Study of climate change effect on water balance in upper Citarum Watershed, the Krueng Cunda Watershed, and the Woske Watershed, Indonesia

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Abstract. The community feels the changes in water availability due to climate change will directly impact water availability, especially water availability in rivers, reservoirs and other water reservoirs. The purpose of this analysis is to determine changes in the rainy season shift, changes in mainstay discharge, and the effect of climate change on water balance. The results show a shift in the rainy season and a significant decrease in rainfall during the last ten years. In the Upper Citarum watershed (UCW), there is a change in the maximum and minimum mainstay discharge in the three watersheds. Climate change significantly affects the water balance in a watershed. Meanwhile, in the Krueng Cunda watershed (KCW) and the Woske watersheds (WW), there was a decrease in the value of the water balance, which was the same as the UCW. However, still able to meet the water needs of the population. There was a decrease in the value of the water balance, which was the same as the UCW, but still able to meet the population's water needs.

key words: Climate Change, Water Need, and Water Balance, Upper Citarum Watershed

1. Introduction

Many international contributions to the Special Edition show that the impact of climate change on water resource analysis is a global concern [1]. Climate change is the condition of several climate elements whose magnitude and/or intensity tend to change or deviate from the dynamics and average conditions and towards a specific direction (trend) (increasing or decreasing). The leading cause of climate change is human activities (anthropogenic) associated with rising greenhouse gas (GHG) emissions that drive global warming and has been going on for almost the last 100 years [2].

The community feels changes in water availability due to climate change, which has been carried out by many researchers [3-6]. However, these changes vary widely and require a different understanding for each place. On the other hand, we still think that the availability of water in Indonesia is abundant. The availability of water is increasingly threatened due to land conversion and climate change. It is essential to know how many water reserves we still have to meet the various needs of human and natural activities. This knowledge will serve as a warning for us to use water wisely to avoid water scarcity in the future.
On the other hand, climate change also brings a positive side. [7-8] reported that future climate change could offset the adverse effects of sustainable reforestation on water resources and present severe opportunities for food production. In areas which, until now, were relatively undeveloped.

This study determines how much climate change influences season shifts (rainy and dry), rain characteristics, climatological characteristics, water availability in rivers, and water balance in the Upper Citarum Watershed Province. West Java, Krueng Cunda watershed in Nanggroe Aceh Darussalam province, and Woske watershed in Papua province.

2. Materials and Methods

2.1 Research Location
This research focuses on the UCW in West Java Province, the KCW in Nanggroe Aceh Darussalam Province, and the WW in Papua Province (Fig. 1). The UCW is one of the largest watersheds in the UCW with a watershed area of 356.05 km², while the KCW has an area of 544.02 km² and the WW has an area 564.69 km². Astronomically, the UCW is located at coordinates 107°37’- 107°48’ East Longitude and 6°59’- 70°14’ south latitude.

![Figure 1. Research Location](image_url)

2.2 Data Sources
The data used in this study are secondary data obtained from relevant agencies and other literature (journals) related to the effect of climate change on rainfall characteristics. These secondary data include:
1. Daily rainfall data for 1991-2000 and 2010-2019 and rain station coordinates from PUSAIR (Water Centre).
2. Climatological data for 1991-2000 and 2010-2019 from Meteorology Climatology and Geophysics Council (BMKG) Indonesia.
3. Types of soil conditions.
4. Population Data of Upper Citarum Watershed, Krueng Cunda Watershed and Woske Watershed from Central Bureau of Statistics.
5. Data on watershed characteristics.
2.3 Climate Change and the Hydrological Cycle
One indication of climate change changes in rain patterns due to climate anomalies such as tropical cyclones and El Nino and La Nina events. Rain is the most varied physical element of the environment, especially in the tropics. Studies in the hydrological cycle and their effects on multiscale climate variability was carried out [9-10]. Rain is seen as one of the most critical weather and climate forecasting variables. It is because it affects the activities of human life [11] in various sectors such as agriculture, transportation, trade, health, the environment [12-13].

2.4 Evaporation Potential
Potential evaporation (ETo) occurs in agricultural areas, plantations, and other areas to carry out evapotranspiration, which is determined by air temperature, duration of sunlight, wind speed, and humidity. Potential evapotranspiration is affected by latitude. In calculating potential evapotranspiration, many methods can be used. One of the most frequently used is the Modified Penman method [14].

2.5 F.J. Mock
The Mock developed the Mock Method [15] to estimate a watershed's discharge amount based on water balance. The data needed to calculate this method include the average monthly rain (mm), the number of average monthly rainy days (days), evapotranspiration, surface runoff, soil storage and base flow. Rainwater that falls (precipitation) will experience evapotranspiration according to the vegetation that covers the rain catchment area. Evapotranspiration is influenced by the type of vegetation, soil surface and the number of rainy days.

2.6 Water Balance
Water balance (water balance) is a balance of water input and output somewhere in a certain period to determine how much water is excess (surplus) or deficit. The need to know the condition of excess or deficient water is used to anticipate disasters that may occur, as well as to make optimal use of water [16].

2.7 Domestic Water Needs
To calculate and estimate domestic water demand requires a calculation of population projections. From the calculation of the population projection, the domestic water demand can be calculated, namely by multiplying the population by a water usage parameter per person. The amount of this parameter varies depending on the environment. The projection of clean water demand can be determined by considering population growth to project the need for clean water for the next fifty years or depending on the desired projection [14]. The population growth projection method uses the geometric method. This method estimates population growth using the basis of flowering interest, so the population growth rate is the same every year, with the equation [14]:

\[ P_n = P_0 + (1 + r)^n \]  

Where:
- \( P_n \) = Total population in \( n \) (people)
- \( P_0 \) = Total population at the beginning of the year
- \( r \) = Percentage of population growth
- \( n \) = Period of review (years)

3. Results and Discussion

3.1 Rainfall
The rain data was taken from the Geophysical rain observation station in Bandung, the Maliku Saleh Aceh meteorological station and the Sentani Papua meteorological station. Rainfall data is in daily
Rainfall for ten years from 1990-2000 and 2010-2019. For rainfall in the UCW and WW, the highest rainfall occurs between December and January (Fig. 2 and 4), while for the KCW, the highest peak rainfall occurs two times a year, namely in April and November (Fig. 3).

**Figure 2.** Monthly Rainfall in the UCW

**Figure 3.** Monthly Rain in the KCW

**Figure 4.** Monthly Rainfall in the WW
3.2 Potential Evaporation

In this study, potential evapotranspiration was calculated using the Penman [17] Modification method. Four parameters are very influential in calculating the Modified Penman method, namely air temperature, sunshine duration, air humidity, wind speed, and latitude of the area under review.

The calculation of potential evapotranspiration based on the Modified Penman formula is as follows:

\[ E_{To} = C \cdot (W \cdot Rn) + (1 - W) \cdot f(u) \cdot (ea - ed) \]  

In the UCW, evapotranspiration increases almost every month, except for September and December (Fig. 5). The KCW increased in February, March, April, June, July, August, September, October, and November (Fig. 6). For WW, there was an increase in January, February, April, May, August, October, and December (Fig. 7). Evapotranspiration in Indonesia tends to increase in the March-April-May period, especially in Sumatra and Kalimantan. This condition indicates changes in the potential for surface water that can be evaporated into the atmosphere as a result of climate change [18].

![Figure 5. Comparison Graph of the ET₀ Value of the UCW](image)

![Figure 6. Comparison Graph ET₀ Value of Krueng Cunda Watershed](image)
3.3 Water Availability

Water availability is water reserves in rivers that can be used for irrigation, raw water needs for residents (households and hydrant units), livestock water needs. Water availability is obtained by sorting the discharge of F.J. Mock [15] for the last ten years from the greatest to the very minimum. The availability of raw water for residents in the Indonesia Public Work Regulation uses a discharge with a reliability of 90%. For this purpose, it is searched for using the Weibull [19] method.

Table 1. Mainstay Discharge of Upper Citarum Watershed Year 1991-2000

| No | Probability | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Des |
|----|-------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| 1  | 9.09%       | 24.52 | 26.06 | 30.41 | 30.03 | 18.82 | 11.01 | 5.39 | 3.23 | 4.65 | 13.68 | 37.37 | 25.77 |
| 2  | 18.18%      | 23.23 | 22.84 | 26.69 | 28.84 | 16.23 | 9.11 | 5.29 | 3.17 | 2.86 | 12.83 | 30.37 | 22.54 |
| 3  | 27.27%      | 20.60 | 19.14 | 25.84 | 25.76 | 16.04 | 6.57 | 3.81 | 2.29 | 2.14 | 10.41 | 22.67 | 18.68 |
| 4  | 36.36%      | 18.49 | 12.10 | 24.62 | 22.27 | 15.11 | 6.20 | 3.60 | 2.16 | 2.03 | 6.92 | 17.29 | 18.05 |
| 5  | 45.45%      | 17.71 | 10.02 | 14.49 | 16.31 | 12.46 | 5.22 | 3.03 | 1.82 | 1.42 | 6.27 | 16.66 | 17.31 |
| 6  | 54.55%      | 12.59 | 9.61  | 12.78 | 14.85 | 11.35 | 5.18 | 2.82 | 1.69 | 1.34 | 5.64 | 16.37 | 12.82 |
| 7  | 63.64%      | 11.83 | 8.17  | 12.02 | 12.79 | 10.59 | 5.07 | 3.82 | 1.69 | 1.13 | 4.41 | 9.88  | 12.70 |
| 8  | 72.73%      | 10.46 | 6.66  | 10.99 | 11.17 | 8.41  | 4.86 | 2.78 | 1.67 | 1.05 | 3.38 | 9.77  | 9.64  |
| 9  | 81.82%      | 8.64  | 6.44  | 5.56  | 10.02 | 7.44  | 4.61 | 2.68 | 1.61 | 1.05 | 2.92 | 9.40  | 9.32  |
| 10 | 90.91%      | 8.59  | 5.48  | 4.84  | 6.59  | 7.20  | 3.52 | 2.05 | 1.23 | 1.03 | 2.86 | 7.00  | 7.67  |
| Q  | 90.00%      | 8.60  | 5.58  | 4.92  | 6.93  | 7.22  | 3.63 | 2.11 | 1.27 | 1.04 | 2.86 | 7.24  | 7.83  |

Figure 7. Comparison Graph ET₀ Value Woske Watershed

Figure 8. Comparison Chart of Mainstay Discharge of 90% UCW
3.4 Population Water Needs

The availability of water is one of the absolute conditions for life. The higher the level of one's welfare, the more water is needed. With the increasing population and developing development in each sector, the need for water will also increase. Domestic demand is the need for drinking water for households consisting of household connections (HC) and public hydrants (PH).

### Table 2. Household Water Needs in the Upper Citarum Watershed

| Parameter                              | Tahun   | 2000      | 2019      |
|----------------------------------------|---------|-----------|-----------|
| Total Population (soul)                |         | 557,331   | 927,521   |
| Service Level (%)                      |         | 80        | 80        |
| Number Served (Soul)                   |         | 445,865   | 742,017   |
| Average Water Consumption (L/person/day)|         | 150       | 150       |
| Total Usage (L/day)                    |         | 66,879,712| 111,302,479|
| Total Water Requirements (L/s)         |         | 774.07    | 1,288.22  |
| **Total Water Requirements (m³/s)**    |         | 0.774     | 1.288     |

### Table 3. Household Water Needs in the Krueng Cunda Watershed

| Parameter                              | Year    | 2000      | 2019      |
|----------------------------------------|---------|-----------|-----------|
| Total Population (soul)                |         | 353,858   | 631,901   |
| Service Level (%)                      |         | 80        | 80        |
| Number Served (Soul)                   |         | 283,087   | 505,521   |
| Average Water Consumption (L/person/day)|         | 150       | 150       |
| Total Usage (L/day)                    |         | 42,463.001| 75,828.104|
| Total Water Requirements (L/s)         |         | 491.47    | 877.64    |
| **Total Water Requirements (m³/s)**    |         | 0.491     | 0.878     |
### Table 4. Household Water Needs in DAS Woske

| Parameter                              | 2000     | 2019     |
|----------------------------------------|----------|----------|
| Total Population (soul)                | 11,431   | 16,047   |
| Service Level (%)                      | 80       | 80       |
| Number Served (Soul)                   | 9,144    | 12,838   |
| Average Water Consumption (L/person/day)| 130      | 130      |
| Total Usage (L/day)                    | 1,188,774| 1,668,877|
| Total Water Requirements (L/s)         | 13.76    | 19.32    |
| Total Water Requirements (m³/s)        | 0.0138   | 0.019    |

#### 3.5 Water Balance

The water balance analysis is an essential part of the hydrological analysis phase. It is obtained by comparing the availability of water (inflow) and water demand (outflow) in a watershed in a certain period. Fig 11-13 show that the water discharge tends to decrease in the period 2010-2019. If there is a surplus condition, the water demand is smaller than the current water availability. Otherwise, if the deficit means that the water demand is greater than the water availability. The watersheds can be used as a basis for water resource planning in water balance analysis requiring the integration of all aspects. Because the availability of water in rivers depends on the natural conditions of the watershed, which is a unitary water system [20].

![Figure 11. Water Balance in the UCW between 1991-2000 and 2010-2019](image1.png)

![Figure 12. Water Balance in the KCW between 1991-2000 and 2010-2019](image2.png)
These climate changes put significant pressure on hydrological conditions, which are an essential asset to ensure the availability of food and water resources for a fast-growing global population [21]. The predicted of climate change scenario shows that a decrease in rainfall in the rainy season and a marginal increase in the dry season are the main factors in the decline in the overall water balance component [22]. The water balance component is more sensitive to rainfall changes than changes in climatology (ETo). More importantly, the groundwater flow component will be negatively affected by projected rainfall and temperature changes.

4. Conclusion
Things that can be concluded from the discharge modelling using the F.J. The mock is as follows:
1. There has been a shift in the rainy season and a significant decrease in the amount of rainfall during the vulnerability of the last ten years.
2. From the calculation results, it is found that changes in water availability (reliable discharge) in each watershed are as follows:
   - In the Upper Citarum Watershed, there is a change in the maximum mainstay discharge from 8.6 m$^3$/sec to 7.98 m$^3$/sec. The initial minimum discharge is from 1.04 m$^3$/sec to 0.4 m$^3$/sec.
   - In the Krueng Cunda watershed, there is a change in the maximum mainstay discharge from 8.76 m$^3$/sec to 7.25 m$^3$/sec, and the actual minimum flow rate of 2.65 m$^3$/sec to 2.25 m$^3$/sec.
   - In the Woske watershed, there was a change in the maximum mainstay discharge from 4.36 m$^3$/sec to 4.22 m$^3$/sec, and the initial minimum discharge from 1.01 m$^3$/sec to 0.89 m$^3$/sec.
3. Climate change significantly affects the water balance in a watershed. From the calculation results, the water balance in the Upper Citarum Watershed in 2019 has a water deficit for three months, namely in July of 0.25 m$^3$ / sec, August of 0.68 m$^3$ / sec, and September of 0.93 m$^3$ / sec. Meanwhile, in the Krueng Cunda watershed and the Woske watershed, there was a decrease in the value of the water balance similar to that of the upstream Citarum watershed but still able to meet the population's water needs.

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