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CLIMATE CHANGE IMPACTS ON HYDROLOGY REGIME AND WATER RESOURCES SUSTAINABILITY IN CIMANUK WATERSHED, WEST JAVA, INDONESIA

*Merri Jayanti[1], Arwin[2], Iwan K. Hadihardadja[3], Herto Dwi Ariesyady[4] and Jakobis J. Messakh[5]

[1]Environmental Engineering Program, Institut Teknologi Bandung, Indonesia; [2,3,4]Faculty of Civil and Environmental Engineering, Institut Teknologi Bandung, Indonesia; [5] Department of Environmental Science, Nusa Cendana University, Indonesia

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ABSTRACT: The goal of this study is to analyze the impact of climate change on the hydrological regime changes in Cimanuk Watershed, West Java, Indonesia, analyzes the existing problems and contributes to the management of water resources in monsoon climate region in Indonesia. The results have shown that climate change is shown by the increasing temperature, meanwhile the air humidity, wind speed, sunshine duration, and evaporation are decrease. Changes of the hydrological regime have been known by the analysis of the main components of the hydrological cycle specifically discharge (Q) and precipitation (P). Precipitation and discharge had shown an increasing trend from 1987 to 2012, but with high variability in annual and monthly period. The critical condition of water availability for four months (June to September), while the excess water condition occurs during eight months (October to May). The Model of input-output correlation between precipitation and discharge have shown a positive correlation 0.9564 for the monthly average, and 0.5417 for the annual. The coefficient of annual water availability is high, shows that the region is monsoon with great potential for flooding. Therefore, it is necessary to optimize the management of surplus water in the rainy season so that it is not wasted.

Keywords: Climate change, Hydrology regime, Monsoon area, Water availability, Water resources

1. INTRODUCTION

Water Resources states where water as a source of life community as dynamic existence that naturally flow to a lower place without knowing the administrative boundaries. Source of water is a natural resource that can be updated through the hydrologic cycle depends on the climate and weather that should be affected by cosmic factors, regional and local (watershed) form though the hydrological regime [2]. Where is the main component of the hydrological cycle of rainfall is an input in the watershed system and the output is the discharge and the quality of surface water (river water) and groundwater reserves. The second component is characterized by random variables and stochastic as well as water drainage to the sea is a deterministic phenomenon.

The historical of hydrologic regime, is unable to cope effectively with the more variable future climate. As a result, the water supply, energy, and environmental water uses cannot be effectively satisfied during future droughts, exposing the system to higher vulnerabilities and risks [5]. Hydrological drought is related to a period with inadequate surface and subsurface water resources for established water uses of a given water resources management system [9].

In hydrosystem engineering designs, uncertainties associated with the resistance of the hydraulic flow carrying capacity and the randomness of events, such floods and rainstorms as the load [1]. Hence, In the design of a hydrologic system, the rainfall data serve as the system input, and the resulting flow rates through the system are considered using the rainfall - runoff and flow routing procedures [8]. Hypothetical rainfall events are used to investigate the response of the river basin at critical cross-sections. It can be considered by different temporal distributions. The amount of rainfall is assumed to be distributed uniformly [8]. Hydrologic criticality in river basin is part of the criticality of environment. Therefore, it is important to understand the process of criticality relating to hydrologic imbalance in a river basin which caused by the effect of land use and climate change [19].

Report of the Intergovernmental Panel on Climate Change (IPCC, 2007) states that the world is more vulnerable to drought in the next 25 years, and climate projections indicate that this will get worse in the future [9]. Impact of climate change on hydrology regime specifically during high flow will impact the sustainable reservoir operation of sediment deposition during flushing [6].

Uncertainties of climate and weather triggered by global warming from greenhouse gas emissions in the atmosphere result in temperature increases the earth [2,5,16]. The presence of water follows the hydrological cycle is closely related to the weather conditions in an area that causes uneven water availability in every time and every region. Changes in surface water availability extreme would be a serious problem in terms of the sustainability of water management [3,15,17,18].

In the monsoon area, water resource availability is a serious problem in terms of the sustainability of water management. Monsoon patterns are characterized by monthly V-shaped rainfall distribution with low seasonal rainfall in June, July or August. In normal conditions, when the west monsoon will get abundant rainfall (rainy season) while in the eastern monsoon the amount of rainfall is very little (dry season). In monsoonal rain patterns the region has a clear distinction between the period of the rainy season and the dry season. Numerous studies have been conducted, some of them are about the availability of water during the rainy season and the dry has a very high degree of variability about scenario development for watershed management [2,13,14,16,20].

Indonesia, especially at most of the production sectors, has suffered heavily from the impacts of climate change and climate variability [4]. The uniformity is not only in physical aspects (such as climate and infrastructures), but also in cultural aspect as the demography of the farmers in the Central Java province is quite homogeneously [21]. The impact of climate change on flood events is infrequent, with most incidents passing with poor or no data acquisition [7]. Therefore, this research specifically examines: a) climate change and hydrological regime changes in Cimanuk Watershed and b) the impact on the water resources sustainability in monsoon regions. Conditions impact of climate change and land conversion may have occurred in the Cimanuk Watershed, as the main water source rivers Jatigede Reservoir.

2. MATERIAL AND METHOD

The quantitative approach has been done to analyze the impacts of climate change through the hydrological regime change. Series precipitation data are used daily and monthly throughout the 26 years (1987 to 2012) from 9 (nine) precipitation stations around the Cimanuk watershed. Data of climate elements derived from Cimanuk Climatology and Wado Discharge Station, while the series of monthly discharge data for 32 years (1980 to 2013).

Figure 1 shows the study area of Cimanuk Watershed, the discharge station namely Q Wado, and for the rainy station from P1 Pamagetan, P2 Pangauban, P3 Kepakan, P4 Tarogong, P5 Leuwigoong, P6 Darmaraja, P7 Pamulihan, P8 Cilimun, P9 Majalengka.

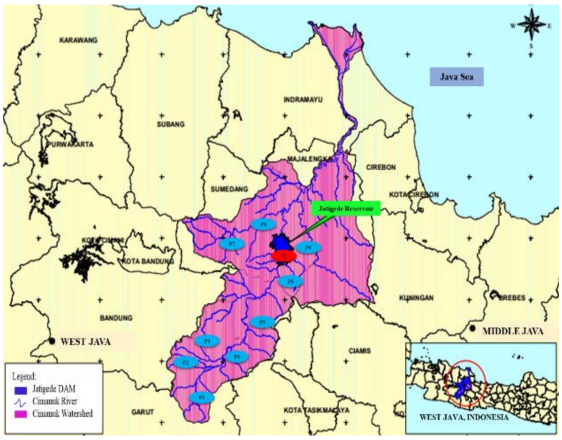

Fig 1. Study Area (Jayanti, 2019)

The analysis of climate parameters, precipitation and discharge trends revealed by the data using the moving average method, the range of values and the average values were compared at different periods. In addition to the analysis of changes in precipitation are also using the IDF Curve method. The significance level between precipitation and discharge, using the Spearman Correlation Test model of a two-way with a significance level of 5%.

3. RESULTS AND DISCUSSION

3.1 Climate Change

Climate parameters which have been analyzed were air temperature, wind speed, air humidity, sunshine duration, and evaporation. Results of the analysis showed that the average air temperature of 28,44°C, the lowest in March at 22,27 C and highs in October amounted to 31,35°C. Relative humidity average is 68,29% with the highest data in January by 98,01% and the lowest in September at 8,9%. For evaporation, the average is 60 mm/day, the highest evaporation occurs in August 88,70 mm and the lowest in October amounted to 43,01 mm. Average wind speed of 1325,66 km/day, the biggest in September amounted to 7861,87 km/day and the lowest in March at 33,8 km/day.

Figure 2 shows the trend of climate change parameters on average time series from 2000 to 2013 (14 years) as follows: temperature has shown an upward trend with changes in average temperature was 0.1037°C per-year, while the trend of global temperature changes 0.7°C every 100 years. IPCC [11] reported that the distribution of increase in the global temperature anomaly is uneven and varies between land and sea, between the northern hemisphere and southern hemisphere, and between regions and between types of land cover are different.

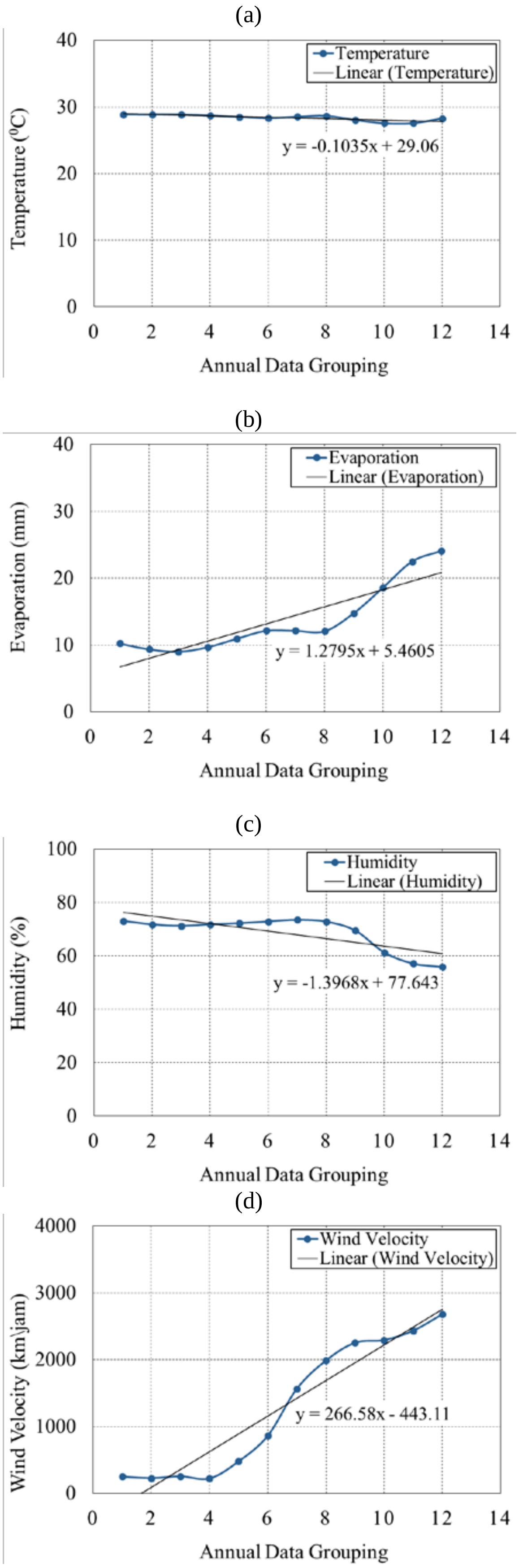

Fig.2 Trend of Climate Parameters Changes: (a) Temperature, (b) Evaporation, (c) Humidity, and (d) Wind Velocity

Other climate parameters results have been shown a downward trend for the 14 years observation period, namely: humidity -1,3968 % per-year; wind speed 266,58 km/day per-year; and evaporation -0.6908 mm per-year.

Result analysis shows the changes in temperature and evaporation are the same climate change theory that rising temperatures will lead to increased evaporation. The temperature's rise is not evenly distributed around the earth cause low pressure and new high pressure. The pattern of wind was shifting and the precipitation patterns were changing either.

Indonesia's geographic position greatly affects the extreme climate events, in this case is flooding and drought. The phenomenon that affects the climate in Indonesia is called ENSO because Indonesia is located between two oceans, the Pacific and Indian oceans. El Niño events will cause drought in Indonesia, especially in areas that have a pattern of monsoonal precipitation. While La Niña phenomenon possibly leads to increase precipitation in Indonesia during the dry season and the rainy season led the advance [2,16,17,18].

The research of Jayanti [12] showed that in 2012 the last year, there was a wet-dry phenomenon happening throughout the year so that the rainy season. This is one example of the extreme climate that occurs as a result of climate change. The changes in climate parameters that occurred can result in a change of the magnitude and distribution of water, and the long-term sustainability of water resources being threatened and requires serious attention.

3.2 Hydrological Regime Changes

Changes in climate parameters possibly give any impact directly or indirectly on the hydrological response of the region further define the availability of water for various needs. Rather on the hydrological regime in this study were observed through changes through the main components of the hydrological cycle that is precipitation and discharge.

3.2.1 Changes of Precipitation Intensity

Changes of the hydrological regime based on precipitacion intensity had been observed among others by changes in precipitation intensity with curve Intensity Duration Frequency (IDF) method. IDF curve is a part of mathematical function that relates the rainfall intensity with its duration and frequency of occurrence.

IDF curve empirical formula was analysis to estimate the rainfall intensity for any duration and any return period with minimum effort. Daily rainfall data for the year 1987 to 2012 was collected from West Java Meteorological Department and the empirical reduction formula was used to estimate the short duration rainfall using different probability distributions. The Chi-Square goodness of fit was used to arrive at the best statistical distribution among Normal, Log-Normal, Gumbel, Pearson, and Log-Pearson. Chi-Square test showed that log-normal is the best probability distribution. The IDF curve was then plotted for short duration rainfall of 5, 10, 20, 40, 60, 80, 120 and 240 minutes for a return period of 2 and 10 years. The use of IDF curves becomes more cumbersome and hence a generalized empirical relationship was developed for the study area Cimanuk watershed, through method of least squares.

In this research, the precipitation intensity data over different time periods was divided in two group for data in 1987 to 1999 and 2000 to 2012. The Analysis of the results for the return period of 2 years had been shown in Figures 3 and the analysis for the return period of 10 years had been shown in Figures 4.

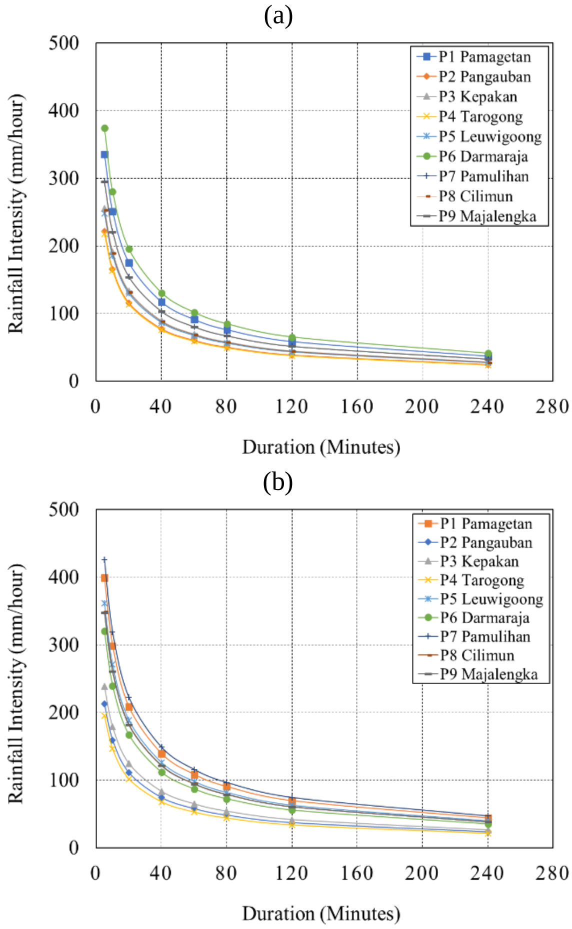

Fig.3 IDF Curve for 2nd Annual Return Period: (a) 1987-1999, and (b) 2000-2012

Based on figure 3, on the return period 2nd annual, overall precipitation stations have a higher intensity of precipitation for the current period (1987 to 1999) compared to the previous period (2000 to 2012).

Pamagetan station has a value greater margin between the two periods of rain showers in the appeal of other stations and also has the highest intensity for a short period of rain (5 minutes).

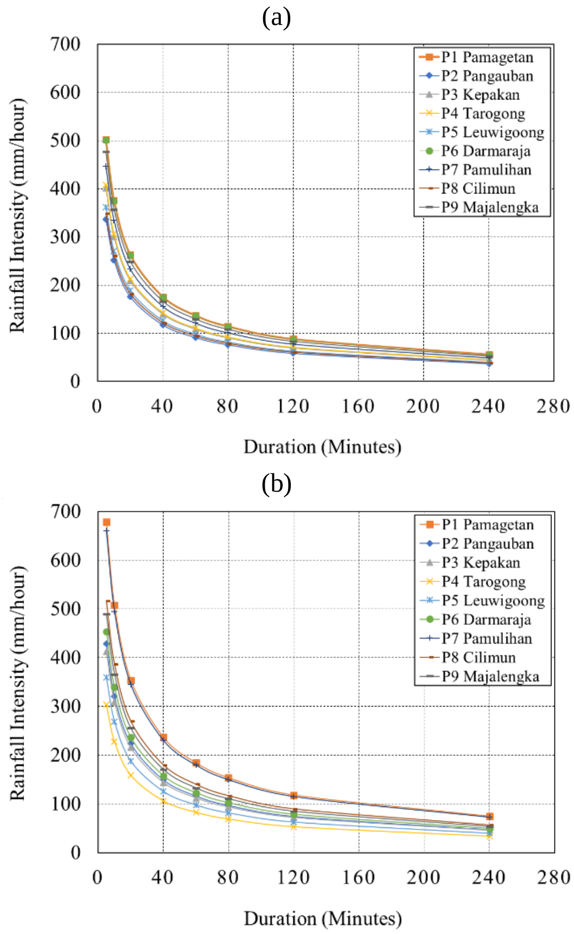

Fig.4 IDF Curve for 10th Annual Return Period: (a) 1987-1999, and (b) 2000-2012

For the 10th annual return period (figure 4), the highest precipitation intensity occurred in urban areas (Darmaraja and Tarogong). The results of this analysis showed that the differences in land use affects the value of the hydrological regime. Condition is consistent with that presented in the IPCC reported [11] that differences in the distribution of land use will result in the increase of global temperature anomalies uneven and different.

At 10th annual return period, a trend increases a few differences in the intensity between the 2 periods of the calculation (the curves coincide). The intensity of rain between the 2nd calculation period (1987 to 1999 and 2000 to 2012) is also getting random between stations because there are stations with the intensity of the period 1987-1999 is higher than the period 2000 to 2012 and on the contrary. From the analysis of the return period 25th, 50th and 100th annual also shows that the greater the return period, the smaller the value of the different intensity precipitation or curve formed by the overlaps.

3.2.2 Precipitation changes

Analysis of precipitation changes had been simulated by using moving average of the rainfall data from 1987 to 2012. The analysis results of precipitation changes can be seen in figure 5.

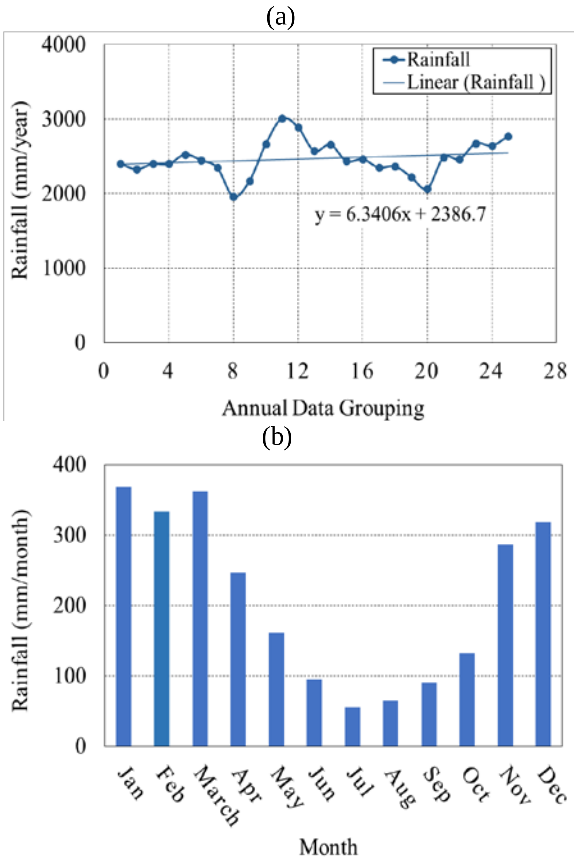

Fig.5 Trend and Distribution of Precipitation at Cimanuk Watershed, Indonesia (1987-2013): (a) Rainfall Trend with Moving Average, (b) Monthly Rainfall (mm/month)

The analysis results of precipitation changes shows increases trend (Figure 5a). Monthly averages in Figure 5b shows the rainy season (wettest month) occurs during the eight months (October to May), while the other four months (June to September) is a dry month, which means that the dominant dry season occurs in the study area.

The average precipitation in October was about 318 mm/month, in December was about 319 mm/month, and the highest average precipitation in January about 369 mm/month. Hence, the average precipitation in June was about 94 mm/month, in August was about 65 mm/month, and the driest average precipitation in July about 54 mm mm/month. Monthly precipitation pattern that occurs is monsoon climate type [3].

Precipitation variability is also different in the rainy season (wettest month) and dry season (dry months). Trend of Average Precipitation in Rainy Season and Dry Season with Annual Moving Average Method can be seen at figure 6.

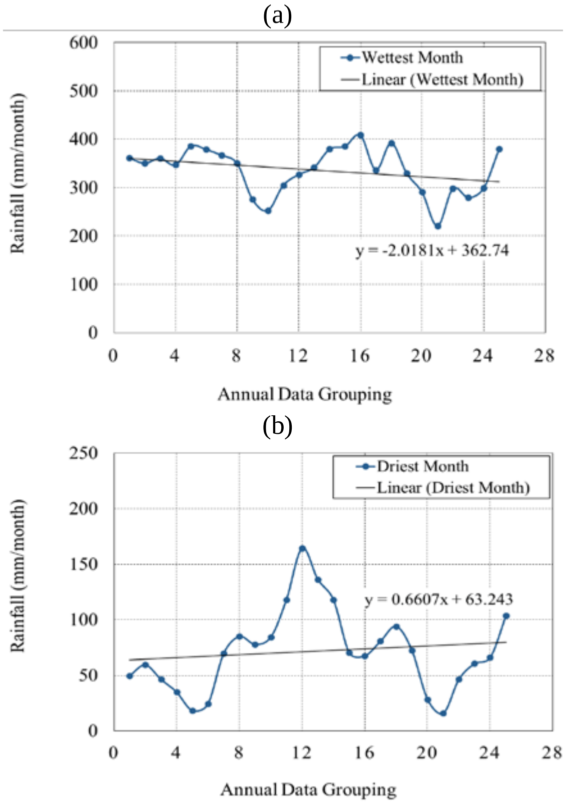

Fig.6 Trend of Average Precipitation in Rainy Season and Dry Season with 3rd Annual Moving Average Method: (a). Rainy Season (Wettest Month), (b). Dry Season (Driest Month)

In the wet months, the more extreme precipitation in the dry season wet while getting extreme precipitation dried (figure 6). This means that climate change may lead to a shift of the season, which will last a long dry season, causing drought. The rainy season will take place with the trend of precipitation intensity is higher than normal precipitation, the impact of floods.

Precipitation data were grouped in two different periods shows the more extreme precipitation in the period 2000-2013 where the average precipitation of 2502,82 mm/year, while in the previous period (1987 to 1999) only amounted to 2386,28 mm/year. Which means that the change increased by 8.10%.

If the precipitation data grouped by rainy season (wettest months) from October to May and dry season (driest months) from June to September. The data also shows that the more extreme the current period in the previous period in the wet in the rain (2209,72 mm versus 2044,06 mm) and in dried drier (293,1 mm versus 342,22 mm).

3.3 Discharge Changes

Analysis of discharge changes had been simulated by using moving average of the rainfall data from 1980 to 2013. The analysis results of precipitation changes can be seen in figure 5.

(a)

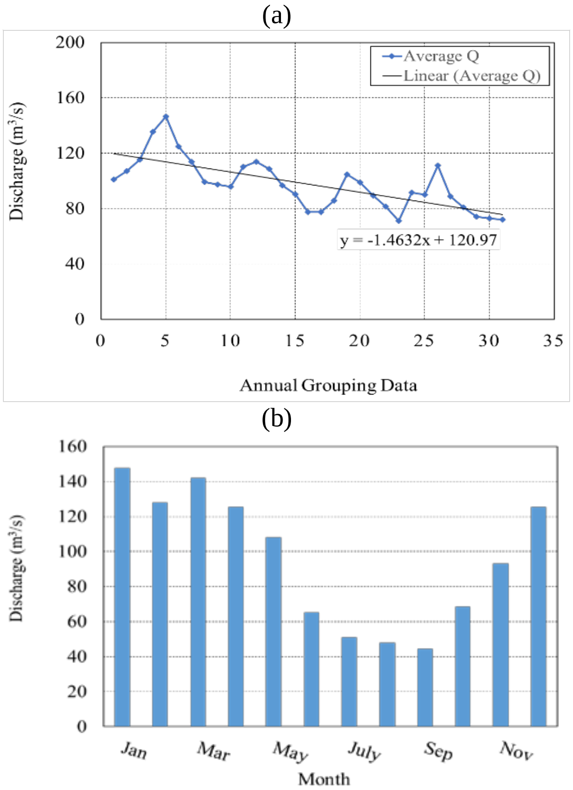

Fig.7 Trend and Pattern of Annual Discharge (1980-2013): (a). Discharge Trend with Moving Average, (b). Average Monthly Discharge

Trend analysis shows an increase in annual discharge changes (Figure 7a). Changes occurring discharge is 96,48 m^3 per-32 years or 0,9648 m3/year. Monthly average discharge showed different distributions of per-month (Figure 7b).

The amount of discharge change between wet months (October to May) is 117,34 m^3/s and dry (June to September) is 52,28 m^3/s. The monthly maximum discharge occurred in January amounted to 147,86 m^3/second, and the smallest was 44,68 m3/second occurred in September with an average discharge of 95,64 m^3/second /months.

The Month from October to May is a condition in which the discharge that occurs above the average discharge, and the month from June to September is a condition in which the discharge occurred under average discharge. This differs from the pattern seen in the precipitation which occurred a shift in the months from October to May (for precipitation) to the month of June to September (for discharge). This happens because of the precipitation that occurred the previous month (October) used to fill the pores of the soil that had vacancies during the dry season. If the soil pores are fully charged (saturated) then becomes surface water (river flow).

Discharge changes also differ in the wettest and driest months. In the wettest month (January) shows the trend of increasing discharge (147,86 m^3/second per-year), as well as the driest month (October), increased 44,68 m^3/second per-year (Figure 8).

(a)

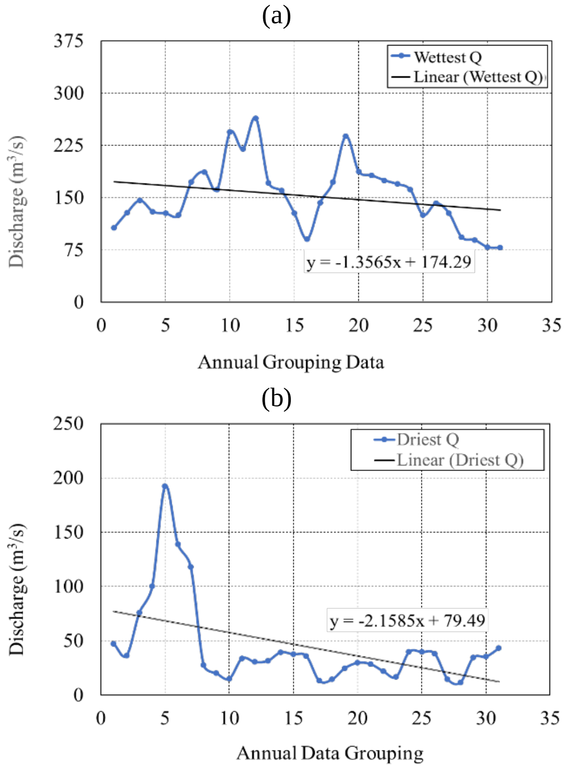

Fig.8 Trend of Discharge in The Wettest Month and Driest Month: (a). Rainy Season (Wettest Month), (b). Dry Season (Driest Month)

Conditions of discharge increase during the driest season, although the value is not significant, in monsoon area that indicates improvements in the condition of the watershed water use planning.

3.4 Correlation between Precipitation and Discharge

Correlation between precipitation and discharge in this study is that the greater the precipitation intensity, the greater the discharge occurs. Spearman correlation test at a significance level of 0.05% two-way test, for a monthly average data shows a correlation value 0,9564 which means that the increase in discharge can be explained 95,64 % due to an increase in precipitation, while the remaining 4.36% is explained by the variables others, such as in wet or dry conditions during the rains, the amount of base flow (baseflow), and other factors. On annual average data, the relationship between precipitation and discharge correlated at 0.5417. The results of this analysis showed that precipitation is the biggest input on discharge of Cimanuk watershed, West Java, Indonesia.

3.5 Hydrology in Monsoon Region

The study area is monsoon regions indicated by the following indicators: (a) the average precipitation 2422,09 mm/year, (b) the number of rainy days with an average of 240 days/year, (c) evaporation 747,14 mm/years, (d) potential evapotranspiration (ETo) 2600 mm/year, and (e) the annual water availability coefficient of 1,468, the water deficit as much as 1338,6 mm/year which results in a high risk of drought.

The critical condition of water availability for four months (June to September), while the excess water condition occurs during eight months (October to May) For the foreseeable future water needs of irrigation and drinking water will increase, especially in the dry season, because it's raw water supply challenges will be even greater.

4. CONCLUSION

Global climate change that also has occurred in the study area that will affect the hydrological response such as, the observed changes in the hydrological regime through the major components of the hydrological cycle that is precipitation and discharge. This change will determine the availability of water for various needs. Increased precipitation and discharge, though with little value, the observation period 1987 to 2012 is a favorable condition for the availability of water in the study area. But with the higher variability between dry season and rainy season that resulted in the need for optimal management of surplus water in the rainy season can be accommodated to be used in the dry season.

Future research requires a more detailed analysis of land use, patterns of exploitation of the reservoir, the rate of population growth impacts water demand, in the context of sustainable water resources management in munsoon regions.

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