration
- \( \Delta s < 0, P < PE \), the value is deficit
- \( \Delta s < 0, P > PE \), the value is surplus

2.3. Water Demand
Calculation of water demand was divided into domestic, agricultural, and livestock needs. Domestic water demand was obtained from interviews with the community about water needs per day, then multiplied by total population in study area. Based on interviews, domestic water demand in study area is 106 liters/capita/day. Water demand for livestock and agriculture were determined by the type of animal livestock and the existing agricultural land, then calculated based on the standard value of SNI 19-6728.1-2002 regarding to water resources balance [10]. The amount of animal livestock in study area was obtained based on BPS (Badan Pusat Statistik) annual data in Gondangrejo, Kalijambé and Plupuh Districts. Water demand standards for each use can be seen in Table 2.
Table 2. Water Demand Standards for Each Utilization.

| Utilization         | Water Demand Standard | Unit         |
|---------------------|-----------------------|--------------|
| Domestic            | 106                   | liters/capita/day |
| Livestock           |                       |              |
| - Cow/ Buffalo      | 40                    | liters/cow/day |
| - Sheep/ Goat       | 5                     | liters/sheep/day |
| - Poultry           | 0.6                   | liters/poultry/day |
| Agriculture (rice field) | 1                 | liters/sec/Ha |

3. Results and Discussions

3.1. Rainfall Pattern

Rainfall pattern in Cemoro River Section Area was calculated using sixteen years of rainfall data (2001 - 2016) obtained from CHIRPS with two probabilities scenarios, 60% and 80%. The probability of 60% has a rainfall value that is greater than the probability of 80%, but the rainfall event with a probability of 60% has less frequent than the probability of rain events 80%. The annual rainfall potential at the Cemoro River Section Area with a probability of 60% is 2162.34 mm/year, while the probability of 80% is 1726.98 mm/year. Table 3 shows the results of rainfall pattern calculations using Isohyet method.

Table 3. Rainfall in Cemoro River Section Area

| Month | P60 (mm/month) | P80 (mm/month) |
|-------|----------------|----------------|
| Jan   | 297.72         | 256.17         |
| Feb   | 328.61         | 288.82         |
| Mar   | 308.21         | 268.14         |
| Apr   | 206.04         | 161.57         |
| May   | 133.83         | 95.94          |
| Jun   | 93.02          | 34.65          |
| Jul   | 36.91          | 21.83          |
| Agt   | 15.88          | 11.25          |
| Sep   | 35.55          | 24.89          |
| Oct   | 110.41         | 59.13          |
| Nov   | 279.1          | 235.43         |
| Dec   | 317.05         | 269.17         |

3.2. Evapotranspiration

Monthly evapotranspiration was calculated using the Thornthwaite Mather method. The input of this method is temperature data from Waduk Cengklik Climatology Station. The average monthly temperature at Waduk Cengklik Climatology Station was converted into temperature data of Cemoro River Section Area using Mock formulation. Temperature data and evapotranspiration values of Cemoro River Section are shown in Table 3.

Evapotranspiration in Cemoro River Section Area varies every month. Based on Table 3, it shows that evapotranspiration value is directly proportional to the temperature value. The highest evapotranspiration rate occurred in October, where the temperature of the month was also the highest among other months. The evapotranspiration value in the two scenarios used has the same amount because the data used in the calculation is temperature data.

3.3. Water Holding Capacity
The WHC value was calculated by overlaying texture and landuse data. The value of WHC in Cemoro River Section is 184. It means that the ability of the Cemoro River Section Area to store water is 184 mm. Landuse in parts of the Cemoro River area affects the value of the WHC. The landuse percentage in Cemoro River Section Area shows in Table 1.

The landuse in Cemoro River Section which is dominated by rice fields influences the value of WHC. The rice field landuse covers 68% of the total landuse in Cemoro River Section. Settlements that cover 14% of landuse also affect the value of the WHC, considering the value of WHC in the study area, it can be concluded that the study area has good ability in holding water.

WHC in settlements area is 0 because the land is unable to infiltrate water. The plantation landuse covers 13% of the total landuse in the Cemoro River Section Area. Plantations are generally able to infiltrate water so WHC values are higher. However, there are also plantation with a loam soil texture that has a lower ability to infiltrate water.

3.4. Water Balance
The results of data on rainfall, evapotranspiration, and WHC processed into water balance data with the final result are surplus and deficit period. As known in Figure 2 and 2, the water balance at 60% probability and 80% probability have a surplus and deficit period in the same months. The surplus period occurs in January, February, March, April, November and December, while the deficit period is from May to October. The surplus value at a probability of 60% is higher than the probability of 80% because it influenced by a higher probability of 60% rainfall.

| Month | Average Temperature of Waduk Cengklik Clymatology Station | Average Temperature of Cemoro River Section | Evapotranspiration |
|-------|------------------------------------------------------------|---------------------------------------------|-------------------|
| Jan   | 25.9                                                       | 25.9                                        | 137.1             |
| Feb   | 26.2                                                       | 26.2                                        | 127.4             |
| Mar   | 26.2                                                       | 26.2                                        | 137.8             |
| Apr   | 26.7                                                       | 26.7                                        | 135.4             |
| May   | 27.4                                                       | 27.4                                        | 150.7             |
| Jun   | 26.6                                                       | 26.6                                        | 133.1             |
| Jul   | 26.2                                                       | 26.3                                        | 134.1             |
| Agt   | 25.9                                                       | 25.9                                        | 130.6             |
| Sep   | 27.3                                                       | 27.4                                        | 147.2             |
| Oct   | 27.5                                                       | 27.5                                        | 157.3             |
| Nov   | 27.1                                                       | 27.1                                        | 152.0             |
| Dec   | 26.8                                                       | 26.8                                        | 145.5             |

3.5. Direct Runoff (DRO)
Direct runoff for every month was calculated with a principal that 50% of the surplus in each month would be stored and issued in the following month. DRO from 2 probabilities produces different values. DRO from 80% rain probability produces smaller amount than DRO from 60% rain probability. Annual DRO from 80% rain probability is 800.26 mm, while 60% rain probability is 1116.38 mm. Values of DRO for each probability shown in Table 4 and Table 5.
Value of DRO in each month for two probabilities is different. The month with higher precipitation doesn’t always have a higher DRO; it influenced by the storage of 50% water from the previous month that issued together with the surplus from the following month. Scenario with 60% probability produces DRO for more than 100 mm in February, March, April, May, and December. While the probability of 80% presents high DRO in February, March, April, and December, values of DRO will be used to calculate discharge.

**Table 5. Direct Runoff of 60% Rain Probability in Cemoro River Section Area**

|         | Jan  | Feb  | Mar  | Apr  | May  | Jun  | Jul  | Agt  | Sept | Oct  | Nov  | Dec  |
|---------|------|------|------|------|------|------|------|------|------|------|------|------|
| S       | 160.66 | 201.21 | 170.37 | 70.67 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 127.12 | 171.57 |
| 0.5     | 80.33 | 100.61 | 85.18 | 35.34 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 63.56 | 85.78 |
| 0.5     | 80.33 | 100.61 | 85.18 | 35.34 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 63.56 | 85.78 |
| 0.5     | 40.16 | 50.30 | 42.59 | 17.67 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 0.5     | 20.08 | 25.15 | 21.30 | 8.83  | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
### 3.6. Discharge

Discharge calculated from the value of annual DRO multiplied by total area from the Cemoro River Section Area. It assumed that precipitation for each month would flow 50% and the rest 50% is infiltrated and will flow in the following month. Discharge of 60% rain probability is 22.125.353 m³/year and 15.860.125 m³/year for 80% rain probability. Table 6 shows monthly discharge for each probability. The probability of 60% produces higher discharge as precipitation in this probability is higher.

Precipitation is the main input of the discharge

**Table 6.** Direct Runoff of 80% Rain Probability in Cemoro River Section Area

| Jan  | Feb  | Mar  | Apr  | May  | Jun  | Jul  | Ago  | Sep  | Oct  | Nov  | Dec  |
|------|------|------|------|------|------|------|------|------|------|------|------|
| S    | 119.11 | 161.43 | 130.29 | 26.20 | 0.00  | 0.00  | 0.00  | 0.00  | 0.00  | 83.45 | 123.68 |
| 0.5  | 59.55 | 80.71 | 65.15 | 13.10 | 0.00  | 0.00  | 0.00  | 0.00  | 0.00  | 41.73 | 61.84 |
| 59.55 | 80.71 | 65.15 | 13.10 | 0.00  | 0.00  | 0.00  | 0.00  | 0.00  | 0.00  | 41.73 | 61.84 |
| 29.78 | 40.36 | 32.57 | 6.55  | 0.00  | 0.00  | 0.00  | 0.00  | 0.00  | 0.00  | 0.00  | 0.00  |
| 14.89 | 20.18 | 16.29 | 3.28  | 0.00  | 0.00  | 0.00  | 0.00  | 0.00  | 0.00  | 0.00  | 0.00  |
| 7.44  | 10.09 | 8.14  | 1.64  | 0.00  | 0.00  | 0.00  | 0.00  | 0.00  | 0.00  | 0.00  | 0.00  |
| 3.72  | 5.04  | 4.07  | 0.82  | 0.00  | 0.00  | 0.00  | 0.00  | 0.00  | 0.00  | 0.00  | 0.00  |
| 1.86  | 2.52  | 2.04  | 0.41  | 0.00  | 0.00  | 0.00  | 0.00  | 0.00  | 0.00  | 0.00  | 0.00  |
| 0.93  | 1.26  | 1.02  | 0.20  | 0.00  | 0.00  | 0.00  | 0.00  | 0.00  | 0.00  | 0.00  | 0.00  |
| 0.47  | 0.63  | 0.51  | 0.10  | 0.00  | 0.00  | 0.00  | 0.00  | 0.00  | 0.00  | 0.00  | 0.00  |
| 0.23  | 0.32  | 0.25  | 0.10  | 0.00  | 0.00  | 0.00  | 0.00  | 0.00  | 0.00  | 0.00  | 0.00  |
| 0.12  | 0.16  | 0.06  | 0.08  | 0.00  | 0.00  | 0.00  | 0.00  | 0.00  | 0.00  | 0.00  | 0.00  |
| Ro   | 59.55 | 140.27 | 175.64 | 133.49 | 73.30 | 36.65 | 18.32 | 9.16  | 4.58  | 2.29  | 42.87 |
| Total | 800.26 |

### 3.7. Water Demand

Domestic water demand was calculated from the total population in Cemoro River Section Area. There are nine villages in this area; Jatikuwung, Rejosari, Wonoasari, Dayu, Krendawahanohono, Krikilan, Bukuran, Ngebung, and Jembangan. Water needs for domestic use were calculated through an interview with 196 respondents from all villages, without considering the population who use PAM (Perusahaan Air Minum) services. Total domestic water demand in a year is 458.631 m³. The difference in water needs for domestic use is caused by water supply, consumption, and economic condition. People in villages...
use various water source to fulfil their needs. Available water sources in communities are well, spring, and PAM (Perusahaan Air Minum)

**Table 7.** Monthly Discharge in Cemoro River Section Area

| Month | Discharge (m³/month) | P60 | P80 |
|-------|----------------------|-----|-----|
| Jan   | 1.592.020            | 1.180.280 |
| Feb   | 3.585.906            | 2.779.904 |
| Mar   | 4.478.118            | 3.480.876 |
| Apr   | 3.783.487            | 2.645.636 |
| May   | 2.241.902            | 1.452.640 |
| Jun   | 1.120.951            | 726.320 |
| Jul   | 560.475              | 363.160 |
| Agt   | 280.237              | 181.580 |
| Sep   | 140.118              | 90.790 |
| Oct   | 70.059               | 45.395 |
| Nov   | 1.294.732            | 849.654 |
| Dec   | 2.977.342            | 2.063.887 |
| Total (m³/year) | 22.125.353          | 15.860.125 |

Agricultural land covers 69% of total landuse in Cemoro River Section Area. Water demand for agriculture was calculated for rice field irrigation. Rice field covers 1.369,19 Ha of the total area. The result shows that water needs for agricultural use are 21.233.127 m³/year (Table 9). Meanwhile, water demand for livestock are 37.936 m³/year (Table 10). Based on the calculation of water demand for domestic, agriculture, and livestock, the total water demand in Cemoro River Section Area is 21.729.694 m³/year.

**Table 8.** Agriculture Water Demand in Cemoro River Section Area

| Village  | Area (Ha) | Water Use Period in a Year (day) | Water Demand (lt/sec/Ha) | Total (liter/year) |
|----------|-----------|----------------------------------|--------------------------|-------------------|
| Jatikuwung | 7.75     | 180                              | 1                        | 120.600.189       |
| Rejosari  | 244.21    |                                  |                          | 3.798.000.988     |
| Wonosari  | 186.01    |                                  |                          | 2.892.785.078     |
| Dayu     | 442.48    |                                  |                          | 6.881.447.947     |
| Krendowahono | 53.70  | 180                              | 1                        | 835.118.441       |
| Krikilan  | 186.08    |                                  |                          | 2.893.921.091     |
| Bukuran   | 120.74    |                                  |                          | 1.877.788.708     |
| Ngebung   | 14.44     |                                  |                          | 224.513.914       |
| Jembangan | 109.89    |                                  |                          | 1.708.950.752     |
| Total     |           |                                  |                          | 21.233.127.113    |
| Total (m³/year) |        |                                  |                          | 21.233.127        |

**Table 9.** Livestock Water Demand in Cemoro River Section Area

| Village  | Number of livestock | Water Demand (lt/year) | Total (liter/year) |
|----------|---------------------|------------------------|--------------------|
|          | Cow | Goat | Poultry | Cow | Goat | Poultry |                  |
| Jatikuwung | 16 | 14   | 1.948    | 232.940 | 25.309 | 426.685 | 684.934          |
Rejosari  151  178  11.028  2.197.349  324.029  2.415.078  4.936.456  
Wonosari  162  213  8.368  2.367.988  388.400  1.832.654  4.589.042  
Dayu  19  18  5.617  281.550  32.261  1.230.068  1.543.879  
Krendowahono  140  111  7.552  2.044.288  202.989  1.653.973  3.901.250  
Krikilan  193  489  22.638  2.811.083  893.186  4.957.713  8.661.982  
Bukuran  272  273  3.323  3.971.695  498.860  727.760  5.198.315  
Ngebung  51  100  508  748.974  181.661  111.159  1.041.795  
Jembangan  192  233  18.966  2.800.417  424.473  4.153.547  7.378.436  
Total  
Total (m³/year)  37.936.089  

| Rain Probability | Runoff Volume (m³/year) | Total Water Demand (m³/year) |
|------------------|------------------------|----------------------------|
| 60%              | 25,000,000             | 20,000,000                 |
| 80%              | 15,000,000             | 10,000,000                 |

Figure 4. Comparison between Water Supply and Water Demand in Cemoro River Section Area

4. Conclusion
Water demand consists of domestic, agricultural and livestock needs. Calculation results show that total water demand in Cemoro River Section Area is 21.729.694 m³/year. Water supply from discharge with 60% rain probability can meet water demand in Cemoro River Section Area, while the discharge from 80% rain probability cannot meet the water demand there. Discharge from 60% rain probability is 22.125.353 m³/year. Agriculture is sector that needs the most water every year for irrigating rice fields.

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