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 Changes in water availability are felt by the community as a result of climate change which will directly impact the availability of water, especially the availability of water 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 that there is a shift in the rainy season and a significant decrease in the amount of rainfall during the last 10 years. In the Upper Citarum watershed (UCW), there is a change in the maximum and minimum mainstay discharge in the 3 watersheds. Climate change greatly 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, but 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 water needs of the population.

Keywords: *Climate Change, Water Need, and Water Balance, Upper Citarum Watershed*

1. Introduction

The large number of international contributions to the Special Edition shows that the impact of climate change on water resource analysis is a global concern [1]. The 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, towards a certain direction (trend) (increasing or decreasing). The main cause of climate change is human activities (anthropogenic) associated with increasing greenhouse gas (GHG) emissions that drive global warming and has been going on for almost the last 100 years [2]

Changes in water availability are felt by the community as a result of 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. In fact, the availability of water is increasingly threatened due to land conversion and climate change. It is important for us to know how much water reserves we still have in order to meet the various needs of human and natural activities. This knowledge will serve as a warning for us to use water wisely so that we can 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 negative effects of sustainable reforestation on water resources and present serious opportunities for food production. in areas which, until now, were relatively undeveloped

Based on this background, this research is very necessary to do in order to find out how much influence climate change has on 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. Basic Theory

2.1 Climate Change and the Hydrological Cycle

One indication of climate change is 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 to review research progress on changes in the hydrological cycle and their effects on multiscale

climate variability was carried out by [9-10]. Rain is seen as one of the most important weather and climate forecasting variables because it affects the activities of human life [11] in various sectors such as agriculture, transportation, trade, health, the environment and so on. [12-13]

2.2 Evaporation Potential

Potential evaporation (ETo) occurs in agricultural areas, plantations, and other areas to carry out evapotranspiration which is determined by several factors, such as 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]

3.3 F.J. Mock

The Mock Method was developed by Dr. F.J. Mock [15] to estimate the amount of discharge of a watershed based on the concept of water balance. The data needed in the calculation of 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.

2.4 Water Balance

Water balance (water balance) is a balance of water input and output somewhere in a certain period, so that we can find out how much water is excessed (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].

2.5 Domestic Water Needs

To calculate and estimate domestic water demand requires 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 taking into account 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]:

$$Pn = Po + (1 + r)^n \text{ ....(1)}$$

Where:

Pn = Total population in n (people)
Po = Total population at the beginning of the year
r = Percentage of population growth
n = Period of review (years)

3. Research Methods

3.1 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 km^2, while the KCW has an area of 544.02 km^2 and the WW has an area of 564.69 km^2. Astronomically, the UCW is located at coordinates 1070 37 '- 1070 48' East Longitude and 60 59 '- 70 14' south latitude.

Fig 1 Research Location

3.2 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 as well as rain station coordinates from PUSAIR (Water Centre).
2. Climatological data for the years 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.

4. **Results and Discussion**

4.1 Rainfall

The rain data used in this study were 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 the form of daily rainfall for 10 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 2 times a year, namely in April and November (Fig. 3).

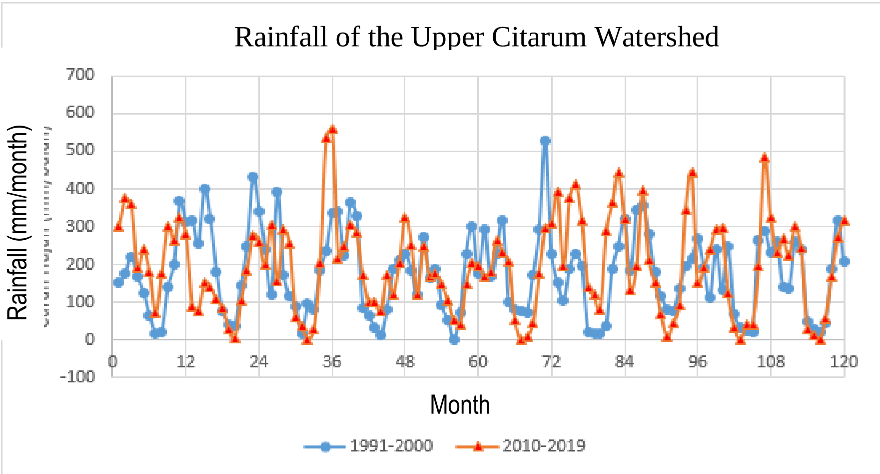

Fig. 2 Monthly Rainfall in the UCW

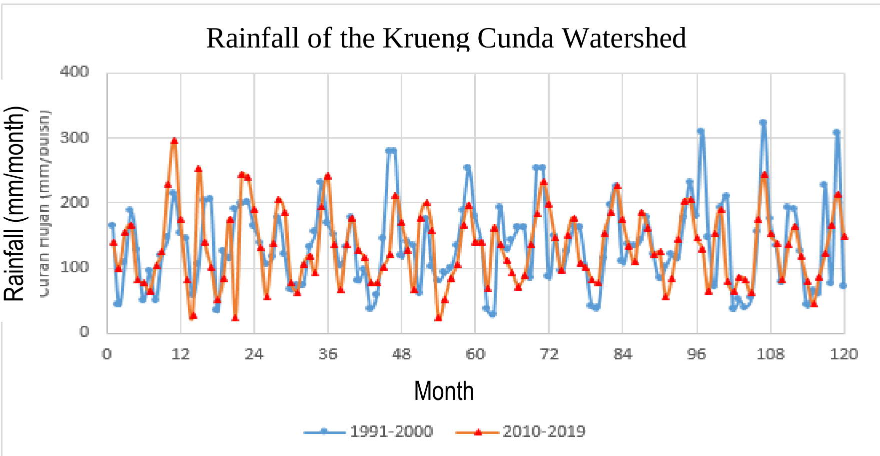

Fig. 3 Monthly Rain in the KCW

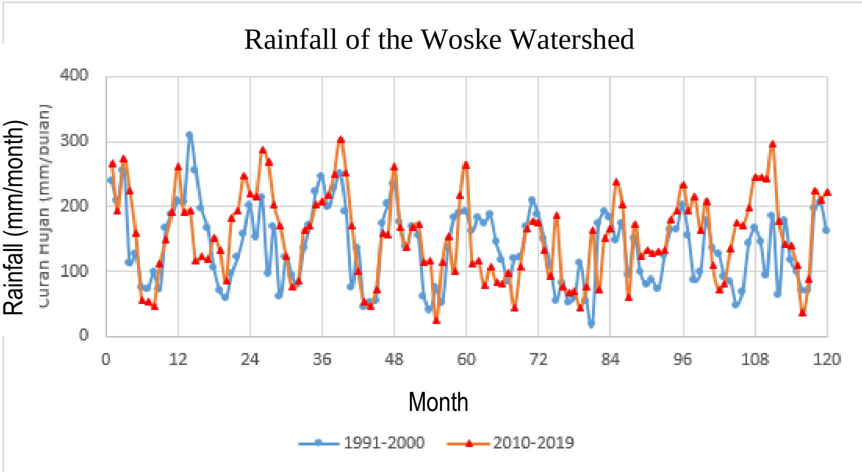

Fig. 4 Monthly Rainfall in the WW

4.2 Potential Evaporation

In this study, potential evapotranspiration was calculated using the Penman [17] Modification method. There are four parameters that are very influential on the calculation of 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:

$$ETo = C \,.\, (W \,.\, Rn) + (1 - W).\ f(u) \,.\, (ea - ed) \ldots\ldots\ldots\ldots\ (2)$$

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 Sumatra and Kalimantan. This is an indication of changes in the potential for surface water that can be evaporated into the atmosphere as a result of climate change [18]

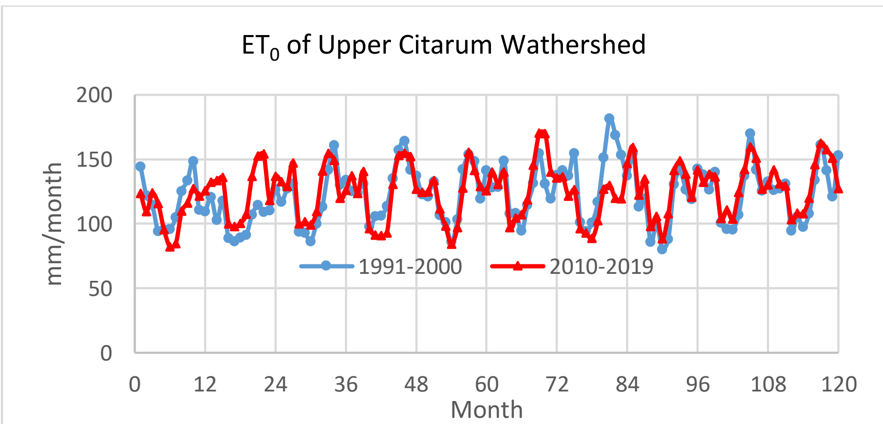

Fig 5 Comparison Graph of the ET_0 Value of the UCW

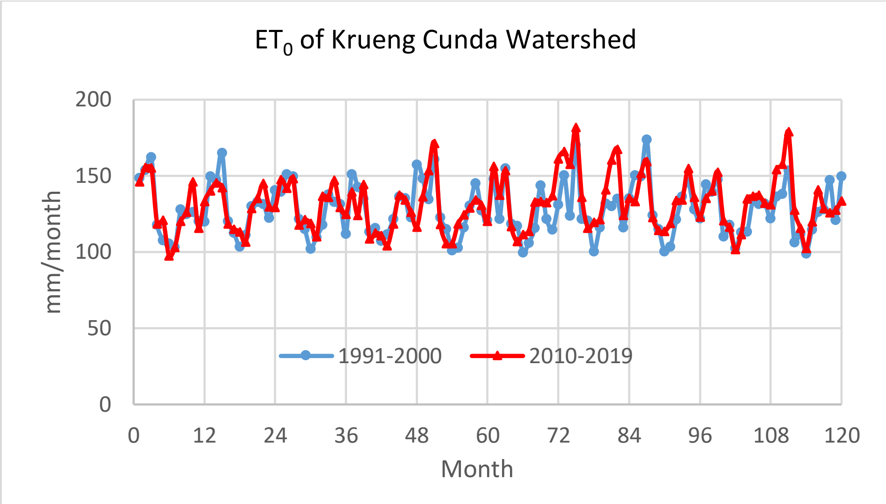

Fig. 6 Comparison Graph ET_0 Value of Krueng Cunda Watershed

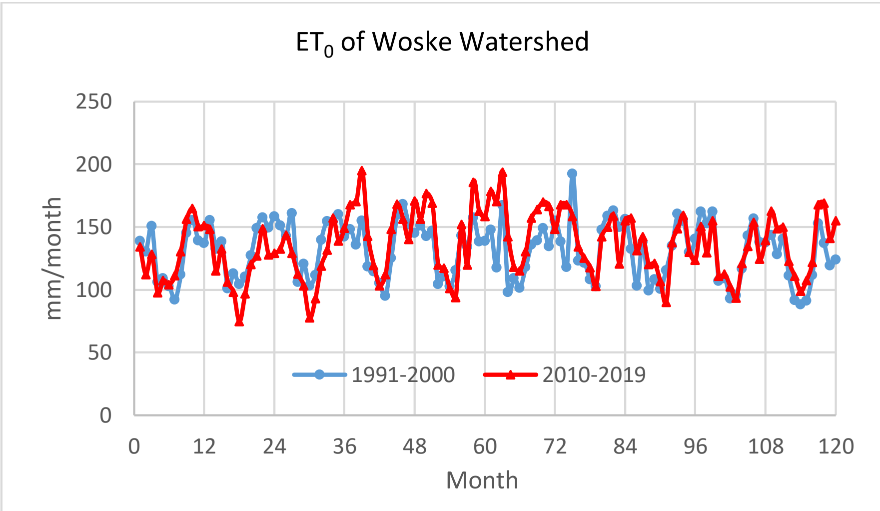

Fig. 7 Comparison Graph ET_0 Value Woske Watershed

4.3 Water Availability

The water availability is water reserves in rivers that can be used for irrigation water needs, raw water needs for residents (households and hydrant units), livestock water needs and so on. The availability of water is obtained by sorting the discharge of F.J. Mock [15] for the last 10 years from the greatest to the very minimum. The availability of raw water for residents in the Indonesia Public Work Regulation uses a debit with a reliability of 90%. To get a discharge with a reliability of 90% it is searched for using the Weibull [19] method.

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

No	Probability	Discharge Recapitulation (m^3/s)											
		Jan	Feb	Mar	Apr	Mei	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	2.82	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**

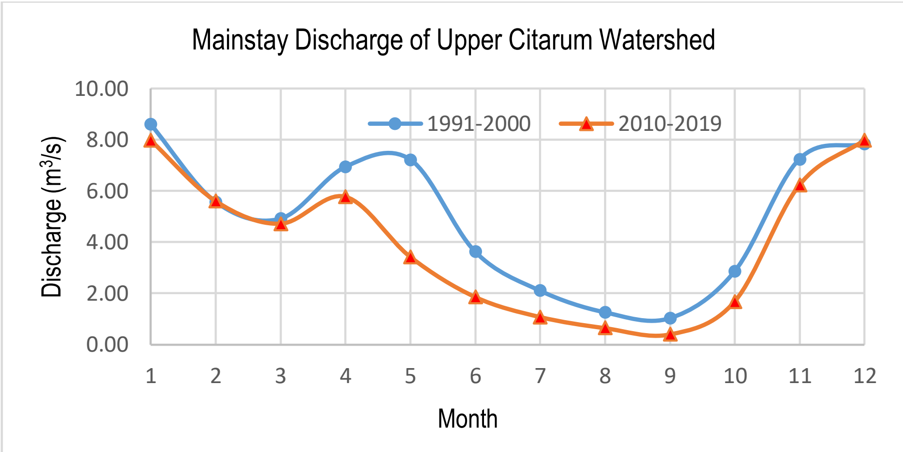

Fig. 8 Comparison Chart of Mainstay Discharge of 90% UCW

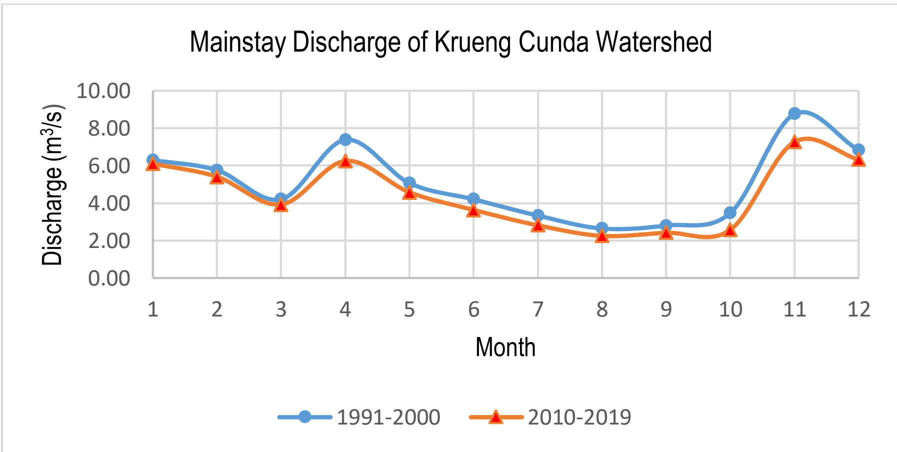

Fig. 9 Comparison of 90% Mainstay Discharge in KCW

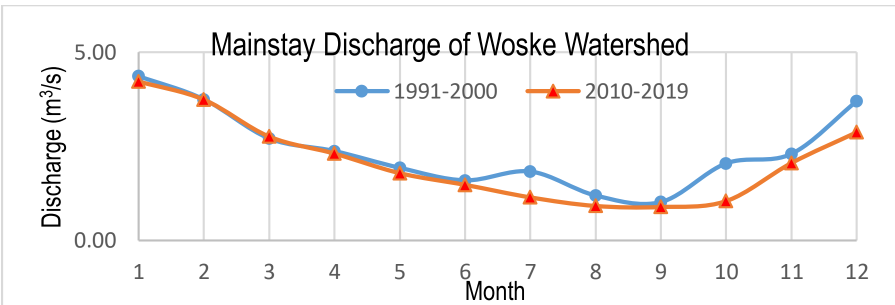

Fig. 10 Comparison of 90% Mainstay Discharge in the WW

4.4 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)	445865	742017
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 Kebutuhan Air Rumah Tangga DAS Woske

Parameter	Tahun	
	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**

4.5 Water Balance

The water balance analysis is an important 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 in period 2010-2019 the water discharge tends to decrease. If there is a surplus condition, it means that the water demand is smaller than the existing water availability and vice versa if the deficit means that the water demand is greater than the water availability. 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]

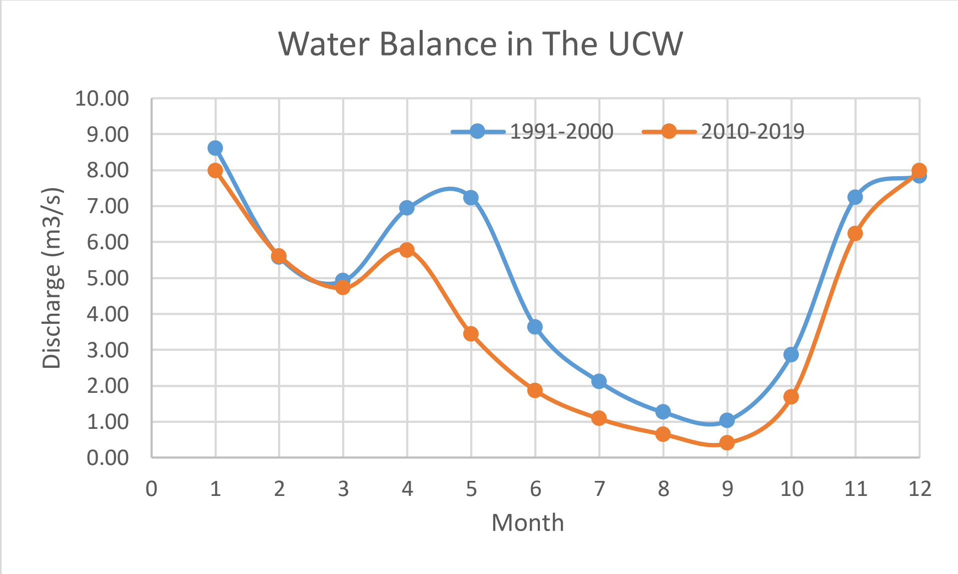

Fig. 11 Water Balance in the UCW between 1991-2000 and 2010-2019

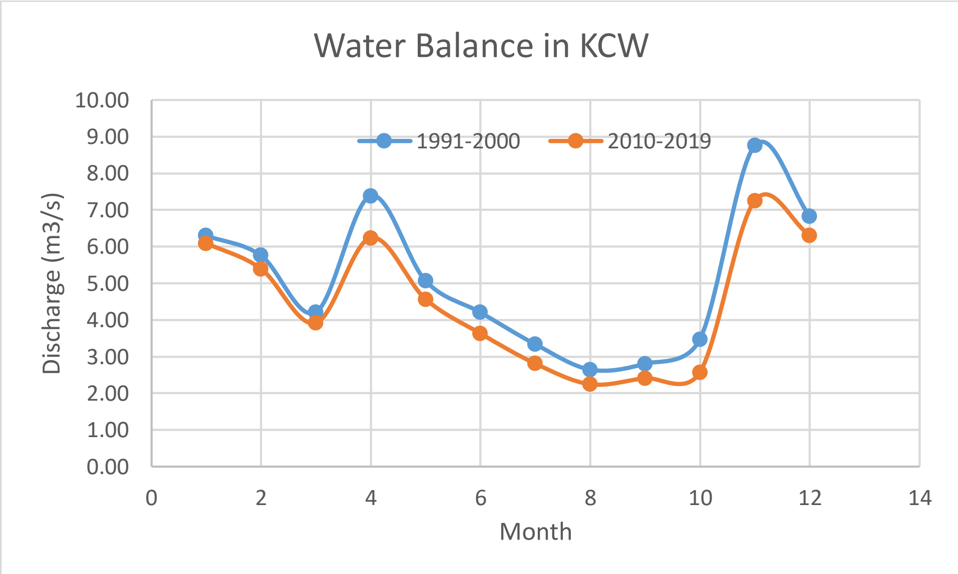

Fig. 12 Water Balance in the KCW between 1991-2000 and 2010-2019

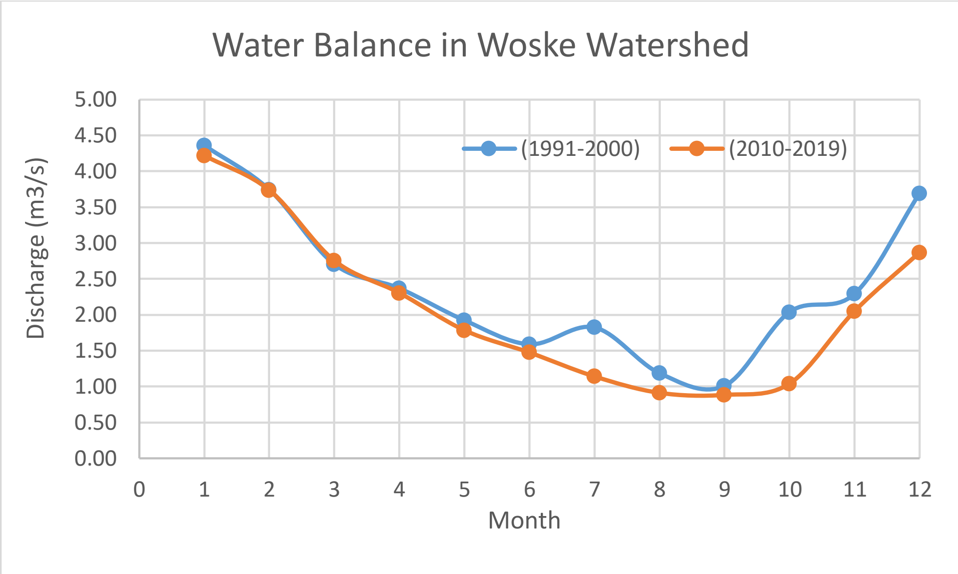

Fig. 13 Water Balance in the WW between 1991-2000 and 2010-2019

These climate changes put great pressure on hydrological conditions which are an important asset to ensure the availability of food and water resources for a fast-growing global population [21]. The predicted 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 changes in rainfall compared to changes in climatology (ETo). More importantly, the groundwater flow component will be negatively affected by projected rainfall and temperature changes.

5. **Conclusion**

Things that can be concluded from the discharge modeling 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 10 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 m3 / sec to 7.98 m^3 / sec, and the initial minimum discharge from 1.04 m^3 / sec to 0.4 m3 / sec.
   - In the Krueng Cunda watershed, there is a change in the maximum mainstay discharge from 8.76 m3 / sec to 7.25 m^3 / sec, and the original minimum flowrate of 2.65 m^3 / sec to 2.25 m3 / 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 greatly 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 water needs of the population.

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