Effect of Climate Change on Water Availability of Bangga River, Central Sulawesi of Indonesia

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ABSTRACT

The objective of this study was to investigate the effects of climate change in evapotranspiration and rainfall for river water discharge of Bangga. Investigation has been carried out using daily data and analyzed on a daily, monthly and yearly. Climate trends and projected changes in the method of Makesens analysis (Mann-Kendall, Sens) and the correlation of rainfall and evapotranspiration discharge used linear regression equation. Similarly, the correlation between changes in soil water storage with rainfall, evapotranspiration and discharge were analyzed in a linear manner. The conclusion of this study is the climate changes in the Bangga watershed was characterized by slowly increasing temperature, decreasing rainfall, and increasing evapotranspiration.

KEYWORDS: climate change, Makesens, Bangga River

INTRODUCTION

Global Climate change has been discussed on the High Level Conference at Rio de Janeiro, Brazil in 1992 [1] and has given more impacts in the world. One of the global climate exchanges are the rising of intensity and frequency of climate extreme which included drought, flood, and hurricane [1]. Previous studies were presented many indicators climate exchange as the rising in sea level [2], drought, flood, and any kinds of problem in water resources development [3]. Drought has been increased in intensity and number on some parts of the world and it is as a natural hazard but with temporarily unbalanced water availability caused by high evapotranspiration and low precipitation, thus resulting in reduced water availability [4]. There was very possible to analyse water balance in many parts of watershed for making sure the impact of climate change in the watershed. As we all know that droughts inflicted economic and social damage worldwide [5]. Their irregular frequent and occurrence has been a special reason for the planning, management and development, and construction design of water resources. Droughts will influence the design and planning of water resources infrastructure. Therefore, hydrologists have to pay more attention to drought pattern of recurrence from the records of stream flow and precipitation [6]. Drought impacted the scarcity of natural water resources, so the understanding of drought recurrence and duration is an urgent importance. Hydrological models are a powerful utilization to know the future and current hydrological exchanges of a watershed [7,8]. Increasing in temperature however will rise the evaporation and it is possible to produce higher water vapour. Long-term changes in precipitation will give impact on socio-economic sectors as well as water such as irrigation, fresh water availability, hydro electrical power, etc.

Revolution of industry which is remarked by the usage of fossil gasoline mainly coal gasoline beginning from about 1840 in Europe, has drastically increased gas of glass house in atmosphere because main result of the gasoline burning is as carbon-dioxide (CO2). Reason of the glass house effect has globally and significantly increased annually the atmosphere temperature of land. The phenomenon is known as global climate change which will be faced beside increasing or decreasing on rainfall of an area, the increasing of atmosphere temperature can also be related with the pattern changes of season, wind, humidity, and radiation. Decreasing of rainfall as the input variable of watershed is as the reason of global climate deviation and it will influence yearly as well as seasonal dynamic of river flow discharge.

This study was carried out to analyze the impact of climate change due to the river water availability which related with the climate factors like temperature, humidity, radiation, wind velocity, and rainfall. The trend of climate change and water balance component will be analyzed and then being predicted.

MATERIALS AND METHODS

This study was conducted in Bangga watershed which was as the affluent of Palu River. The watershed administratively is located in Bangga Village, Dolo District, Sigi Regency, and Central Sulawesi Province of

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Indonesia. The study area was falls between south latitude 01° 15’07” and 01°21’30” and east longitude 119° 49’20” and 119° 56’05”. Location of study is as in Figure 1 below.

Secondary data that was used in this study included: 1) daily rainfall data of Upper and Lower of Bangga Stasion in the year of 1993-2011; 2) climate data of Blora Stasiun in the year of 1980-2011; 3) daily discharge data of Bangga River in the year of 1995-2011; and 4) topography map with the scale of 1:50,000.

To investigate the effect of climate exchange (evapotranspiration and rainfall) due to discharge of Bangga River, it was necessary to carry out some steps of methodologies as follow: 1) analysis of area rainfall; 2) analysis of potential evapotranspiration; 3) to formulate model of discharge; 4) analysis of groundwater storage; 5) to detect climate exchange and prediction. Table 1 presented the summary of formula that was used in this study.

Figure 1 Map of location
Table 1 Summary of research formula [9][10][11][12]

<table>
<thead>
<tr>
<th>No</th>
<th>Item</th>
<th>Model</th>
<th>Data</th>
<th>Method</th>
<th>Output</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Watershed rainfall rate [8]</td>
<td>( \bar{E} = \frac{1}{n}(E_1 + E_2 + \ldots + E_n) )</td>
<td>Daily rainfall</td>
<td>Arithmetic mean</td>
<td>Regional rainfall rate Jan to Dec</td>
</tr>
</tbody>
</table>
| 2  | Potential evapotranspiration [6] | \( E_{\text{To}} = \frac{\lambda(E_0 - G) + \mu \frac{\sigma}{\mu} \left( \frac{G}{\sigma} - \frac{\mu}{\sigma} \right)}{\lambda + \mu} \) | - Temperature max, min, ave  
- Relative humidity max, min, ave  
- Wind velocity max, min, ave  
- Time of sunshine max, min, ave | Perman Montieth | ETo Jan to Dec               |
| 3  | Discharge model [10] | \( Q = a + b \cdot R + c \cdot E_{\text{To}} \) | - Historical discharge  
- Daily rainfall  
- Potential evapotranspiration | Liner regression | Relation among discharge, rainfall and potential evapotranspiration |
| 4  | Soil water storage [10] | \( dS = R \cdot E_{\text{To}} - Q \) | - Yearly rainfall  
- Yearly potential evapotranspiration  
- Yearly discharge | Liner regression | Relation among soil storage, rainfall and potential evapotranspiration |
| 5  | Detect of climate change [11] | \( S = \frac{1}{n} \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \text{sign}(x_j - x_i) \) | - Temperature max, min, ave  
- Relative humidity max, min, ave  
- Wind velocity max, min, ave  
- Time of sunshine max, min, ave  
- Rainfall max, min, ave, monthly, yearly  
- Potential evapo max, min, ave  
- Soil water storage max, min, ave  
- Discharge max, min, ave | Mann-Kendall method | Trend climate change  
- Monthly  
- Yearly |
| 6  | Trend slope [12] | \( \hat{\beta} = \frac{\sum_{i=1}^{n} (x_i - \bar{x})(y_i - \bar{y})}{\sum_{i=1}^{n} (x_i - \bar{x})^2} \) | - Temperature max, min, ave  
- Relative humidity max, min, ave  
- Wind velocity max, min, ave  
- Time of sunshine max, min, ave  
- Rainfall max, min, ave, monthly, yearly  
- Potential evapo max, min, ave  
- Soil water storage max, min, ave  
- Discharge max, min, ave | Sens method | Trend slope climate change  
- Monthly  
- Yearly |

RESULTS AND DISCUSSION

Climate and the exchange of water balance

Time series curve of climate components in Bangga River was presented as in Figure 2 and the result of climate change using Mann-Kendall Method was described as in Table 2 below.
Figure 2 showed that during the period of 1980-2011, $T_{\text{min}}$ and $T_{\text{ave}}$ were relative unchanged due to the $T_{\text{max}}$ but $T_{\text{max}}$ indicated the tendency to increase. The relative humidity (RH$_{\text{max}}$, RH$_{\text{min}}$, RH$_{\text{ave}}$) is fluctuated in the period of 1980-1992 and then it was almost plain until the year of 2011. The wind velocity (V$_{\text{max}}$) did not almost have meaningfull increasing until 2011. V$_{\text{ave}}$ occured the decreasing in the year of 1988 and the increasing in the year of 2007 and 2008, but V$_{\text{max}}$ was fluctuateve, even in the year of 2009 there was very high wind velocity. Duration of radiation ($S_{\text{min}}$ and $S_{\text{max}}$) was not significantly changed due to the time, but $S_{\text{ave}}$ was fluctuated and had tendency to decrease. Rainfall ($R_{\text{min}}$ and $R_{\text{max}}$) was fluktuated and it was significantly decreasing until the year of 2011. Evapotranspiration (ET$_{\text{min}}$ and ET$_{\text{max}}$) was not meaningfull changed during the period of research, on the contrary ET$_{\text{min}}$ and ET$_{\text{max}}$ until the year of 1999, then it was plain until the year of 2011. Discharge of $Q_{\text{ave}}$ was almost not changed during the observation, but on the contrary $Q_{\text{min}}$, $Q_{\text{max}}$, and $Q_{\text{sum}}$ was fluctuated and the highest discharge was occured in the year of 2008. On the contrary of pattern was occurred in the change of soil water storage) which d$S_{\text{ave}}$ was not meaningfull change, but d$S_{\text{min}}$, d$S_{\text{max}}$, d$S_{\text{sum}}$ was occured on the contrary pattern of discharge pattern.

Analysis result of Mann-Kendall was presented as in Table 2 which T$_{\text{min}}$ did not indicate the significant change but T$_{\text{max}}$ and T$_{\text{ave}}$ indicated the positive and significant change. Relative humidity (RH$_{\text{max}}$, RH$_{\text{min}}$, RH$_{\text{ave}}$) had positive and significant change in all of the months and years, while wind velocity was occurred change but in general it was not significant. Duration of radiation ($S_{\text{min}}$) had positive and significant change, but $S_{\text{min}}$ and

Figure 2 Time series curve of climate components
S_{ave} was occurred change but it was not significant. The change of rainfall which was significant enough was only indicated by $R_{ave}$ but $R_{max}$, $R_{min}$ and $R_{sun}$ were occurred change but it were not significant. Evapotranspiration (yearly of $ET_{max}$, $ET_{min}$ and $ET_{ave}$) had significant change, but monthly of $ET_{ave}$ had less significant of change. Discharge indicated positive but less significant of change. This pattern was also occurred in soil water storage but the trend of change was negative or in the opposite of discharge change.

Based on the analysis of Mann-Kendall, it could be concluded that the increasing of maximum temperature, decreasing of rainfall, increasing of relative humidity, and the consequences to the increasing of maximum evapotranspiration [9] were as the indicator of climate exchange in Bangga watershed, but this conclusion might be different if the period had been changed. It was similarly with if the whole data was limited by available data of river discharge (1995-2011), the result might indicate the different thing. So it was very necessary to remember that time period and number of time series data in the same quantity for all of climate data which would be analyzed. Level of significant also influenced the analysis result.

To know the effect of climate change and how the influence toward discharge (Q) and change of water storage (dS), it’s needed graphic correlation between yearly rainfall with discharge, evapotranspiration and the change of water storage, as can be seen in figure 3.

![Figure 3](image)

Figure 3 The correlation between the change of water storage with yearly rainfall, discharge and evapotranspiration

As can be seen that the possibility of the climate change was occurred after 1998 with anomaly rainfall at year 1995 and year 2009 but this situation do not influence the change of water storage significantly.
Table 2 Recapitulation of climate change based on Mann-Kendall Method

<table>
<thead>
<tr>
<th>Variable</th>
<th>Trend</th>
<th>Jan</th>
<th>Feb</th>
<th>Mar</th>
<th>Apr</th>
<th>May</th>
<th>Jun</th>
<th>Jul</th>
<th>Aug</th>
<th>Sep</th>
<th>Oct</th>
<th>Nov</th>
<th>Dec</th>
</tr>
</thead>
<tbody>
<tr>
<td>Precipitation</td>
<td>Mann-Kendall</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Test 1, max</td>
<td>Pos and YS</td>
<td>1.16</td>
<td>2.03</td>
<td>1.93</td>
<td>3.40</td>
<td>3.49</td>
<td>2.60</td>
<td>2.43</td>
<td>2.46</td>
<td>2.68</td>
<td>2.56</td>
<td>2.48</td>
<td>4.10</td>
</tr>
<tr>
<td>Test 1, min</td>
<td>Neg</td>
<td>-0.8</td>
<td>-1.3</td>
<td>-1.8</td>
<td>-2.2</td>
<td>-2.0</td>
<td>-2.2</td>
<td>-2.0</td>
<td>-1.9</td>
<td>-1.3</td>
<td>-1.3</td>
<td>-1.0</td>
<td></td>
</tr>
<tr>
<td>Test 2, ave daily-1</td>
<td>Mann-Kendall</td>
<td></td>
<td></td>
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<tr>
<td>Test 2, ave daily-2</td>
<td>Pos and YS</td>
<td>3.11</td>
<td>3.00</td>
<td>3.71</td>
<td>3.40</td>
<td>3.49</td>
<td>3.71</td>
<td>3.40</td>
<td>3.49</td>
<td>3.71</td>
<td>3.40</td>
<td>3.49</td>
<td>3.71</td>
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<tr>
<td>Test 3, max</td>
<td>Neg and YS</td>
<td>1.16</td>
<td>2.03</td>
<td>1.93</td>
<td>3.40</td>
<td>3.49</td>
<td>2.60</td>
<td>2.43</td>
<td>2.46</td>
<td>2.68</td>
<td>2.56</td>
<td>2.48</td>
<td>4.10</td>
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<tr>
<td>Test 3, min</td>
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<td>-1.3</td>
<td>-1.8</td>
<td>-2.2</td>
<td>-2.0</td>
<td>-2.2</td>
<td>-2.0</td>
<td>-1.9</td>
<td>-1.3</td>
<td>-1.3</td>
<td>-1.0</td>
<td></td>
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<tr>
<td>Potential Evapotranspiration</td>
<td>Mann-Kendall</td>
<td></td>
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<td></td>
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<td></td>
</tr>
<tr>
<td>Test 4, max</td>
<td>Pos and YS</td>
<td>1.16</td>
<td>2.03</td>
<td>1.93</td>
<td>3.40</td>
<td>3.49</td>
<td>2.60</td>
<td>2.43</td>
<td>2.46</td>
<td>2.68</td>
<td>2.56</td>
<td>2.48</td>
<td>4.10</td>
</tr>
<tr>
<td>Test 4, min</td>
<td>Neg</td>
<td>-0.8</td>
<td>-1.3</td>
<td>-1.8</td>
<td>-2.2</td>
<td>-2.0</td>
<td>-2.2</td>
<td>-2.0</td>
<td>-1.9</td>
<td>-1.3</td>
<td>-1.3</td>
<td>-1.0</td>
<td></td>
</tr>
<tr>
<td>Precipitation</td>
<td>Mann-Kendall</td>
<td></td>
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</tr>
<tr>
<td>Test 5, max</td>
<td>Pos and YS</td>
<td>1.16</td>
<td>2.03</td>
<td>1.93</td>
<td>3.40</td>
<td>3.49</td>
<td>2.60</td>
<td>2.43</td>
<td>2.46</td>
<td>2.68</td>
<td>2.56</td>
<td>2.48</td>
<td>4.10</td>
</tr>
<tr>
<td>Test 5, min</td>
<td>Neg</td>
<td>-0.8</td>
<td>-1.3</td>
<td>-1.8</td>
<td>-2.2</td>
<td>-2.0</td>
<td>-2.2</td>
<td>-2.0</td>
<td>-1.9</td>
<td>-1.3</td>
<td>-1.3</td>
<td>-1.0</td>
<td></td>
</tr>
</tbody>
</table>

Significance levels: Pos = Positive, increasing trend, Neg = Negative, decreasing trend, YS = Yes significant (YS), NS = No significant (NS), Neg = Negative, decreasing trend, YS = Yes significant (YS), NS = No significant (NS), NT = No trend
Estimation of water discharge

This study intended to find there was or would be the discharge change caused by local climate change. Therefore, it was necessary to be found the relation among discharge by considering rainfall and evapotranspiration. Based on the yearly data (1995-2011) of rainfall, evapotranspiration, and discharge, it was obtained the linear relation of \( Q' = 0.449 \times R + 1.72 \times E - 1254.666 \). This formula could be used as a model predictor of discharge due to rainfall and evapotranspiration. The correlation between observed data (Q) and estimation data (Q') was presented as in Figure 4. The left of Figure 4 showed that evapotranspiration was almost not changed due to the time, rainfall was fluctuated and had the decreasing trend, but discharge was fluctuated and had the trend of significant enough increasing, and the peak was occurred in the year of 2008. It indicated that though the increasing of rainfall and evapotranspiration was not significant increasing, but the discharge had significant enough of increasing, it meanted that there was the other factor as the cause. The right of Figure 4 indicated that the relation between historical data (Q) and prediction data (Q') with relative small of \( R^2 \) indicated the less good of correlation. It might be caused by the other factors as well as rainfall and evapotranspiration which influenced discharge [10].

Trend of water discharge and soil water storage

The left of Figure 4 showed historical discharge data (1995-2011) and the projection of change until 2030. Soil water storage change (dS) was straight compared with rainfall (R) and contrary compared with evapotranspiration (ET) and discharge (Q). The similar condition was also occurred in the right of Figure 5, which soil water change (dS) was contrary compared with discharge (Q), it meanted that the bigger discharge and evapotranspiration would cause the smaller soil water storage change [11]. There was interesting occurrence in the left of Figure 5 that was the relation between discharge and rainfall which the more decreasing of rainfall would cause the bigger discharge. It indicated that discharge could not only be influenced by the factors of rainfall and evapotranspiration but there was also influenced by the other factor such as land cover [11][12].
CONCLUSION

Based on the daily, monthly, and yearly measurement and analysis in the period of 1980 until 2011 using Mann-Kendall Method, it could be concluded that there was climate exchange in Bangga watershed. The changes could be seen from the slowly increasing of temperature, decreasing of rainfall, and increasing of evapotranspiration. The phenomenon of climate exchange was very clear in the decreasing of average rainfall and increasing of daily maximum evapotranspiration which indicated dry season occurred in the watershed and gave impact in river discharge and soil water storage.

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